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Volume I

Creating built environments of new opportunities

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Preface

1. CIB World Building Congress 2016

CIB World Building Congresses (WBCs) are triennially arranged major research events for the built environment and construction sector. In 2016 this congress is organized in Finland (www.wbc16.com). This event is gathering together academic experts together with industry representatives from different parts of the world. The theme for CIB World Building Congress 2016 is "Intelligent built environment for life”. It highlights the importance of build environment and its development to the society.

The WBC16 congress is a major event for all experts from industry, public sector and academia for advancing the development of built environments. The main theme of the WBC16 ”Intelligent built environment for life” presents a cogent message that the built environment is a very important enabler for the well-being of its citizens, the success of its companies and the competitiveness of whole society, region or country. By defining the role of built environments in this way we can see the fundamental importance of our real estate and construction sector. In the WBC16 congress we turn our attention to the development of built environments in different conditions, countries and continents. Such developments can happen in different forms and scales, but always in a way where interplay between different stakeholders and experts play crucial role. These developments also need access to the latest knowledge and understanding which can be based both on industrial experiences and research-based findings.

Together, and by learning from each other we can be stronger and smarter for carrying out efforts where the main target is to deliver solutions that can be called Intelligent built environments for life. Our global umbrella organization CIB has three priority themes which are seen as focus areas for overall development and transformation of real estate and construction sector. These themes are Sustainable Construction, Integrated Design and Delivery, and, Resilient Urbanisation. The CIB priority themes present the overall framework for the content of this congress, supported and underpinned by specific congress sub-themes. In the WBC16 event a holistic viewpoint over this topic is presented that includes different dimensions from built environment as a system down to pragmatic end-user experiences and daily operations.

Seven sub-themes were developed to showcase the main areas where the majority of contributions was expected in the forms of presentations, workshops, special sessions and relating papers. Each sub-theme is presented using a simple but general challenge that expresses direction or need for different contributions. Each of these areas represents a broad totality. Thus, anyone whose work and expertise relates to the built environments can clearly place their work in one of these seven areas easily. The activities of CIB constitute work by a wide variety of different Working Commissions and Task Groups. The contributions from these bodies are linked to these sub-themes (Figure).

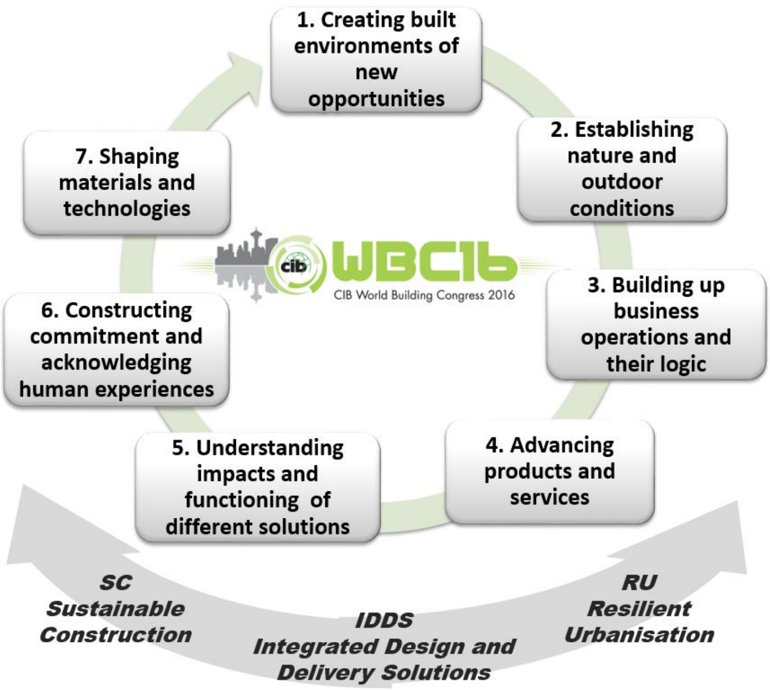

Figure. The sub-themes of the World Building Congress 2016.

2. Introduction to the WBC16 proceedings

The WBC16 call for papers produced 550 paper proposals. All abstracts and full paper submissions were double blind reviewed by the members of WBC16 International Scientific Programme Committee. Finally, 360 paper contributions were accepted to be published in the WBC16 proceedings. We would like to take this opportunity to express our sincere appreciation to the WBC16 International Scientific Programme Committee and all editors of the WBC16 proceedings. All members of this committee can be found in the chapter four of this preface.

The WBC16 proceedings comprise five pdf-books (Volume I-V). The contents of different books are according to the sub-themes of WBC16 as presented on the following.

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3. Introduction to the Volume I of WBC16 Proceedings

Volume I includes 75 paper contributions linked to the congress sub-theme “Creating built environments of new opportunities”. This includes topics of three different levels. First the macro-level contributions cover aspects such as development policies and programmes on national or international levels for creating desirable systemic changes (sections: I, II). Second the meso-level aspects mean here certain topics relating to e.g. organizations and their operations, implementations or performance of new solutions or systems such as complete buildings (sections: III-VII). Third the micro-level topics are addressing particular contexts and their solutions, such as a specific building code, structure, material and analyses relating those (sections: VI-IX). The paper contributions included in Volume I are classified into the following nine book sections.

I: Policies and programs for the development of built environment (11 papers)

II: Lessons learned from regional challenges (9 papers)

III: Meeting successfully different stakeholders and their interests (11 papers)

IV: Towards advanced solutions for sustainability and resilience (10 papers)

V: Reshaping processes for construction operations (9 papers)

VI: Successful implementation of BIM technologies for the realisation of potential benefits (7 papers)

VII: Innovative buildings and their performance (8 papers)

VIII: Building regulations and control in the face of climate change (6 papers)

IX: Moisture and mould Issues (4 papers)

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Radical Programmes for Developing the EU Residential Building Sector

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Abstract

The economic recession has hit especially hard the residential building sector in the EU region, e.g., the number of the housing completions has decreased -49% and the total residential output has been squeezed down by -24% between 2007 and 2014 (Euroconstruct, 2015). In turn, the aim of our paper is to suggest a set of radical, novel programmes for developing the national residential building sectors within EU member countries up to 2025. We have applied the framework of strategic niche management (SNM) to the diagnoses of the current portfolios of the innovation, R&D programs in our two member country contexts. In the case of the Northern Finland, the prime example is Hiukkavaara, the largest district to be built in the City of Oulu. Homes will be constructed for 20,000 new residents. Hiukkavaara is a model for climate-conscious design in the northern hemisphere. Energy and materials are conserved, nature is valued and human beings adapt to their environment. One sub-programme involves Future Buildings and Renewable Energy Project. In the case of the Netherlands, the prime example is Energiesprong (Energy Leap), i.e., the innovation programme commissioned by the Dutch Ministry of the Interior. The aim is to make buildings energy-neutral and boost large-scale initiatives. The sub-programmes are targeting homes owned by housing associations, privately owned homes, office buildings, shops and care institutions. This programme is about ensuring new supply by encouraging companies to package a variety of technical sub-solutions, full services and financing options as well as about asking clients to put out tenders and ask for quotes in novel ways, with the government making changes to the rules and the regulations. Experiences on which the Dutch case in this paper focuses are sub-programmes for residential buildings which includes Rapids, All Lights on Green and Our Home Deserves It. Based on the emerging Finnish and Dutch evidence, we are suggesting key elements to be incorporated into future national residential programmes within EU member countries on: (1) radical direction with balanced stakeholder groups, trustworthy advocates, contextual goal-setting and barriers management, (2) radical networking with entrepreneurial roles and causal links, novel expertise, transparent choices and digital platforms and (3) radical learning processes to arrive at better informed markets on user preferences, co-innovating, new rules and regulations, higher performance/price ratios, higher quality, new roles and responsibilities assignments.

Keywords: Hiukkavaara, Energiesprong, innovation programme, residential building sector

1. Introduction

The economic recession within the EU member countries has had its negative consequences vis-à-vis the real estate and construction sector. Especially, the residential building sector has been hit hard, e.g., the number of the housing completions has decreased -49% and the total residential output has been squeezed by -24% between 2007 and 2014 (Euroconstruct, 2015). Therefore a new innovation impulse is needed. The aim of our paper is to suggest a set of radical, novel programmes for developing the national residential building sectors within the EU.

The concept 'system of innovation' is widely accepted as a unit for studying innovations. Its operating level varies. For industries like construction, the national level is the most appropriate level (Lundvall, 1999). Research is not the only source of industrial innovation, i.e., other sources include knowledge flows, co-operation and technology diffusion (OECD, 1998). Moreover, common culture, legal framework, education, customer preference, institutions and other variables impact innovation. For industries like construction the latter may be more significant than research. Manseau and Saeden (2001) have shown that some countries have established technology and best-practice diffusion networks in construction.

In turn, the aim of our paper is to suggest a set of radical, innovative programmes for developing the national residential building sectors within EU member countries up to 2025. We have adapted the 3-area framework of strategic niche management (SNM) to diagnose national programmes (Section 2). We have selected a case programme within Finland (Section 3) and another within the Netherlands (Section 4) to exemplify and diagnose some radical solutions and features readily being adopted, such as participative district planning and the co-alignment of wilderness and residents. Finally, we put forth the key suggestions (Section 5).

2. Programme diagnosis method and data

2.1 Theoretical diagnosis framework

For innovation at the level of (a part of) an industry, generally the term transition is used. Socio-technical transitions have emerged from evolutionary economics (Nelson & Winter, 1977; Dosi, 1982). From the studies of former major societal changes, the insights have emerged about experimentation, multi stakeholder learning, coevolution of technologies, organisational forms, rules, regulations and financial systems. This has resulted in the theories of Strategic Niche Management (SNM) and Multi Level Perspective (MLP) (Geels & Kemp, 2007; Loorbach & Rotmans, 2006) that can be used to evaluate innovations. Innovations start in niches, but their further development is highly dependent on developments at different societal levels. SNM describes the role of emerging innovative niches in becoming mainstream in combined social and technological systems. This innovation management perspective focuses on the formation of niches in which innovations can flourish. SNM describes the transition by reporting on the three processes which enable for a successful technological niche (Kemp et al., 1998):

- The articulation of expectations and visions. Such articulation would provide a direction to the learning process of parties involved and help to attract attention from necessary stakeholders and legitimate involvement and support.
- Construction of social networks. The interaction of stakeholders is needed to collect resources (time, expertise and money) and commitment required.
- Learning on multiple aspects. Such aspects include technical aspects and design specifications, market and user preferences, cultural and symbolic meaning, infrastructure and maintenance networks, industry and production networks, regulations and governmental policies as well as societal and environmental effects.

In turn, MLP uses the following indicators for reviewing the stabilization of niche-innovations that are ready to break through: (a) learning processes have stabilized in a dominant design, (b) powerful actors have joined a network, (c) price/performance relations have been improved and there are strong expectations of further improvement and (d) the innovation is used in niche markets, which amount to a market share of more than 5% (Grin et al., 2010).

For the context of this paper, we have merged the three processes distinguished by Kemp et al. (1998) and the list of the sub-topics with the indicators specified by Grin et al. (2010) into a diagnosis framework containing (1) clear direction, (2) network formation and (3) learning on the six aspects, i.e., (a) market and user preferences, (b) product and process innovations, (c) new rules and regulations, (d) price and performance improvements, (e) architecture, environment and quality improvements as well as (f) roles and responsibilities.

2.2 Prior empirical studies enabling the diagnosis

The diagnosis of the Finnish innovation programme, Hiukkavaara district in the City of Oulu, is based on the review of references published in English and Finnish, available via the website.

The diagnosis of the Dutch innovation programme is in part based on the case study research on the two of the 4 sub-programmes and the annual report of Energy Leap (Energiesprong, 2015). For the study of the Rapids sub-programme different pilot projects were visited in Heerhugowaard (7 April 2015), Nieuw Buinen and Emmen (both on 24 April 2015) and Soesterberg (3 June 2014). More direct information came from the meetings with Energy Leap and Rapids and conversations. The additional information was accessed via the websites of the partners of the programme. The detailed results have been reported via Oostra (2015a-b). In turn, the study of the LALOG sub-programme is based on the experience of Oostra as a member of the board of #ENEXAP between November 2013 and April 2015. Various projects were undertaken to facilitate owner-occupants to make their desires and needs explicit, to analyse the situation in their houses and to gather the information necessary for the inclusion of professionals, the formation of consortia, to provide training to make them fit for the job, etc. Data was gathered via action research, board meetings, occupant meetings, meetings with Energy Leap, study meetings with companies, meetings with other LALOG initiatives and conversations with people involved. The key results have been reported via Oostra (2015b) and Oostra & Been (2016).

3. Finnish case programme diagnosis

3.1 Hiukkavaara District as the case programme

The City of Oulu boasts to be “the Capital of the Northern Scandinavia”. The prime example is the Hiukkavaara, the largest district to be built. The development started in 2008. Homes for 20,000 new residents will be constructed around the old barracks area. The housing plan includes 10 000 homes, i.e., 3 200 apartments, 3 300 terraced houses, 2 000 semi-detached houses and 1 500 single-family houses (City of Oulu, 2015). 1,800 workplaces are being facilitated. In addition, the nearby Hiukkavaara Centre will serve 40,000 Oulu residents. Hiukkavaara is a model for climate-conscious design in the northern hemisphere. The Head of Urban Developments assures that energy and materials are conserved, nature is valued and human beings will adapt to their environment (City of Oulu, 2015). Best practices for developing construction and zero-energy buildings are being identified, assessed and implemented. The construction started in 2013. The first buildings were ready in Summer 2014. The building physical modeling started in the end of 2014. About 80% of the target area will be under construction by Winter 2015. The piloting culture in the City of Oulu is being continued via this project (Seppälä & Mikkonen, 2015).

3.2 Results of the diagnosis of Hiukkavaara district

(1) FINNISH CLEAR DIRECTION. The City of Oulu has defined the 14 guidelines for the development of Hiukkavaara Disctrict, i.e., to take into account (i) the nature and landscape values, (ii) a densely-built neighbourhood of urban houses in a versatile environment, (iii) dense 7-zone residential areas bordering on large green areas, (iv) comprehensive services, (v) cycling, walking and public transportation, (vi) facilities and areas for sports, recreation and outdoor activities, (vii) an integrated storm water system, (viii) alternatives and impact assessments, (ix) participatory planning, (x) cost efficiency, (xi) development projects on Living Lab platform, (xii) energy efficiency, (xiii) city farming and (xiv) art in urban space (Kallioniemi, 2012). During 2008-2015, a series of the pilot projects have concerned calculating life-span efficiency in city building (KERVO; Vainio et al., 2012), integrating urban development concept, partnering for an arctic, smart and sustainable city (INURDECO), consulting builders in choosing concepts for renewable energy efficiency solutions (RESCA), innovating public procurement with life-span and R&D, arranging the Living Lab and services, researching winter city, stimulating the creative sector in the former military barracks area, engineering ICT solutions for traffic, safety and lighting, designing home information systems, and piloting Smart City ICT platform and service center, RadioCity 2020 (Kallioniemi, 2012).

In turn, the goal of the Future Buildings and Renewable Energy Sub-Project is to create common operating models to builders and to exchange and implement the best renewable energy and energy efficiency practices generated during the pilot project. The sub-goals of the joint project are (i) to intensify the development of renewable energy technologies, (ii) to promote the spreading of successful solutions to other cities throughout Finland and (iii) to develop them into business models (Seppälä & Mikkonen, 2015).

(2) FINNISH NETWORK FORMATION. Companies and educational institutions co-develop products and jointly execute research. User experience and information about the operability of new solutions is being collected via Living Lab. A 3-circle network is being established. The inner circle involves the 12 pilot site builders and each of them is collaborating with design offices, material suppliers, etc. The builders have been selected based on their proposals to meet one of the three energy efficiency levels. In Group 1, each project including nearly zero energy solution or E-Number < 35 can freely choose a lot. In Group 2, each project where heat loss and E-Number are at maximum 60% of the minimum level defined in the norms can select the best possible lot after Group 1. In Group 3, each project where heat loss and E-Number are equal or less than 70% of the minimum level defined in the norms can get a lot, if it is not selected earlier. The middle circle consists of Building control of the City of Oulu and Business Oulu's seminars/educational events having around 80 enterprises and nearly 1000 participants. The broader circle with the E-mail list has over 250 contacts (Seppälä & Mikkonen, 2015).

(3a) FINNISH LEARNING ON MARKET AND USER PREFERENCES. City of Oulu is developing its user-oriented Hiukkavaara as follows. It listens to its residents and companies, has conversations with them and serves them. This "low-threshold" city gives its residents space to express themselves and creates opportunities to exercise recreational activities and enjoy the nature. Apartments, buildings, blocks, yards, streets and parks are all designed for human-scale life. Residents can walk, cycle and ski. Nature starts at the front door, yet shops and cultural events are within walking distance. Dwellings are accommodating specific client groups: young, middle-aged and older residents. Future residents can choose their own ways of life. Urban gardening allows for home-grown vegetables and herbs. Services include schools, day-care centres, youth centres, a residential community centre, health services, commercial services, a swimming pool, an ice stadium, a sports hall, sports fields, a fitness centre, Aalikkokangas Sports Centre and 250 kilometers of cross-country ski tracks. Old Hiukkavaara is a meeting point for actions and ideas. The culture life has discovered the renovated old barracks. Crazy ideas have resulted in successful companies. Work, activities and new business ideas are based on creative energy. Hiukkavaara is already one of the biggest centres of the creative sector in the Northern Finland. There are some 250 rehearsing bands. Artists, photographers, graphic designers and sheet-metal workers are merging with the new growth platforms. All this is being blended with the ICT expertise of the city (City of Oulu, 2015). Officials and experts are giving occupants advice on the usage and maintenance of buildings (Seppälä & Mikkonen, 2015).

(3b) FINNISH LEARNING ON PRODUCT AND PROCESS INNOVATIONS. Hiukkavaara district offers premises for R&D, testing and launching to tackle critical issues like "How can a home become energy efficient?", "How are renewable energy sources utilised?" and "What kind of new services are needed in the future?" Companies developing services can get inspiration by observing the behaviour of locals. The performance of energy production and consumption, building automation systems and building physics are being measured and analysed. The challenges are related to the levels of energy design, moisture management as well as automation and control systems. For example, Saikotek Oy has installed the building-physical measurements in its pilot building. University of Oulu is modelling the building-physical operation of structures by utilising data from these measurements. In Sonell Oy's building, heat is produced by a ground-source heat pump and distributed to room air by a radiant floor heating system. About 30 m2 of the solar collectors are on the roof of a shared technical room. A home automation system is controlling heating, ventilation and safety systems (Seppälä & Mikkonen, 2015). Besides, Hiukkavaara has an international digital service home where ICT companies take part in developing services to support living and recreational activities. Living Lab is packed with the development themes of a sustainable city, i.e., energy efficient dwellings, intelligent electric networks, block models of a winter city, alternative and regenerative forms of energy, ecological water system, centralised waste management, functional public transportation, safe wintertime cycling and related ICT services (City of Oulu, 2015).

(3c) FINNISH LEARNING ON NEW RULES AND REGULATIONS. Subarctic and arctic areas like Hiukkavaara district require special technologies and skills to build climate friendly, energy efficient and user oriented winter cities with innovative services and logistics processes. For example, the Ecocity Evaluator software is used to assess the energy consumption of the community development, the carbon dioxide emissions and the costs based on the master and city plans. The software enables the assessment of the emissions of both production and consumption. The assessment takes into account buildings, traffic, energy production, industry, agriculture and carbon sinks. Comparisons with other Nordic cities are also being relied upon (Kallioniemi, 2012).

(3d) FINNISH LEARNING ON PRICE AND PERFORMANCE IMPROVEMENTS. The initial present value of the life-cycle costs for Hiukkavaara district as a whole is about EUR 3,4 billion. Thereof, the majority share of the residential buildings is EUR 3,0 billion (87%), the share of the community services is EUR 165 million (5%) and the share of the infrastructures is EUR 280 million (8%). Both the present value method and the annuity method have been relied upon. The calculations are based on the 50-year life-cycle and the 3% interest rate. All the costs are reported as those of the first quarter of the year 2012 without VAT. Concerning each of the three sectors, the five sub-cost categories include lot prices, construction, maintenance, operations and demolition. When the district plan accommodates 20 000 residents, the average life-cycle costs per resident is about 170 000 euros (Vainio et al., 2012).

(3e) FINNISH LEARNING ON ARCHITECTURE, ENVIRONMENT AND QUALITY IMPROVEMENTS. Hiukkavaara acts as the centre of city life in all four seasons, also as a big recreational area. The land area is 1,500 hectares. The architecture of a snowy city, the sunshine of a crisp winter day and the joys of winter time sports provide new opportunities for district design. For example, the same designated areas are used in the winter for storing snow and in the summer for playing floorball and basketball. Different routings are provided: if weather is good, people can enjoy fresh air, but if it is bad, they can choose a covered route protecting from rain. Streets and parks create opportunities for walking a dog or doing some parkour. Special attention is being paid to make nature and wilderness an integral part of the design, connecting nearby beaches along riverbanks and lakeside, heathlands, boulder fields and marshes with paths and duckboards. Arctic wilderness involves forest animals, snowmobiles and hounds. Ideally, "recreational areas are within walking or cross-country skiing distance. Seasonally changing light and nature are part of city life. The district is designed to be the model city for sustainable community planning. Houses, streets, districts and landscapes create a rich and diverse cityscape. Houses come in different shapes and sizes, even on top of each other. Various lifestyles are visible in its architecture. Urban gardening is visible in gardens and on rooftops." (City of Oulu, 2015).

(3f) FINNISH LEARNING ON ROLES AND RESPONSIBILITIES. The adoption of the viewpoint of sustainable development in construction creates new and expands existing business opportunities during all phases within building processes. In addition to life-cycle projects suitable for large companies with risk-bearing capacity or novel networks, sustainable construction offers opportunities also for small, local companies. In the design of one- and two-family house dominated residential areas, value chains from general design to finished residential areas take many years. Designers and contractors alike are being advised to retain possibilities to make future changes instead of meeting exact needs among particular clients. Value chains are developing solutions for changing operating environments and uses of buildings (Vainio et al., 2012).

4. Dutch case programme diagnosis

4.1 Energy Leap as the case programme

The Dutch innovation programme described herein is Energy Leap (Energiesprong, 2015), commissioned by the Dutch Ministry of the Interior. The extended programme ran between 2010 and 2015. The aim was to make buildings energy-neutral and boost large-scale initiatives targeting dwellings, office buildings, shops and care institutions. The four most ambitious sub-programmes targeted at dwellings, i.e., (i) All Lights on Green (LALOG Lokaal Alle Lichten Op Groen) with owner-occupants was seeking to make homes energy-neutral, (ii) Rapids Rental (Stroomversnelling huur) was set to renovate rental houses to the level of nearly zero energy buildings and to overcome the financial problems and the restricted resources that the housing associations were dealing with, (iii) Rapids Purchase (Stroomversnelling koop) focused on the market for owner-occupants and (iv) Our Home Deserves It (Ons huis verdient het) campaign was launched to show to banks and companies that owner-occupants are interested in converting their homes to net zero homes and the TV show highlighted the results of Rapids Purchase. When the national funding of Energy Leap came to an end in December 2015, the arrangements have been put in place to continue the funding via the partners already involved. In many regions, e.g., Utrecht, Brabant and Overijssel/Gelderland, plans have been made to set up regional agreements with dedicated (new) partners to retrofit substantial amounts of dwellings.

4.2 Results of the diagnosis of the four sub-programmes and the pilot projects

(1) DUTCH CLEAR DIRECTION. LALOG provided support to the groups of owners in Apeldoorn, Wageningen, Den Bosch, Hoorn, Amsterdam and Amersfoort. The objective was to bring at least 20 homes in each municipality to energy-neutral via the process of learning by doing by residents, builders, municipal officers, contractors, brokers, appraisers and bankers. In turn, the goal of Rapids Rental was set to deeply retrofit and convert the 111.000 rental houses owned

by the associations before 2020 to the level of zero-to-the-meter (on a yearly basis), block by block, within two weeks, for 45k/dwelling and satisfied occupants. This clear goal has become the joint ambition of an entire network. Rapids Rental was considered to be the best example by the Building Performance Institute Europe (Staniaszek, 2014). Rapids Purchase was aiming at similar goals for individual privately owned dwellings.

(2) DUTCH NETWORK FORMATION. Considerable efforts have been made in the building of all sorts of networks to come up with technical and social innovations that are needed for large scale retrofitting of dwellings without additional subsidies. This provided a solid base to further integrate necessary solutions and make operations more cost efficient. At the beginning, ad hoc coalitions were created for zero-to-the-meter retrofitting, project-by-project, in design competitions. The next step was to create coalitions in municipalities, in which demand would be clustered for local builders (LALOG). However, it turned out the incentive for proper innovation was still not enough. Next step in Rapids Rental was to make deals including the supply chains and housing associations for a series of projects and, thus, fostering a situation in which innovations could emerge across projects. Supporting parties like e.g. brokers, municipalities and financial experts have also been linked to the network. This finally got the innovation process going.

(3a) DUTCH LEARNING ON MARKET AND USER PREFERENCES. The Energy Leap programme provided the opportunity to cluster the preferences of housing associations, tenants and private house owners in different municipalities and contexts. The people executing the Energy Leap programme took the time and effort to reflect on this in several settings. This made it possible for them to draw conclusions on what was necessary to develop a highly industrialized approach for the retrofitting of mass-produced housing from the fifties, sixties and seventies. Also attention was given to the preferences of tenants in order to develop approaches to win them over.

(3b) DUTCH LEARNING ON PRODUCT AND PROCESS INNOVATIONS. In Rapids Rental, the idea was that retrofitting methods can be improved and gradually scaled up to industrial production levels by employing integrated prefabricated building components and deals that included the perspective on a series of projects, to convince the construction sector to make the necessary investments. Process changes were also needed to speed up execution, as well as to improve quality and customer satisfaction. (see for more information: Oostra, 2015b) Originally, the knowledge and the experiences gained by each team related to a specific retrofit project, supply chain or client. In Rapids valuable insights were disseminated via planned sessions with all programme participants and focused meetings with e.g. the housing associations only. The contractors, i.e., Volker Wessels, Dura Vermeer, Ballast Nedam and BAM developed and integrated technical solutions and social innovations to meet the high ambitions set for tenant satisfaction, price levels and house performance levels. Now a new, rather large market is opening up for zero-on-the-meter retrofitting, interactions are set up with the big building product suppliers like BASF and Mitsubishi to realise new products for this market and thereby making concepts even more cost effective and of higher quality (e.g., Gent and Lippens, 2015). Major innovative steps have been made including: new facade components & service components as an integral part of new specific retrofit concepts and the use of BIM, lean and 3D scanning to speed up the preparation and execution processes. All this is fundamentally different from traditional contracting where the room left for project-specific innovations and risk taking is rather restricted.

(3c) DUTCH LEARNING ON NEW RULES AND REGULATIONS. During Rapids Rental, many adjustments to legislation and regulations were deemed necessary. It turned out crucial to make it legal for social housing associations to use the money tenants pay for energy as a source to fund the retrofit. The problem was that for many houses the rent would go up over the allowance-limit for many houses, if the rent would also include the envisioned energy performance fee. Amendments were also needed in the areas of licensing, energy labelling and exemptions. Exemptions were deemed necessary since related procedures often take half a year. Such delays are costly for stakeholders. Environmental assessments can be speeded up because all the Rapids retrofitting concepts are obliged to meet the requirements set out in the rules for zoning, the Building Act and the Flora and Fauna Act.

(3d) DUTCH LEARNING ON PRICE AND PERFORMANCE IMPROVEMENTS. The first three retrofitting projects of Energy Leap were commissioned in the form of a competition. In the De Kroeven project in Roosendaal in 2010, 244 family homes were renovated by the designs of the two architectural firms, at just over 130,000 euros per home. This reduced energy consumption for heating from 200-150 kWh/m2 to 30-20 kWh/m2. In Kerkrade, 153 homes were renovated in 10 days each at an average of 100,000 euros per home. The homes were fitted with the new façades and roofing, solar panels, high-efficiency combi boilers and mechanical heat recovery ventilation. Monthly, this saved 101 euros, but the tenants saw their charges reduced by just 37 euros a month because of a 64 euro rent increase. In Apeldoorn in 2013, 188 homes should have been renovated in Het Schilderskwartier dating from 1951, at an average cost of 80,000 euros. However, none of the consortia met the financial requirements. In the end, only one plan could match the housing association's requirements by providing for the establishment of an energy company called Energy BV. Since the residents did no longer have a say in the matter, their resistance grew and only 60% of the residents approved the plans, well short of the 70% required by law. This is why the plan for this third project has not been executed. Instead, the housing association opted for a regular B label renovation and continued the energy-neutral experiment on a smaller scale (Oostra, 2013). With the more systemic innovation started with Rapids Rental, the costs of a zero-to-the-meter retrofit for standard row houses dropped to 60k. Plans are in place with the housing associations involved to retrofit a substantial part of their portfolio. Although only about 500 dwellings have been retrofitted by 2015 (van de Groep, 2015), the plan is still to retrofit in total 110 000 houses before 2020. In order to attain such high numbers, it is necessary that the government approves the new regulations concerning the energy performance fee. During the 4-year programme, a considerable improvement of quality (architectural concepts, integrated technical solutions and performance) has been realised in combination with a price drop of more then 50% (Oostra 2015b).

(3e) DUTCH LEARNING ON ARCHITECTURE, ENVIRONMENT AND QUALITY IMPROVEMENTS. An important requirement for housing associations is that these concepts improve the architectural quality of the existing dwellings. Dutch housing associations have noticeably attention to maintain or rather improve the architectural qualities of both the dwellings, as well as the neighbourhood in which these dwellings are located. In New Buinen e.g., the neighbourhood as a whole will be restructured, by swopping public and private side of the houses and by re-introducing a canal, a typical landscape element for these peat areas. Quality improvement was an aim, but of course there were also teething problems in projects part of Rapids. In Heerhugowaard for example, delamination occurred of the facade finishing (Oostra, 2012b).

(3f) DUTCH LEARNING ON ROLES AND RESPONSIBILITIES. The Energy Leap programme has proved that real progress can be made within four years towards a cost-effective, quick, up-scalable and occupant friendly retrofitting approach. These developments forced professionals in private companies and public bodies alike to rethink their roles and the ways to do business. Thus, discussions were, and are still, being held within many consortia to (re-)organize themselves in order to deliver retrofits with ease, performance and cost efficiency. Builders are intensifying and extending the integration of supply chains to deliver suitable solutions. In the same vein, this implies that companies are focusing on the tasks they themselves are good at and able to invest in. Entire supply chains need to become more client-focused. In the case of #ENEXAP, a lot was asked from the professionals involved. The occupants were eager to keep modifications already made to their homes, including the measurements for saving energy and generating durable energy mainly via solar panels. They also asked for additional changes to their home, which made matters for consortia even more complex to handle (Oostra 2015a).

5. Discussion and conclusions

The decisive impacts of the housing sectors on the development of the EU countries, economies, socio-political constellations, technologies and environmental footprints are widely recognized, not forgetting the mutual dependencies between all these spheres, regionally and country by country. In reality, severe barriers are still being met across the EU member countries, such as highly uncertain housing demand, prolonged project development times, late-arriving local public services, still-missing infrastructure, obvious needs for change in involved organisations and supply chains, changing preferences within wider social and institutional context, etc. Thus, we are herein arguing that, for many national stakeholders, it is far from clear how the transition of the EU housing sectors could be directed towards the socio-politically balanced, economically integrated, technologically advanced and high-sustainability sectors we would like them to be, let alone what key roles and tasks stakeholders should become engaged in. This uncertainty triggered us to write this joint paper and explore what kinds of radical elements could be implanted into national residential development programmes within the EU region. For this purpose, we have diagnosed the prime Finnish and Dutch experimental programmes in the previous sections. Relying on the 3-area diagnosis framework introduced in section 2.1, we would like to put forth a set of the suggestions for making radical progress as follows.

For ensuring (1) clearly and radically directed residential programmes, we suggest that key public decision making bodies, at a governmental, regional and/or city/municipality level, or an organisation that is appointed to represent one of these, define clear goals with support from some key stakeholders, daring to be frontrunners. These goals are set (1a) to improve outcomes on each of the socio-political, economic, institutional, technological and environmental contexts, (1b) to unite stakeholders in terms of balancing their aims and benefits, (1c) to stimulate the sector to include other (only value adding) stakeholder groups in order to be able to reach goals and overcome barriers to be met, and (1d) not to be afraid of asking for radical innovations on key dimensions, such as living quality, space, technical performance, public and private services, mobility, costs, etc. The attainment of ambitious goals and the realization of wide action plans both start with small-scale pilot projects and alike in order to allow for the evaluation and re-setting of goals before programmes are actually started and desired innovations are becoming up-scaled. The Finnish and Dutch experience with the pilots and programmes have proven that such an approach is realistic.

For forming (2) radical networks, we suggest that a range of alternative networks be classified in terms of (2a) developing new key entrepreneurial roles that stakeholders can assume, (2b) initiating multi-dimensional, causal links between different stakeholder/party roles, (2c) leaving room to introduce novel expertise and insightful stakeholders to deal with missing expertise, to advocate, facilitate, enable and moderate during every phase of the (sub-)programme, (2d) evolving memberships through the phases of the programme and beyond, (2e) making key decisions, activities and tasks included in each network class transparent for all to criticise, while not hampering the creativity necessary for innovation and (2f) innovating all kinds of institutional, digital and physical supportive systems and tools that parties can rely upon. A programme directorate then compares gains and losses by each network class, chooses the most radically viable ones and plans networking sub-programmes accordingly directed at upscaling.

For enhancing (3) radical learning, we suggest that a range of alternative ways of learning, exploiting existing knowledge and creating new solutions, be selected and planned by learning areas, to arrive at: (3a) a flexible, highly sustainable market and better knowledge of user preferences in relation to changing demographics, public, private and third sectors, built environment, nature, etc., (3b) product and process innovations, incremental/disruptive, solo/co-innovated, co-funded, given/openly competed, scaled up/down, etc., (3c) new rules and regulations to mend hampering or missing legislation, on city/country/EU levels, by areas and units, etc., (3d) affordable prices, performance improvements and guarantees for stakeholder groups and participant roles, home/apartment/house types, public and private buildings, infrastructure, etc., (3e) improvement of architectural quality, environmental quality and building quality to enhance the realisation of appealing cities, attractive country-sides, meaningful places, true well-being, environmental sustainability, personalised living, inclusive society, regional prosperity, etc. and (3f) commitment from stakeholders to take on new roles and responsibilities designated to realise the goals set and provide performance warranties. The members of the programme compare the alternative routes, choose the most effective ones and integrate them accordingly in designated sub-programmes to start the next learning cycle.

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Research Road Map on Construction in Brazil: method and results

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Abstract

The purpose of this article is to present the method used for preparing the Research Road Map on Construction in Brazil and the results of this study that involved a broad participatory process. Academia and the private sector, with the participation of the public sector, jointly reviewed and proposed strategies, under the leadership of two institutions: The Brazilian Chamber of the Construction Industry (CBIC) and the Brazilian Association of Technology of the Built Environment (ANTAC). Although elaborating strategic proposals normally involves a complex approach, a working method was chosen that simplified this procedure. A more orthodox approach would have required mounting an extensive data survey, and undertaking numerous analyses and diagnoses; a wide spectrum of research sources would have been needed for this. A shorter method was adopted, commencing with the preparation of a document that described inter alia the resources that already existed for the production of STI in the Built Environment, and that indicated the level of subject-relevant collaboration existing between academia and industry. This document analysed the main postgraduate centres relevant to the subject in Brazil. A series of challenges to be confronted by the construction industry was also identified, as well as various issues that needed to be resolved prior to tackling them. The document also emphasized the need to establish an STI policy for the construction industry. The second step was to hold five thematic workshops, bringing together experts from academia, government agencies, and companies and their offshoots. They hosted 318 guest participants. Given their expertise and the dynamic interface established, the data collection, analysis and diagnosis phase was avoided, and the participants progressed quickly and confidently to formulate a set of consistent and relevant strategies. The output from these workshops led to a set of 19 strategic lines of research. Nine obstacles were identified that needed to be overcome, and a description was included of the type of STI infrastructure required for the successful of their implementation. Six strategic projects for developing STI, together with four strategic public policies, were proposed and detailed for overcoming these barriers and for deploying the required STI infrastructure.

Keywords: Brazil, research road map, construction, construction industry, technology foresight

1. Context and working method

In 2002, the Brazilian Association of Technology of the Built Environment (ANTAC), with support provided by the Ministry of Science, Technology and Innovation, the Ministry of Development, Industry and Foreign Trade, and the Ministry of the Cities, issued a document called "The Strategic Plan for STI in the Built Environment with a focus on Housing Construction". The aim of the document was to establish strategic priorities for actions to promote Science, Technology & Innovation (STI) in Brazil (ANTAC, 2002). While this document was useful for guiding public sector STI initiatives, the Construction Industry, regardless of its key role in Brazil's sustainability, continued to be disregarded as a priority STI development sector. Furthermore, the initiative failed to change corporate culture concerning innovation and did nothing to encourage companies to work more closely with academia. ANTAC brings together and represents the community of researchers and technical experts in the field of Technology of the Built Environment.

In 2007, the Brazilian Chamber of the Construction Industry (CBIC) and its partners launched the Technological Innovation Project (TIP) with a view to "making technological innovation an inseparable part of the competitive strategy of the construction sector and its companies throughout the entire supply chain" (CBIC; NGI, 2009). Completed in 2009, the TIP study proposed a range of development projects needed to boost innovation in the sector. ANTAC was invited by the CBIC to proceed with one of these projects: "Project 7 - Science and Technology for Innovation in Construction." CBIC represents the construction industry players from a political standpoint, promotes the integration of them at the national level, and serves as a mouthpiece for 79 construction trade unions and employer associations in Brazil´s 26 states and the Federal District.

An opportunity therefore arose for addressing the issue in a new light: by broadening the goal of Project 7, the academic and private sectors, with public sector participation, joined forces to review and propose new strategies as a first step towards formulating an STI Built Environment Policy for the country. This resulted in the emergence of the Brazilian Research Road Map on Construction.

While strategy formulation is usually a complex, multiphase process, the working method adopted for Project 7 was eminently straightforward. It was decided that the strategies would embrace an STI policy that would genuinely enable the construction sector to evolve and thus contribute more substantially to the economic, social and environmental sustainability of the country. More wide-ranging discussion, although it would have helped to shape more precisely the three dimensions involved, would not have changed the core premise. It was noteworthy that, notwithstanding the abovementioned studies, stakeholders had made little headway in their approach to STI. This was also the case with the government agencies responsible for formulating STI policies.

The next step in the process was also simplified: how to reach this goal? An orthodox approach would have meant exhaustively scrutinizing a mass of data, analytical and diagnostic studies. Research would have needed to focus on many different fronts: research institutions and universities; laboratories; companies and their various representative associations; public agencies; and entities responsible for formulating and promoting STI policies. It would also have been necessary to examine similar studies already done in countries such as Ireland (ICSTI; FORFÁS, 1999), France (Bougrain and Carassus, 2003), Australia (Hampson, 2004), Denmark (National Agency for Enterprise and Construction, 2006), United Kingdom (Department of Trade and Industry, 2002; Edkins et al., 2008), South Africa (Rust et al., 2008), USA (National Research Council, 2009), and New Zeland (Bates and Kane, 2009), as well as the countries of the European Union (ECTP, 2005a and 2005b; Goodier et al., 2008) or even larger groupings (Barrett, 2005; CIB et al., 2010).

The adopted route was in fact considerably shorter, starting with the drafting of a document with a number of clear goals. One of the goals of the exercise was to examine the existing infrastructure for producing construction industry-related STI, paying particular attention to the level of cooperation in STI between academia and the productive sector on the subject. The paper listed the main postgraduate centers working on STI in the Built Environment in Brazil, identifying their main active lines of research, the precise subjects being researched, their prospects, and the challenges faced. Reference was also made to the many challenges still to be faced by the civil construction industry, including various bottlenecks that needed to be surmounted. Finally, the paper underscored the need to establish an STI policy for the sector and discussed the opportunity for creating a specific Sector Fund (Cardoso, 2011).

The second decisive step was to organize five thematic workshops bringing together experts from academia, from companies and their representative associations, and from government agencies. These workshops were intended to cover the main thematic areas of Built Environment Technology.

The workshops were held between October 2011 and October 2012. They involved a total of 318 invited participants, including 88 senior research professors from 29 Brazilian educational and research institutions, and one from abroad. The expertise of the participants and the positive energy generated in the workshops created substantial synergy and convergence of ideas, while avoiding the usual data collection, analysis and diagnosis phases, and resulted in the rapid and reliable formulation of coherent, relevant strategies.

The thematic areas addressed in the five workshops were as follows (Cardoso, 2012):

- **Workshop 1 - Construction systems and processes and production management:**

□ Production management: quality, productivity and sustainability.

□ Rationalization, innovative systems and construction processes.

- **Workshop 2 - Building materials and components:**

□ Innovation in materials and components for sustainable development.

□ Innovation in materials and components to improve productivity in building construction.

□ Materials and components innovation to improve building performance.

· **Workshop 3 - Water, Energy and Comfort:**

□ Water use in buildings.

□ Energy use in buildings.

□ Acoustics in buildings.

□ Comfort and energy on an urban scale.

· **Workshop 4 - Project Design, Use and Operation:**

□ Design process management.

□ Operation and maintenance of buildings (Facilities Management) and post-occupancy evaluation.

□ Information and Communications Technology and Building Information Modeling (BIM).

· **Workshop 5 - Cities:**

□ Urban infrastructure.

□ Housing management.

□ Real Estate.

2. Results: Research Road Map on Construction

The workshops resulted in a three-part Research Road Map on Construction in Brazil (Cardoso, 2013):

- Proposition and description of 19 strategic lines of research in the Built Environment;
- Identification and description of nine obstacles to be overcome and the STI infrastructure required for the successful implementation of the proposed strategic lines of research;
- Proposition and description of projects for developing STI, together with four strategic public policies for overcoming these barriers and for deploying the required STI infrastructure.

2.1 Strategic lines of research for STI in the Built Environment

The proposals put forward in the workshops envisaged 19 strategic lines of research for STI in the Built Environment, covering the different life cycle phases of a project:

- Line 1 - Carrying out studies on (i) competitiveness and value creation by conducting research on innovation-inducing mechanisms in companies; (ii) the economics of the construction sector; (iii) articulation and modernization of the supply chain; (iv) public and sectoral policies; and (v) improving the professional competencies and productivity of the workforce at every level. Particular efforts need to be focused on micro, small and medium-sized firms.

- Line 2 - Strengthening fundamentals, methods and tools with a view to scaling up sector-relevant practices in the real estate segment in areas such as: improving decision-making processes and strategic and tactical planning in companies; improving the presentation of real estate products; identifying the concerns and needs of different consumers; defining the relationship between business and government with regard to urban planning and environmental regulations, and the operationalization of instruments such as public-private partnerships, urban planning schemes and the granting of concessions.

- Line 3 - Development of design process management systems in public and private works focused on organization, contract and coordination models.

- Line 4 - Development of collaborative design processes using Information Technology in Construction (ITC) and Building Information Modeling (BIM) concepts and tools.

- Line 5 - Development of a knowledge management system to support projects to ensure the sustainability and performance of buildings and urban infrastructure. This knowledge management system involves setting up and using databases and other information sources that will contain inter alia: key environmental parameters maps; information on materials deterioration agents; reference service life of materials, components and urban elements; thermo-hygrometric behavior of materials and components; acoustic characteristics of wall materials; technical catalogs and Building Information Models (BIM) of materials and components; performance evaluation inventories according to the user´s point of view; inventories on use, operation and maintenance indicators; inventories of socio-environmental sustainability indicators; inventories of the generation potential, consumption and end-use of energy in cities; inventories of urban solid and liquid wastes, and their power generation capacities; data on the activities of real estate markets in Brazilian cities.

- Line 6 - Development of a simplified method of Life Cycle Assessment (LCA) applicable to different-sized companies, in order to facilitate the introduction of verifiable Environmental Product Declarations (EPDs). This involves e.g. defining the scope of each product, as well as its governance models and Product Category Rules, etc.

- Line 7 - Development of models, methods, tools (including test equipment) for evaluating the continuous development and improvement of performance evaluation technology for buildings and urban infrastructure.

- Line 8 - Development of a National Codes of Practice System and a knowledge management system to support it, including the development (creating and assembling) and application (dissemination and use) of best design practices, and the construction, use, operation and maintenance of the buildings and urban infrastructure systems and elements, including control practices at every stage.

- Line 9 - Development of ITC in the design, construction, operation and maintenance of buildings and urban infrastructure and Building Information Modeling (BIM) at the design, construction, control, use, operation and maintenance stages of buildings and urban infrastructure.

- Line 10 - Development of components, systems and innovative processes, and of open industrial systems based on principles such as modular coordination, easy connectivity, increased productivity, reduced product delivery times, improved performance and durability, lower environmental impact during the product life cycle, lower consumption of materials and lower losses, etc.

- Line 11 - Development of materials, components, equipment and eco-efficient systems, and improvement of the eco-efficiency of existing materials, etc., always considering the typical life cycle of the built environment. This initiative should include finding solutions to improve the durability of materials, components, equipment and systems, to assess their prospects for dematerialization, potential reuse, recycling or regeneration, and to reduce losses by employing the correct tools for selecting materials.

- Line 12 - Development of research on water use in buildings, to include exploring concepts, methods and tools to reduce user demand. Also to study possible safe ways to ensure domestic water supplies from alternative sources, to encourage the rational use of water, to design cold and hot water, drainage and sewerage systems for buildings, and to evaluate climate change and the performance of building systems.

- Line 13 - Development of research on energy use in buildings, to include exploring energy-related concepts, methods and tools used in buildings with regards to natural ventilation, thermal performance, bioclimatology natural lighting, and using models to simulate energy-efficient buildings.

- Line 14 - Development of studies on concepts, methods and tools related to buildings acoustics: acoustic characteristics of internal and external sound-reducing materials; floor-insulating materials and technologies; vibration; subjective acoustics; and using numerical and computational simulation.

- Line 15 - Development of integrated technological and management production systems. Exploring the development of methods, tools, indicators and their respective benchmarks focused on production systems management, involving items such as costs, target dates and risk management, people management, logistics and supply management (procurement), and clean production.

- Line 16 - Development of fundamental concepts, methods and tools for consolidating the use, implementation, maintenance and adaptation of the concepts concerning the use, operation, maintenance, post-delivery and security of products, and the management of facilities. Development of methods and tools for commissioning buildings and their parts, and urban infrastructure; post-handover and management of occupied buildings; automation and oversight of buildings and urban infrastructure management procedures; control and oversight of building and infrastructure use; costs management during warranty periods; management of operating costs, maintenance and life cycle of buildings and urban infrastructure.

- Line 17 - Development of urban-wide design methods and interventions aimed at integrating urban morphologies with infrastructure and housing systems. This should involve considering topics such as: the growth dynamics of cities and rural areas, including both small and large size cities; risk prevention, security, accessibility, comfort, energy, urban planning and the adaptation of buildings; the development of inclusion and different living styles in cities; classification and upgrading of the housing stock; and accessible and appropriate information technologies for participatory decision-making and activities.

- Line 18 - Development of models for housing production programs, and of public policy proposals for housing, taking into account the diversity of cities and different income levels and market segments. Studies to be carried out on ways to improve existing practices.

- Line 19 - Development of fundamentals, methods and tools for environmental comfort and energy on an urban scale, involving topics such as: the behavior of urban heat islands (UHI); the impact of urban geometry and building density on accessibility to natural resources, and in response to local climate change; the development and measurement of urban thermal comfort indices; thermo-hygrometric behavior of native vegetation clusters in urban areas; thermo-hygrometric behavior of urban building materials and components, and the effects of the reflection coefficient (albedo) in urban areas.

2.2 Obstacles to be surmounted and STI infrastructure required

The workshops identified the obstacles blocking successful development of the strategic lines of research:

- Distancing between academia and the market and between academia and the public sector;
- Poor liaison between construction industry players;
- Problems with access to knowledge;
- Conservatism of construction industry players;
- Short-term view held by construction industry players;
- Legal constraints affecting development of STI;
- Use of inadequate mechanism for evaluating research by academia focused on technological innovation;
- Unavailability of data in support of STI; and
- STI held back by shortage of standards and regulations as well as by their limited application.

The workshops also identified and described STI infrastructural limitations vital for successful development of the strategic research lines in the laboratorial, human, and financial resources areas.

Further details can be found in Cardoso (2012).

2.3 Strategic projects for developing STI and strategic public policies

The discussions on ways to surmount obstacles and secure the necessary infrastructure for STI to ensure the successful development of the strategic research lines led to six strategic projects for developing STI in the Built Environment being identified and defined:

- Employing STI development models to bring academia, the market and the public sector closer together;
- Enhanced cooperation between construction industry players;
- Increased knowledge dissemination;
- Scaling up research evaluation mechanisms for research focused on technological innovation;
- Increased resources for STI; and
- Better human resources training for STI.

Finally, discussion on ways to overcome the obstacles identified and to guarantee an infrastructure for STI led to four strategic policies being identified and defined:

- Tax incentives to promote investment in STI;
- Industrial policy for development of the construction supply chain;
- Changes in public procurement and contracting; and
- Increased access to information on STI.

More details can be found in Cardoso (2012).

3. Final comments

The Research Road Map contributes to filling a gap by working up strategies for formulating an STI policy for the construction industry focused on the Built Environment in Brazil. The process of strategic formulation does not however end with this Road Map. The strategic lines of research and the proposals put forward for projects to surmount obstacles and barriers and for public policies vital for achieving an STI policy for the sector call for a more accurate definition of objectives. Action plans need to be drawn up for each strategic research line, and people appointed to be responsible for taking them forward successfully. Targets, deadlines and a procedural road map are also vital components, together with the necessary human, technological, scientific and financial resources and strategies for obtaining them. Rapprochement between academia, the market and the public sector is essential for moving this process forward.

Notwithstanding its limitations, the Research Road Map on Construction provides guidance for decision making on investments in STI by construction companies and other sector stakeholders and government funding entities. The Road Map also steers research institutions towards the lines of research that need to be adopted, thus contributing to the modernization of the construction sector and quickening the pace of innovation therein. Above all, it is hoped that the strategies proposed will lead to the effective formulation of an STI policy for a sector that is vital for Brazil's economic development and the welfare of its population.

Although the Research Road Map on Construction has been developed for Brazil, the results are similar to those of studies done in other parts of the world, which suggest that the construction sector depends heavily on the performance of the players involved in the industry as a whole. All share inherent views on the need to develop STI, and confront similar obstacles, regardless of the level of development of the different countries. A worthwhile initiative would be to conduct a comparative study on the methodological approaches of the studies cited above (and others) and on the data outcomes produced on the situation of the construction sector, with a view to gaining further invaluable knowledge about the sector´s basic characteristics.

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Construction in Developing Countries: Current imperatives and potential

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Abstract

The study is a review of the state of knowledge on the construction industries in developing countries and an attempt to explore new ways to address the task of developing the industries to enhance their capabilities to deliver the buildings and infrastructure which the countries require to improve the quality of life of their citizenry. The nature of the long-term national development task of the developing countries is discussed to provide the background for the examination of the ways in which the construction industry can contribute to the fulfilment of the broad aspirations of the nations, and the attainment of their developmental goals.

The objectives are: to consider the needs for built items in the developing countries in the context of national development; to examine the challenges and problems facing the construction industries and consider the usual solutions suggested; to explore possible new, contextually relevant ways in which the industries can be developed and their performance improved; and to consider how construction in developing countries can leapfrog developmental stages, and draw lessons for the industrialised countries.

The study is based on an analysis of data on existing needs of construction items in the developing countries; and a review of literature on the development of the industries in these countries. An analysis of relevant key overarching issues and factors in the economies of the developing countries and a consideration of the construction industry from its basic nature, informed the drawing of inferences on new ways of improving the performance of the construction industries in the developing nations. The possibility of leapfrogging in many areas is explored. It is suggested that the construction industries in the developing countries have the potential to offer lessons for their counterparts in industrialised countries.

Keywords: construction industry, developing countries, infrastructure, future, leapfrog, lessons

1.0 Introduction

The construction industries of the developing countries have been studied since the mid-1960s. The earliest works were by the University College Economics Research Group (UCERG) which undertook many studies for the World Bank and International Labour Office. The development of knowledge on the subject is presented by Ofori (1993, 2012a). This study is a review of the state of knowledge on the construction industries in developing countries. Its aim is to explore new ways to develop the industries. The objectives are to:

1. consider the needs for built items in the developing countries in the context of national development
2. examine the challenges and problems facing the construction industries which must fulfil these needs and consider the usual solutions proposed
3. explore possible new, contextually relevant ways in which the industries can be developed and their performance improved
4. consider how construction in developing countries can leapfrog developmental stages, and draw lessons for the industrialised countries.

The study is based on an analysis of data on the needs of the economies and how construction can contribute to their realisation; a review of recent literature on the development of construction industries; and an analysis of the construction industry from its basic principles. The possibility of leapfrogging stages and lessons for industries in industrialised countries are considered.

2.0 Development needs, goals and programmes

2.1 Washington and Post-Washington Consensus programme

Various approaches have been taken to set the poorer countries on a path to long-term development. The Washington Consensus of economic development which was applied by the World Bank, International Monetary Fund, United Nations agencies and the US government over the 1980s and 1990s comprised (Williamson, 2004): Fiscal discipline; Public expenditure priorities – moving them away from subsidies and administration; Tax reform; Financial liberalisation; Exchange rates - managed to induce growth in non-traditional exports; Trade liberalisation; Increasing foreign direct investment; Privatisation; Deregulation; Secure intellectual property rights; and Reduced role for the state. This ‘package’ was intensely debated and criticised (Williamson, 2004). It went through many changes. By the late 1990s, it comprised: sound fiscal and monetary policies; broad-based taxes levied at moderate rates; market determination of prices and quantities; discriminating use of infant industry protection; an acceptance of foreign direct investment; active government provision of education, health care, and infrastructure; and anti-poverty programmes. Stiglitz (2004) presents a sharp critique of the approaches in the 1980s and 1990s, and concludes that, given the differences among countries, there cannot be any consensus as a one-size-fits-all solution cannot work.

The Millenium Development Goals (MDGs) provided the framework for socio-economic development from 2000 to 2015. Progress was made in many areas including poverty reduction (in 1990, half of the population in developing countries lived on less than $1.25 a day, that proportion dropped to 14 percent in 2015; the number of people living in extreme poverty declined from 1.9 billion in 1990 to 836 million in 2015); and primary education (net primary school enrolment rate in developing regions reached 91 percent in 2015, from 83 percent in 2000; the number of out-of-school children of primary school age worldwide reduced by half, to 57 million in 2015, from 100 million in 2000) (United Nations, 2015a). The progress in connectivity is impressive. By 2015, 95 percent of the world's population was covered by a mobile-cellular signal; the number of mobile-cellular subscriptions grew tenfold over 15 years, from 738 million in 2000 to 7 billion in 2015. Internet penetration grew from 6 percent of the world's population in 2000 to 43 percent in 2015; and 3.2 billion people were linked to a global network of content and applications.

However, many of the targets were missed and much remains to be done (United Nations, 2015a). For example, in 2015, 91 percent of the global population was using an improved drinking water source, compared to 76 percent in 1990; 147 countries had met the drinking water target, but only 95 countries had met the sanitation target and 77 countries had met both targets. Worldwide, 2.1 billion people had gained access to improved sanitation, but 29.7 percent of the urban population in the developing countries still lived in slums in 2014 (although this fell from 39.4 per cent in 2000).

2.2 Post-2015 Development Agenda

The Post-2015 Development Agenda is built around the attainment of the Sustainable Development Goals (SDGs) (United Nations, 2015b). The SDGs are presented in Figure 1, categorised with respect to relevant aspects of construction. United Nations (2015b) considers the SDGs as being integrated and indivisible, global and universally applicable, taking into account different national realities, capacities and levels of development and respecting national policies and priorities. Unlike the previous 'consensus' approach, it recognises that each government would set its national targets guided by the global level of ambition but taking into account national circumstances; and decide how the targets should be reflected in planning processes, policies and strategies. Countries could use different visions, models and tools, in accordance with their contexts and priorities.

Basic human and national needs	**What construction must do**
* Goal 1. End poverty in all its forms everywhere * Goal 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture * Goal 3. Ensure healthy lives and promote well-being for all at all ages * Goal 4. Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all * Goal 5. Achieve gender equality and empower all women and girls	* Goal 9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation * Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable **Some of construction's results** * Goal 6. Ensure availability and sustainable management of water and sanitation for all * Goal 7 Ensure access to affordable, reliable, sustainable and modern energy for all

* Goal 8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all	
Inputs and methods of construction industry * Goal 12. Ensure sustainable consumption and production patterns * Goal 13. Take urgent action to combat climate change and its impacts * Goal 14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development * Goal 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss	**Broad international goals** * Goal 10. Reduce inequality within and among countries * Goal 16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels **A key international 'wherewithal'** * Goal 17. Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development

Figure 1 Sustainable Development Goals

2.3 Role of construction in meeting development needs

The subject here is to consider the contribution the construction industry can make to the effort to find viable solutions to the development challenges of developing countries. The literature provides evidence on the potential of construction in development. Authors such as Lopes (2009) continue the work began in the 1960s at UCERG on the developing countries (Ofori, 1993). Ofori (2012a) and Zawdie and Murray (2008) examined how the construction industry could help to attain the MDGs; and Ofori (2015) investigates its potential in the pursuit of the SDGs. Construction influences development mainly through the provision of the physical infrastructure. Easterly and Levine (1997) found that infrastructure is strongly and significantly co-related with economic growth. Fedderke and Bogetic (2006) found a long-term relationship between infrastructure and growth in South Africa. Calderon and Serven (2008) found that Africa's economic growth per capita would be 1.0 percent higher if it had South Korea's infrastructure. In a study on Africa in general, Escribano *et al.* (2008) found that infrastructure has a substantial effect on total factor productivity. Foster and Briceño-Garmendia (2010) found that: infrastructure has been responsible for over half of Africa's recent improved growth performance. Models for assessing competitiveness of countries give much weight to infrastructure provision (Schwab, 2016). Thus, whereas the Post-2015 Development Agenda and the SDGs themselves continue to be subjects of debate (Ofori, 2015), there is a consensus on the importance of infrastructure for sustainable development.

Infrastructure needs are greatest in Sub-Saharan Africa, as shown in Table 1. Its infrastructure networks increasingly lag behind those of other developing countries and are characterised by missing regional links and stagnant individual access; its infrastructure services are twice as expensive as elsewhere. Power is Africa's largest challenge; 30 countries face regular shortages.

The role of the construction industry in economic growth and national development is well recognised in developing and industrialised nations. As an example of the latter case, an element of the vision for UK construction by 2025 is an industry "that drives and sustains growth across the entire economy by designing, manufacturing, building and maintaining assets which deliver genuine whole life value for customers in expanding markets both at home and abroad". Governments of many industrialised countries have broader expectations of the construction industry than in developing nations. In New Zealand, the government noted: "At home, we need to address a persistent productivity gap to make sure our businesses remain competitive on the world stage. Infrastructure will play a key role in lifting productivity and ensuring we can take advantage of opportunities in the global economy…" (p. 7). Government of Ireland (2014) observed that in its path towards economic recovery (following the 2008 economic and financial crisis), Ireland needed a strong and sustainable construction industry, because it needed good quality homes and high-quality commercial developments to underpin recovery and growth, and infrastructure fit for the future. Sugii (1998) suggested: "From the perspective of building social infrastructure efficiently, the improvement of labour productivity in the construction sector will lead to greater efficiency and international competitiveness of the overall economy, as well as to the long-term development of the construction industry". Thus, a strong and efficient construction industry is a strategic national asset and it is necessary to explore its full potential, from the perspectives of developing countries.

Table 1 Africa's Infrastructure Deficit

Normalized units	*Sub-Saharan Africa low-income countries*	*Other low-income countries*
Paved-road density	31	134
Total road density	137	211
Main-line density	10	78
Mobile density	55	76
Internet density	2	3
Generation capacity	37	326
Electricity coverage	16	41
Improved water	60	72
Improved sanitation	34	51

Source: Yepes, Pierce and Foster (2008)

Note: Road density is measured in km per 100 square km of arable land; telephone density in lines per thousand population; generation capacity in megawatts per million population; electricity, water, sanitation coverage in percentage of population.

3.0 How ready is construction?

3.1 Construction industry problems and challenges

The problems and challenges of the construction industries in developing countries are well catalogued. The findings of two recent studies in Africa can be outlined. Windapo and Cattell (2013) found the following in South Africa (in rank order): increases in the costs of building materials; access to affordable mortgage/credit; high interest rates; high rate of enterprise failure/delivery capacity and performance; mismatches between available skills and required skills; availability of infrastructure; external influences such as government legislation; availability of suitable land; public-sector capacity; poverty; critical global issues/globalisation; procurement practices/ capacity for sustainable empowerment; and technology. In a study of 323 public-sector projects in Botswana, Ssegawa-Kaggwa *et al*. (2013) found these deficiencies in the construction industry: (a) Deficiencies of clients – inadequate competent human resources, inadequate project briefs, lack of project management approach, lack of effective project supervision, lack of a prompt payment system for suppliers; (b) Deficiency in the regulation of professionals, contractors and the procurement process – ineffective and inefficient regulation of project procurement process, ineffective regulation of consultants, ineffective regulation of contractors; (c) Deficiencies of suppliers – incompetent consultants, inefficient and ineffective contractors, unreliable utility providers; and (d) Deficiencies of facilitators (such as firms which provide information).

Planning Commission (2013) highlighted these constraints of the construction industry in India: less than 6 percent of workers had structured training; lack of a unified national regulatory framework for construction firms; lack of an efficient and stable regime for dispute resolution; shortcomings in contracting procedures (they are cumbersome and costly); lack of standardisation of core contract conditions, procedures and evaluation criteria; time and cost over-runs; high operation, maintenance, and financing costs; low access to institutional finance (it is inadequate and costly); poor state of technology leading to inefficiencies, wastage and low value added; poor quality of construction; low productivity growth; and low investment in research and development (R&D).

Some examples of new challenges facing construction industries in developing countries which have not yet been addressed can be raised. The first of these is the high volume of uncompleted buildings. Williams (2015) found that, in Ghana, a study of over 14,000 local government projects showed that about one-third are never completed, although these were small projects (with a median budget of US$36,000 and scheduled duration of five months). The second issue is the large volume of debt owed to construction companies by public-sector clients. Whereas delays in payment have been among the key problems highlighted by researchers for many decades (Sambasivan and Soon, 2007), the situation, in many developing countries, has significantly worsened, with the delays running into many years (Fugar and Agyakwa-Baah, 2010). This situation will require a novel approach to solve, considering the size of the debt compared to annual public-sector development budgets and the need to continue to fund current and future projects. The third issue is the increasing level of importance of stakeholders including traditional rulers, community leaders and ordinary people, now well informed, and empowered by mobile telephony (Thasarathar, 2016). Also important is the emergence and growth of non-governmental organisations (NGOs) dedicated to monitoring projects, such as Road Watch in the Philippines, and the emergence of multi-stakeholder initiatives such as the Construction Transparency Initiative (Ofori, 2016).

The construction industries in all countries face challenges and problems. Examples of recent reviews of construction industries in industrialised countries are now considered. The weaknesses of the UK construction industry identified in a strategic review were (HM Government, 2013): (a) low vertical integration in the supply chain, with high reliance on sub-contracting which often leads to fracture between design and construction management and a fracture between the management of construction and its execution leading to lost opportunities to innovate; (b) low investment in R&D and intangible assets; (c) lack of collaboration and limited knowledge sharing; and (d) high construction costs in comparison with the industry's competitors, driven by inefficient procurement and processes. It was suggested in the review that the industry could significantly enhance its performance (HM Government, 2013). The ambition, under the strategy, was to achieve by 2025: 33 percent reduction in both the initial cost of construction and the whole life cost of assets; 50 percent reduction in the overall time from inception to completion for new build and refurbished assets; 50 percent reduction in greenhouse gas emissions in the built environment; and 50 percent reduction in the trade gap between exports and imports for construction products and materials.

The issues to be addressed under Ireland's construction industry strategy included (Government of Ireland, 2014): a strategic approach to the provision of housing, based on real and measured needs; continuing improvement of the planning process, striking the right balance between current and future requirements; availability of financing for viable and worthwhile projects; ensuring the country has the tools to monitor and regulate the sector so that it underpins public confidence and worker safety; and ensuring a fit for purpose sector supported by a highly skilled workforce achieving high quality and standards.

The proposals being made in the developing and emerging economies for addressing their construction challenges are similar to those in the industrialised countries. The aim of Malaysia's "Construction Industry Transformation Programme 2016-20" is: "a transformation of today's construction industry into a modern, highly productive and sustainable industry that is able to enjoy continued growth and enable Malaysian companies to compete with international players whether domestically or abroad". The programme has four strategic thrusts: Quality, Safety and Professionalism; Environmental Sustainability; Productivity; and Internationalisation.

3.2 Developing country exceptionalism

It is necessary to consider the special nature of the industries in developing countries. Ofori (2012b) shows that there are differences between the construction industries in industrialised countries and those in developing countries with respect to appropriate responses to the inherent features of construction owing to the differences in resources, sophistication of their administrative systems and maturity of their industries; differences in the industries' capabilities and performance; and how they deal with the industry's driving forces. Ofori (2012b, p. 8) argues that: "As, in the developing countries, resources for implementing the policies and programmes are limited, the need is great and time is of the essence, it is important that the knowledge that forms the foundation of the policies and programmes should be sound and practically and directly relevant". For example, Foster and Briceño-Garmendia (2010) estimated the cost of Africa's infrastructure needs at about $93 billion per year in capital, and operation and maintenance expenditure (required capital spending on power, on water supply and sanitation, and on transport were 26.7, 14.9 and 8.8 billion per year respectively). The fragile states face an impossible burden and even resource-rich countries lag behind. The construction industry also has a greater technical, professional and social responsibility in the developing countries because the clients and users are often not knowledgeable about the construction process; and the legislative and administrative systems are relatively weak.

Thus, the construction industry should: (a) deliver projects which meet the greatest level of performance with regard to the parameters (including new ones here such as affordability, durability, social performance); (b) contribute to economic growth and long-term national development; (c) provide employment and enhance incomes; (d) enhance the quality of life of the populace; and (e) further grow and develop as an industry. There is also a need for action across a broad spectrum of areas because the project goals and performance parameters are closely inter-related. For instance, the latest International Monetary Fund (2016) forecasts indicate that the economies of many developing and emerging countries are facing stress, and thus, public budgets are tight. Thus, there should be, initial cost savings so that a bigger volume can be constructed; and higher quality and durability, in order to reduce repair and maintenance needs.

3.3 Some ideas for improved industry performance

Some of the suggestions on improving construction industry performance which have been made in industrialised countries for many decades, but which are only practised in exceptional circumstances could be key in the developing countries. Six pertinent examples could be considered. These are: (a) effective co-ordination and integration of the contributions of members of project teams; (b) project health; (c) community participation in aspects of projects; (d) project governance; (e) post-occupancy evaluation; and (f) best practices. First, many reviews of construction industries highlight the fragmentation of the industries as a negative feature. HM Government (2013) considers the separation of design from construction and reliance on subcontracting as among the most important weaknesses of the UK construction industry. The structures of the construction process which are applied in the former metropolitan nations have been adopted in the different cultural and administrative contexts in developing countries (Ofori, 1993). Some studies consider the project arrangements used in developing countries as contributors to poor performance on projects and highlight the cultural disconnect (Rwelamila *et al*. (1999). Thus, in the developing countries, a fresh approach can be taken. The roles of participants could be based on the selection of the most appropriate persons and teams on the basis of their technical and professional suitability in the context of the project concerned. Local cultural norms should inform the design of contractual arrangements and project relationships, which are, currently, 'foreign'.

The second example is project health: tracking key performance indicators on construction projects while they are underway, to enable action to be taken on them at relevant points has been proposed by some authors (Humphreys *et al*., 2004). This makes the learning of lessons a dynamic process. Otherwise, as noted in HM Government (2013), lessons are never learnt, owing to the uniqueness of projects, differences in teams for each project and poor data capture, analysis and dissemination in construction. In developing countries, the idea of maintaining *project health cards* rather than undertaking *project post-mortems* at the commissioning and feedback stages should be fostered.

The third example is the participation of other stakeholders in the construction process. Community participation in various aspects of the construction process, such as design, has not been widely accepted among the design professions (Wates and Knevitt, 1987), and has been applied on projects only as an exception (Moodley and Preece, 2008). The community's involvement can make the design more culturally and contextually relevant; optimise benefits to users and the community; and ease disruptions to the lives and livelihoods of residents. The community's involvement can extend to the operation and maintenance stage when members can provide performance information.

The fourth issue is that of project governance. Construction has a poor reputation among other sectors, as evinced by its score in the Bribepayers' Index (Transparency International, 2012). This is more important in developing countries for many reasons. These nations have poor records with regard to corruption, for example, on Transparency International's (2016) Corruption Perception Index, more than six billion people live in countries with a serious corruption proble. The global average score was 43 (out of 100); that for Africa was 33, and for the Asia-Pacific region, 43. Thus, ethics is a key issue, and it should be incorporated into project structures and procurement and contractual arrangements, educational and training programmes in the developing countries.

The fifth example is post-occupancy evaluation (POE) which has also been proposed for many decades (National Academy Press, 2001), but remains highly uncommon. Projects can produce a stream of information for improving their own performance and those of similar ones in future. Such evaluations can be undertaken at regular intervals after the completion of the item. For example, in developing countries where green building benchmarks have not yet been firmly established, the POE could incorporate environmental performance and could be undertaken some years after completion rather than during the design stage, followed by regular assessments. The possibility of establishing a national database on various aspects of the performance of items of construction could be considered. This information could be developed into best practice guides.

The final example is "best practices" (which might cover some of those discussed above). In construction, best practices occur in exceptional situations only. Construction Industry Institute (2015) categorises "best practices" under headings including: Advanced Work Packaging; Alignment – where project participants are working within acceptable tolerances to develop and meet a uniformly defined and understood set of project objectives; Benchmarking and Metrics; Change Management; Constructability; Disputes Prevention and Resolution; Front End Planning; Lessons Learned; Materials Management; Partnering; Planning for Modularisation; Project Risk Assessment; Quality Management; Team Building; and Zero Accidents Techniques. Cain (2003) presents six goals for construction best practice: delighted end users and clients; lowest optimum cost of ownership; elimination of inefficiency and waste; specialist supplier involvement in design; single point of contact for clients; and proof of performance from measurement. Federal Facilities Council (2007) proposes best practices owners should adopt at various stages of projects to minimise contract disputes. Lahdenpera (1998) suggested actions “to modify the operational modes of the construction industry for the common good”. Considering the needs and circumstances, in developing countries it would be appropriate to apply best practices routinely on all projects.

The availability of information and communication technology makes the wide application of these six practices in developing countries possible. Thasarathar (2016) highlights technological trends in construction including: 3D printing, the Internet of Things (IoT), robotics, drones, cloud computing, infinite computing, reality capture, augmented reality, gaming engines, crowd-funding, crowd-sourcing, generative design, big data and artificial intelligence. He notes that in future, the cloud will place a theoretically unlimited amount of processing power at the disposal of any company, regardless of size, location, or experience, on demand to: solve complex problems; connect to an unlimited number of people to get ideas; and raise capital for projects, through funding techniques such as crowd-funding. As an application for POE, Rogers (2016) suggests that a database from a building information model (BIM) linked to real time sensors can log many metrics to determine the building’s performance against what the designers predicted and the quality of service it provides.

4.0 What is to be done?

The construction industry in each developing country should ask itself: (a) in the changing national and global economic and social developments, what does our nation need from the "built environment" 'sector'? (b) how can the industry be set up to enable the pursuit of innovation and continuous performance improvement? (c) how best can the industry benefit from existing and emerging enablers, such as information technology? Each industry should seek context-specific solutions to its problems and challenges. It should scrutinise its practices and procedures and question assumptions which form their bases of practice elsewhere. For example, In the US, Federal Facilities Council (2007) notes that: "Given the infinite complexities of delivering a building or infrastructure project, the multiplicity of organizations and individuals involved, and the magnitude of the dollars at risk, it is perhaps not surprising that the construction industry has been characterized by an adversarial operating environment that generates disputes and conflicts" (p. 1). Developing countries cannot afford to adopt this “practice norm”.

As another example, Construction Industry Board of UK (1996) proposed a strategy to improve the industry's image. The internal objectives in the industry were: provide better value for the client; improve the achievement of quality, professionalism, efficiency and profitability; and improve the professional relationships between constructors, consultants and clients. The external objectives were: attract greater investment; encourage more construction work to the responsible contractors and consultants; improve environmental and social relationships; attract high-standard recruits; and encourage equal opportunities. One could argue that this range of objectives is what should be attained on projects on a routine basis. In the developing countries, these should be the norm.

Developing countries can leapfrog stages of development. First, the role of the community in projects can be applied through the traditional system of governance and the increasing strength of "development committees" representing particular districts. The chiefs and local committees can contribute to many aspects of the projects in their areas over their life cycle. This will also make stakeholder management necessary, resulting in leadership by the developing countries in that area. The community could pool ownership and crowd fund essential infrastructure and social projects in the area. Construction companies could set up joint venture entities with the communities.

Second, developing countries have the opportunity to derive meaning for, or apply aspects including: construction as a contributor to value and wealth creation; effective, culture-sensitive and contextually-relevant project team selection and dynamics; innovative community involvement in project planning, design, operations and maintenance; effective value chain formation and management, including strategic alliances among firms in design and construction for continuous operations and possibly, formation of multi-disciplinary firms as a norm. Finally, the availability of infinite computing power to the industries in developing countries offers many possibilities. Examples include: (a) enhancing briefing, planning and design processes using augmented and virtual reality; (b) using the capabilities of the IoT – to collect and analyse performance data in operation of items, such as the volume of passengers, trade carried on a road, in order to guide decisions on maintenance or rehabilitation; and (c) small firms using the available computing power to set up effective project and enterprise management systems.

5.0 Conclusion

No construction industry is perfect. There is also no panacea for the challenges faced by the industries. It is important to widen one's horizon in seeking to improve the industries in developing countries. In construction, only the best is good for the poor. If one thinks of the ideals of construction, that is what the developing countries need. The ideals include: ensuring that each project and each constructed item contributes effectively to national sustainable development, and applying this in awarding and implementing projects; harmonising and aligning motivations and obtaining the maximum commitment and contribution from each project participant; optimising the combination of the participants' contributions; applying best practices in all aspects of projects; effectively developing the construction industry from each project; and providing leadership to the community. More research is needed to explore the application of best practices and each of the six previously proposed approaches in developing countries. Maturity of the industry might not be a prerequisite in all these cases; it could even be a hindrance. If the construction industries in developing countries apply these ideals, they can teach their counterparts in industrialised nations.

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Urban Sustainable Resilience Values: Driving Resilience Policy that Endures

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Abstract

Countries across the globe are likely to face significant challenges in coming years that will test the resilience of their cities. However, there is often a lack of proactive evidence-based analysis of available options and their outcomes as well as indicators of success or progress. Without such analysis it is difficult to clearly gauge progress towards set goals, to improve effective policy development and implementation, and to create an active learning culture that can efficiently and effectively tackle future challenges. The present work offers an introduction to research being done to develop a policy evaluation and implementation framework that can help policy-makers produce more effective resilience policies which are sustainable over time. The term *sustainable resilience* has some usage in the literature but has had limited uptake and has not been formally characterised until now. This new concept creates a clear differentiation from reactive disaster resilience which is often the sole focus of urban policy development. This paper contributes to developing a working concept and guiding principles for urban sustainable resilience policy. This work suggests that sustainable resilience policy will need to take into account the complexity within and between the various systems that form cities, rapidly changing technologies, environmental conditions, and emerging forms of governance. This paper also briefly outlines the methodology that will be used to continue to develop a sustainable resilience policy framework and evidence-based assessment tool.

Keywords: resilience, sustainable, policy, evidence-based assessment.

1. Introduction

Cities currently host more than half of the world's population, a number which is projected to reach 66% by 2050 (UN, 2014). In 2014, countries such as Australia, Japan, Qatar, the Netherlands and Uruguay had less than 11% of their population living outside of urban settlements (The World Bank, 2015). Cities also generate large percentages of the national gross domestic product (GDP) and are important sources of employment. In Australia for example, 80% of GDP and 75% of employment is produced in cities (Commonwealth of Australia, 2011). Climate change and fast technological progress, among other factors, will bring considerable challenges for urban policy makers and implementers. They will need to be able to keep pace with the unforeseeable and a future that will likely be significantly different from past experience, while also aiming to maintain and increase liveability and social well-being.

This realisation has led to a surge of resilience literature and policies for ecosystems and urban settlements. The academic literature has been particularly prolific in providing different interpretation of the term. A recent literature review for example analysed 172 resilience studies and found 25 distinct definitions of the term "resilience". Half of the definitions were centred on a specific threat and 40 percent focused on a static (single-equilibrium) view of resilience (Meerow, et al., 2016). Even within disaster focused resilience literature there is a range of definitions. Manyena (2006) for example was able to separate 12 definitions. Policies are thus guided by different understandings of resilience. Davoudi (2014) argues that many of them are in fact driving a new form of "resilient urbanism" which is focused on short-term emergency response rather than long-term adaptive capacity. These are driven by the objective of quickly returning to a state of equilibrium after being affected by sudden external shocks, such as climate events, and often pay little attention to chronic long-term stress sources. These "*high time preferences*", namely valuing the present above the future, has been argue to generate a perception of time which is incompatible with cycles that shape civilisation. Further to this, Moffat (2014) argues that this short-term vision devalues the key idea of resilience and that "*until time preferences change, progress towards resilience will be very slow, regardless of changes to public policy or technical expertise*". The concepts of *sustainable resilience* and *sustainably resilient policy* aim to challenge this trend and bring the focus of the debate towards how to deliver urban policies that can be proactive in creating enduring resilience and prompting sustained action.

The present work explores and outlines the concept of sustainable resilience, which has usage in literature but has received marginal application, particularly when compared to concepts such as socio-ecological resilience. It is argued here that the concept of sustainable resilience requires a more solid foundation in the resilience literature. This approach creates a clear differentiation from reactive conceptualisations of resilience that have a short-term narrow focus. This paper also proposes that cities not only require policies that encourage resilience which is sustainable over time or enduring, but also require policies that themselves are sustainably resilient. The following sections therefore explore policy implications of using this concept and introduce the ongoing research being carried out to develop a sustainable resilience policy framework and assessment tool.

2. Research Methodology

This paper presents the early findings from a research project that aims to develop a sustainable resilience policy evaluation and implementation framework. The following sections outline the working concept and draft guiding values or principles resulting from an initial literature review. These are now being tested through a systematic literature review. The detailed methodology and outcomes of this ongoing research will be later published through a journal article.

The initial literature review was based on a thematic analysis of published *personalised* resilience concepts. These are definitions that, although they might be based on mainstream concepts, have been expanded to include a more comprehensive set of characteristics based on a focus on urban/community planning and management. The working hypothesis is that a large portion of these emerging resilience concepts are guided in part by sustainability values, either explicitly or implicitly. In some cases, the authors do not completely outline a new concept but argue for changes in the way resilience is defined in order to become more sustainable over time (see for example Meerow, et al. (2016)). The concept of sustainable resilience has also been used in the literature (see section 3) but has yet to be defined. This paper aims to provide a characterisation of this concept, including a working definition with a focus on urban policy implications.

The inclusion criteria for the thematic literature review is: academic and policy papers and book chapters discussing resilience policy, sustainability thinking, resilience thinking, sustainable resilience, proactive resilience, urban policy for complex problems and multi-actor networks, and climate change policy; papers published in English; and papers published since 1970. This initial literature review included 93 references.

Within the context of this research, policies are understood as the positions taken and articulated by government and other organisations that recognise a problem and state, in general terms, the actions to be taken to address the problem (Dovers, 2005). These are composed of a set of objectives, targets, instruments and agents (Vogel & Henstra, 2015).

3. Sustainable Resilience: A Concept to Bring them All and Bind them

The word resilience has existed in the English language for a couple of centuries and has evolved into a number of types of resilience applied to different scopes and used for policy development worldwide (Alexander, 2013). Different resilience concepts have significantly different policy implications. “Bouncing back” or equilibrium-based concepts tend to generate policies that focus solely on recovery and often underestimate the difficulties of managing complex and highly adaptive systems such as cities (Fiksel, 2006; Davoudi, et al., 2012). By focusing only on recovery from and vulnerability to acute unexpected disturbances, such as earthquakes and floods, policies may be limiting the impact of the initiatives they encompass and the long-term resilience of the cities they apply to.

The terms *urban resilience* and *sustainability* are closely related and, in more recent times, increasingly used interchangeably (van der Heijden, 2014). The links between sustainability and resilience have also been highlighted by a number of authors over the last 20 years (Ahern, 2011; Fiksel, 2006; Fiksel, 2003; Perrings, 2006; Arrow, et al., 1995). These however often focus on the use of resilience principles to achieve environmental sustainability.

The term *sustainable resilience*, on the other hand, has been used in some publications (Steiner, et al., 2007; Steiner, et al., 2006; Vogel, et al., 2007; Bonstrom & Corotis, 2012; Afgan & Veziroglu, 2012). There are also a number of publications that advocate integrating sustainability principles with resilience thinking, such as Angeon and Bates (2015). Nevertheless, the concept itself, clearly outlining the characteristics of a type of resilience which is sustainable over time or enduring, has not been fully developed in the literature.

The relatively low uptake and development of this concept may be related to two facts. On the one hand, some proponents see sustainability and resilience as interchangeable concepts voiding the need, in their view, to define a form of resilience which is sustainable. However, although complementary the two terms can lead to significantly different policy outcomes; some sustainability policies may not increase the resilience of cities and some resilience policies may be unsustainable. On the other hand, the term sustainability is often highlighted as ambiguous as well as having charged ethical (Fiksel, 2003) and political undertones (Dovers, 2005). However, we propose that formalising the concept of sustainable resilience which is already emerging can help improve policy development and leverage decades of scientific literature already available. The following sections propose a working concept and guiding values based on sustainability thinking applied to urban resilience policy.

3.1 Sustainability as an Approach to Resilience

Sustainability as an approach can be applied to a number of goals as an overarching guide. It requires taking into consideration the dynamic interactions and behaviours of complex self-organising systems to support coordinated action to address challenges in the context of uncertainty and incomplete information (Ahern, 2011). A sustainability approach also encourages a long-term vision leading to preventive and proactive attitudes. Lederach (1997) for example used the term *sustainable reconciliation* in his book about conflict resolution emphasising that this goal requires a long-term, integrated, inclusive and holistic view of the issues and objectives. The following four overarching values or principles are dominant in the urban sustainability literature and much of the more recent resilience literature.

- Adaptive/dynamic capacity: Although these words may not always be explicitly used, literature about sustainable development and resource management often deals with practices and processes related to adaptation and dynamic systems (Smit & Wandel, 2006; Fiksel, 2006). In this sense, it refers to the capacity of systems to dynamically adapt to changing challenges and opportunities in order to better cope with and manage them (Smit & Wandel, 2006).

- Sustained/persistent: At the core of most definitions of sustainability is the ability to sustain human and ecological systems. The way in which this may be done and measured is open for debate, but the ultimate objective is to allow systems to continue to function and persist into the future (Gale & Cordray, 1994).
- Preventive/proactive: Another core characteristic of strong sustainability is its focus on long-term futures (which are inherently uncertain) in order to ensure the survival of future generations (Brown, et al., 1987; Dedeurwaerdere, 2014). This is sometimes referred to as the precautionary principle in environmental sustainability management (Dovers, 1995).
- Holistic/quadruple bottom line: Sustainability science and policy typically deal with balancing goals of various stakeholders and aiming to identify potential conflicts (Dedeurwaerdere, 2014). The idea of the quadruple bottom line provides a holistic approach where urban sustainability resides in the interaction of four drivers: economic development, social development, environmental protection and effective governance. Within the present context, the latter refers to the institutional capacity of the urban system (Teriman, et al., 2009).

These values have also been highlighted as requirements for long-term sustained resilience. Adger, et al (2011) for example write about resilience highlighting the relationship between adaptive capacity and the confluence of economic development, technology, human capital and governance structures.

3.2 Sustainable Resilience Network Values

The above overarching values from sustainability thinking were used to map specific network values that are highlighted in the literature as underpinning forms of resilience which can be sustained in the long term. The following recur throughout this literature.

- <u>Dynamic</u>: A complex systems view of cities is required in order to understand and cope with cascading effects of stress events (McIlwain, et al., 2013). Characteristics of complex dynamic systems often mentioned include: non-linearity, uncertainty, emergence (sometimes described in terms of surprise), scale and self-organisation (Berkes, et al., 2003; Damper, 2000). A dynamic view of the urban system emphasises the constant state of flux and change as well as the uncertainty surrounding future stress sources (Folke, et al., 2002).
- <u>Socio-eco-technical interactions</u>: The fact that cities can be seen as socio-ecological systems is hardly debated since the rise of socio-ecological resilience. These socio-ecological interactions create the opportunity for technological progress (Folke, et al., 2002). In turn, technology can be used as a tool to enhance the resilience of cities (Fiksel, 2003). Technological progress has also been acknowledged as providing both new challenges and opportunities for urban resilience (Smith & Stirling, 2010). However, information technologies are evolving into socio-technical systems and slowly becoming integral to every aspect of urban asset management and governance. Therefore, sustainably resilient systems also include dynamic technological change and socio-

ecological as well as emerging socio-technical system interactions as part of the environmental context.

- Sensitive and adaptive: There is a need to make management and governance systems adaptive and flexible in order to be able to deal with uncertainty. This approach emphasises an ongoing and active learning capacity which is sensitive to feedback from the system components and environment, including the community context (Berkes, et al., 2003; McIlwain, et al., 2013). The Rockefeller Foundation for example talks about reflective and resourceful systems referring to the ability to learn and change behaviours in response to changes (100 Resilient Cities, 2015). Jabareen (2013) further argues that urban resilience in the face of climate change requires uncertainty-oriented planning policies so the system can cope with statistical uncertainty and a continuous range of conditions. Labaka et al. (2015) additionally highlight the need for ongoing data acquisition, monitoring and evaluation in order to maintain the sensitivity of the systems to current conditions.
- Coordinated and cohesive: Cities are formed by systems of networks that function based on their connectivity in order to increase cohesiveness and coordination (Ahern, 2011). Here cohesion refers to the existence of linkages across system components (Fiksel, 2003) and coordination relates to more effective multi-scale network functions (Ahern, 2011). Horizontal and vertical coordination across the components of the systems are necessary for it to function as a whole while maximising its adaptability. This should include feedback loops between and across the components and governance systems (McIlwain, et al., 2013). This for example refers to coordination across infrastructure network governing bodies as well as across political governance levels such as councils and state organisations in order to achieve a cohesive system.
- Capacity to persist: This characteristic is related to having a proactive approach to risk mitigation and abating at different time-scales. It is about reducing the likelihood of stress events occurring and affecting the system in the short, medium and long-term. In the short-term it refers to being able to withstand both acute shock events and chronic stress due to the robustness of the systems, existence of redundancies and flexibility in the face of changing conditions (McIlwain, et al., 2013; 100 Resilient Cities, 2015). In the medium-term it takes in part from evolutionary resilience in that stress events are opportunities to *"bounce forward";* that is to move away from simple recovery and towards renewal to improve the resilience of the city and the community (McIlwain, et al., 2013). In the long-term is about prevention of future sources of stress, this includes for example climate change mitigation initiatives (Jabareen, 2013). Although having a different understanding of resilience, Register (2014) argues "*if we start thinking in really basic terms, we may realize that the city that is best for adaptation adapts least – because... it doesn't have to*". Register also argues against seeking to adapt to changes while ignoring the root cause, principles and likely futures. Truly sustainable resilience policy should address short, medium and long-term time scales.
- Embraces diversity: This relates to the existence of redundancies and promotion of modularisation to spread risk across time, geographic and system scales. This is for example provided by distributed and decentralised systems (Ahern, 2011). Diversity of redundant components means that the system has back-up structures and does not depend

on a single component. Systems are made of sub-systems which are relatively independent of but provide support to and complement each other (McIlwain, et al., 2013). It encourages multiple forms and behaviours in order to create inherent resilience across the whole system (Fiksel, 2003; 2006).

- Efficient: It refers to the efficient use of capital and resources through multi-functionality. It supports response diversity within single functions while being able to perform more than one function either simultaneously or progressively (Ahern, 2011). This characteristic can be complementary to diversity where one component can create redundancies by performing multiple functions to maximise the efficiency of the resource investment (Ahern, 2011). It is also closely related to the capacity to persist in that by using resources more efficiently, there is less resources needed and less risk of loss as well as less demand. This can potentially also reduce long-term risks (Fiksel, 2003; Register, 2014). It requires a clear understanding of the system needs, limits and opportunities for synergies across system components.

3.3 Sustainable Resilience Concept

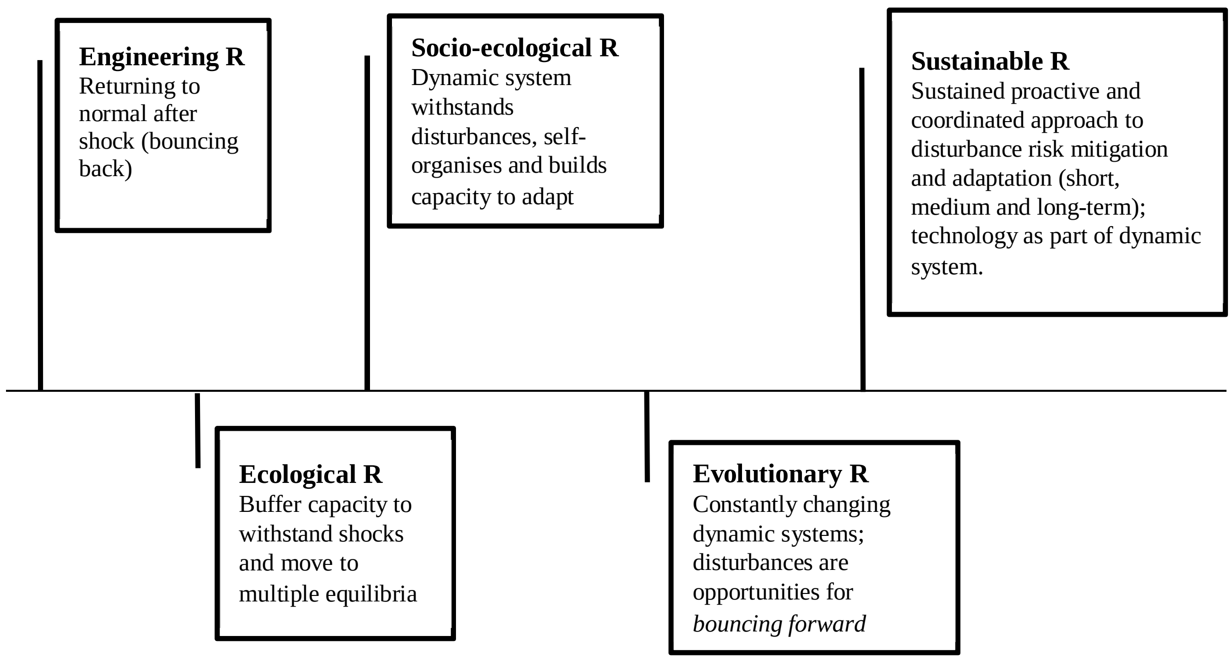

Figure 1 Characteristics of some common concepts compared to Sustainable Resilience

From the above discussion it follows that dominant concepts of resilience may be insufficient for the development of more comprehensive resilience policy which can be sustained over the long term. The lack of mainstream concepts that openly include sustainability principles may be a result of perception biases, either because authors use the terms interchangeably or because they consider the term “sustainability” too loosely applied, vague or semantically charged (van der Heijden, 2014). Whatever the case, there are good reasons to bring core sustainability aspects to our thinking of resilience in order to improve the effectiveness of urban policy. This is reflected by (although not always explicitly) academics and policy-makers proposing new conceptualisations of resilience that expand the defining characteristics based largely on sustainability principles. These new conceptualisations may be summarised through the following working definition, referred from here on as urban sustainable resilience:

Urban sustainable resilience is the capacity of socio-eco-technological complex dynamic urban systems to tolerate disturbances, which can be chronic or acute, and persist in a sustained manner through ongoing learning and adapting to changes to the environment and the needs of the system. It requires efficient, diverse, coordinated and cohesive strategies that proactively address short, medium and long-term challenges. Urban sustainable resilience is underpinned by sustainability and dynamic system resilience principles in order to define practical policy aspects that allow cities to tolerate disturbances, evolve with the changing environment (where environment refers to climate, social sentiment and technological context) and mitigate future sources of stress.

Figure 1 briefly outlines some of the different policy implications for some more common resilience concepts and the proposed sustainable resilience concept.

4. Urban Sustainably Resilient Policy Qualities

"Urban policies are critical in making cities more resilient and are crucial factors in bringing the governance of global environmental problems to urban contexts" (Jabareen, 2013). However, from an offer and demand point of view, policy-makers struggle to offer policies that address long-term resilience challenges and citizens often do not provide a sustained demand for policy interventions. This is in part due to the short election cycles and people often failing to understand the urgency of having a long-term vision. This leads policy-makers to take advantage of windows of opportunity when disaster strikes to introduce resilience policies (Vogel & Henstra, 2015). The constantly changing political, economic and social environment also prompts short-term interventions rather than sustained action (Broniatowski & Weigel, 2008). However, resilience as conceived here, requires continual action incompatible with constantly changing policies. In addition to urban policies' goals, targets, instruments and agents striving to create more sustainably resilient urban systems, it is therefore hypothesised that the policies themselves can have sustainable resilience qualities in order to ensure sustained outcomes. Under this hypothesis policies themselves should show the seven values outlined in the previous section. After exploring the implications of this proposition (to be published at a later date), the following policy qualities are suggested to form the policy development guiding principles.

- <u>Political resilience:</u> The political environment has a clear impact on the choice of policies and the time-scale of their objectives and implementation. Short-term political cycles commonly translate into short-term goals and policies but to achieve sustainable resilience of urban systems a long-term strategy is also required. "*A system designed under these circumstances must be able to deliver value under a constantly shifting political environment... These systems must therefore have an architecture that allows for political sustainability"* (Broniatowski & Weigel, 2008). Political resilience means that policies need to be designed to withstand changes in government within and across levels of governance. This is closely related to policy goals, values and interests, and although it depends on the perception of delivered value, this is not a sufficient condition

(Broniatowski & Weigel, 2008). Multi-level governance perspectives can leverage on opportunities and identify contradictions that arise from the interpretation of challenges that apply to different scales and spheres of governance and authority (Bulkeley & Betsill, 2005). Promoting a resilience-based culture across stakeholder groups can also help improve coordination and communication, and lead to more politically resilient policies (Labaka, et al., 2015). Political resilience also relates to the way issues are framed and perceived by policy-makers (Vogel & Henstra, 2015). Sustainable resilience policies should be framed in such a way that urgency that springs to action is conveyed without politicising the issues. This can help reduce the risk of changes in the government's political views affecting the objective assessment of policy outcomes. In the long-term, policy-makers should aim to integrate successful aspects of implemented policies into the overarching values that guide the evaluation and implementation of subsequent policies and laws; including across other policy fields. "*To be robust and durable over time, adaptation principles and objectives must be integrated into day-to-day planning and decision-making processes*" (Vogel & Henstra, 2015).

- Economic resilience: Political will, the collective willingness to do something, is critical to successful policy implementation but may waver depending on a number of aspects (Vogel & Henstra, 2015). Funding of any policy is commonly closely tied to political will. This often leads to funding short-term programs with ribbon-cutting opportunities at the expense of long-term cost (Herrmann, et al., 2009). Setting resilience priority areas and cost-benefit analysis can help deal with limited funding for capital investment. However, designing policies that encourage infrastructure that has more than one function while increasing urban resilience and providing potential financial gains can support political resilience by providing economic resilience (McIlwain, et al., 2013). Policies should take into account the financial sustainability of the initiatives but also be able to absorb additional cost brought by evolving challenges as they arise (Labaka, et al., 2015). Economic resilience could entitle transforming sunk costs into returns on investment (ROI) by leveraging inter-governance synergies (e.g. integrating urban waste treatment, district heating/cooling and industrial waste heat disposal). Assessing commercial co-benefits and partnering with industry for long-term financing of resilience initiatives as well as coordinating budgets across governance boundaries can also help achieve this (McIlwain, et al., 2013).
- Social resilience: Stakeholder support commonly influences policy choices and actively addressing stakeholder concerns can help avoid implementation failure (Vogel & Henstra, 2015). Resilience policies should include "*adaptable social infrastructure to assure meaningful participation*" (Ahern, 2011) in order to maintain sensitivity to the constantly changing needs and interests of the system. Additionally, for policy to be sustainably resilient in the face of constant change it is suggested that it needs to be able to steer or adapt to changes in social sentiment (general priorities and views of the local public). Achieving this may require integrating deliberative democracy processes which have been proposed as a way of delivering long-term transformational policy objectives (Hartz-Karp, et al., 2013). Progress towards higher levels of resilience often also requires social uptake of new behaviours (McIlwain, et al., 2013). Long-term policy effectiveness and social support requires active engagement with stakeholders and brokering

knowledge in a way that the community can be receptive to it. This could mean integrating educational programs or gaining insight into how decisions are made by individuals in order to frame policy actions appropriately (Shediac-Rizkallah & Bone, 1998). The growing fields of opinion mining and sentiment analysis may also be of use (Pang & Lee, 2008).

- Environmental or contextual resilience: A network value of sustainably resilient systems is proposed to be that their environment is formed by its socio-ecological components as well as by technology. The latter is often a key part of urban resilience policy actions and frequently changes at a higher pace than the built environment and models used to design the policy in the first place (McIlwain, et al., 2013). Action plans and strategies resulting from resilience policy need to be able to remain sensitive and adapt to changes in the ecological and technological environment in order to stay effective over time. The understanding of the policy priorities and what forms, for example, critical infrastructure may also change over time (McIlwain, et al., 2013). This means that resilience policy programs should include active learning and monitoring processes that encourage frequent and comprehensive reviews of the needs and opportunities provided by the changing environment.

5. Future Research

This work is part of a three-year project. Future research will continue a systematic literature review of academic and government documents related to urban resilience and policy. This effort will meticulously map the characteristics of emerging concepts of urban resilience which are framed as more sustainable over time; following sustainability principles explicitly or implicitly. This will be used to complete the working concept and draft framework which will be tested through expert consultation that includes academic, government and industry professionals. The revised version will be further developed into an evaluation framework consisting of specific indicators for urban sustainable resilience policy assessment. This will be tested through a series of international case studies that will also include policy content and processes analyses. This research will aim to deliver three main practical outcomes: (i) best practices based on success factors of sustainable resilience policy from international case studies; (ii) a set of comparators/indicators that allow evaluating these types of policies across city and state borders; and (iii) a practical tool for policy-makers for evaluation and implementation of more effective and sustainable urban resilience policies.

6. Conclusions

This publication briefly explores the relationship between resilience concepts and urban policy as well as suggest a working concept for the term *sustainable resilience*. This is done by drawing from emerging resilience concepts which are implicitly or explicitly driven by sustainability principles. The authors also introduce a set of urban sustainable resilience values and policy principles. Future research will continue a systematic literature review to increase the robustness of the proposed concept and framework as well as continue developing them. The resulting framework will be tested and validated through further research.

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CIB Smart City Road Map and Vision

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Abstract

Urbanization had been rapid, currently 54% of the global population lives in cities and it is projected to rise to 70% by 2050. New cities have emerged, and hundreds are expected to be built in coming years. Cities are also engines of economic growth, accounting for 80 % of the global GDP (UN habitat 2015). But they also consume around 75 % of global primary energy and responsible for 70 % of the global greenhouse gas (GHG) emissions (UN Habitat 2015, EIP SCC). All sectors associated with urbanization (transport, building construction and maintenance, housing, waste management, energy, etc.) are registering trends that raise sustainability issues.

Urbanization trends pose a need for strategic and innovative approaches to urban design, planning, management and governance. The accompanying trends in technologies play a significant role in 21st Century urbanization as technologies are increasingly supporting business functions, city logistics and grids, transport, delivery of basic services, environmental management systems, government operations, data-driven industries like finance, and people-to-people interactions.

CIB Task Group 88 has created smart city roadmap were the main findings were following. Technologies have a crucial role and potential in address the urban challenges, presenting new opportunities and smart approaches for the global community to make cities inclusive, safe, resilient, and sustainable.

Due to climate change and lack of critical resources energy management and technologies to transform our cities low carbon becomes important. Digitalisation and new technologies enables us to use more and more data in real time. In addition internet of things makes it possible to use, combine and enrich data from many different sources. The future city actors and stakeholders are changing internet of things to internet of meaningful information. New technologies enable also service based solutions. Future construction business is in transformation. Construction will change to services: living as a service, energy as a service, urban environment as a service. Future smart cities are sustainable and resilient and they are constructed from self-healing materials and systems. Zero carbon resource efficient solutions are created without compromising peoples' well-being.

Keywords: smart city, sustainability, energy, buildings, urban planning, traffic

1. Introduction

All around the world, urbanization is a growing trend. As more and more people get together, smart systems and their integration need to be developed, not only to provide the services that people need but also to do so efficiently with minimum impact on the environment. It can be said that efficient ICT, one part of which is the Internet of Things, is a common dominator: tying together services, residency, mobility, infrastructure and energy. It is a global challenge to reduce environmental impact and the carbon footprint.

At the same time, societal development needs to be addressed and the focus put on people's well-being. Pressure is growing to reduce our environmental impact, and there is a parallel compelling need for business to remain globally competitive. Sustainable transformation of cities is only possible when it is done in a smart way. Smart city design, operation and management need to be done at system level. Sub-optimization of individual components will not lead to optimal performance of the system. Multi-target optimization is not an easy task, but it becomes necessary as different components and systems are interlinked and interconnected – irrespective of where they are physically located. Traditional sector-based industries and value chains are also changing, and completely new business models are starting to emerge. Radical innovations and paradigm shifts are changing our whole city systems.

Cities are a driving force in generating world's economic growth. Cities are becoming even more important as urban population and populated areas grow leading to a rapid increase in resource consumption and emissions. The principal challenges for cities, around the globe, are to deliver better services while being globally competitive, and meeting climate targets. Expenditures on improving energy efficiency, modernizing infrastructure and on creating high quality living and working environments are enormous. At the same time, cities have limited and less financial and resources for governance and services.

Innovation in the form of 'smart city solutions' can deliver technologies, products and services that meet the dual challenges of reducing greenhouse gas emissions and delivering more efficient services. Cities worldwide are modernising and becoming poles of competitive strength. There is a clear need for resilient, sustainable, safe, energy efficient, connected, good quality to live and work in cities.

The rapid development of information technology, technologies for local small-scale energy production, as well as the transport solutions are the key enablers for cities becoming more resource efficient although at the same time meeting the users' needs better. The built environment, i.e. buildings and transport and utility networks, cannot remain only a passive platform. It also needs to be reshaped to make optimum use of the technology opportunities.

The aim of this work was to compile the CIB community's vision and perspectives on the future of cities under the impact of the expected development of the new technologies (distributed energy, virtual services, urban transport and living/working opportunities). In addition this task group created strategic roadmap for the building and construction related research needed for envisioned future smart cities. The challenges and contributions were identified from the political, social, market, environmental and technological perspectives but also the values and their effect on different perspectives were considered in the workshops.

2. Methodology

The roadmap work started with the conceptual framework, how we define smart city in the CIB context and what aspects are included in our frame. After framing the CIB context in smart cities the state-of-the art was defines and the identification of priorities and priority themes were defined. Highlighting today's state-of-the-art it was logical to set the vision how we want to see a smart city in the future. Setting the vision sets also the requirements for development strategy and research as well as industry needs to realise the vision.

The first task group meeting and workshop were organised in Finland on February 2014. The workshop had 15 participants among the 22 task group members. The second meeting was organised as a webinar in June 2014 and the third workshop meeting was held in Washington on September 2014. The initial roadmap was send to feedback and validation for the CIB community as well as for expert and stakeholder consultation. The interactive work process and schedule are shown in Figure 1 below.

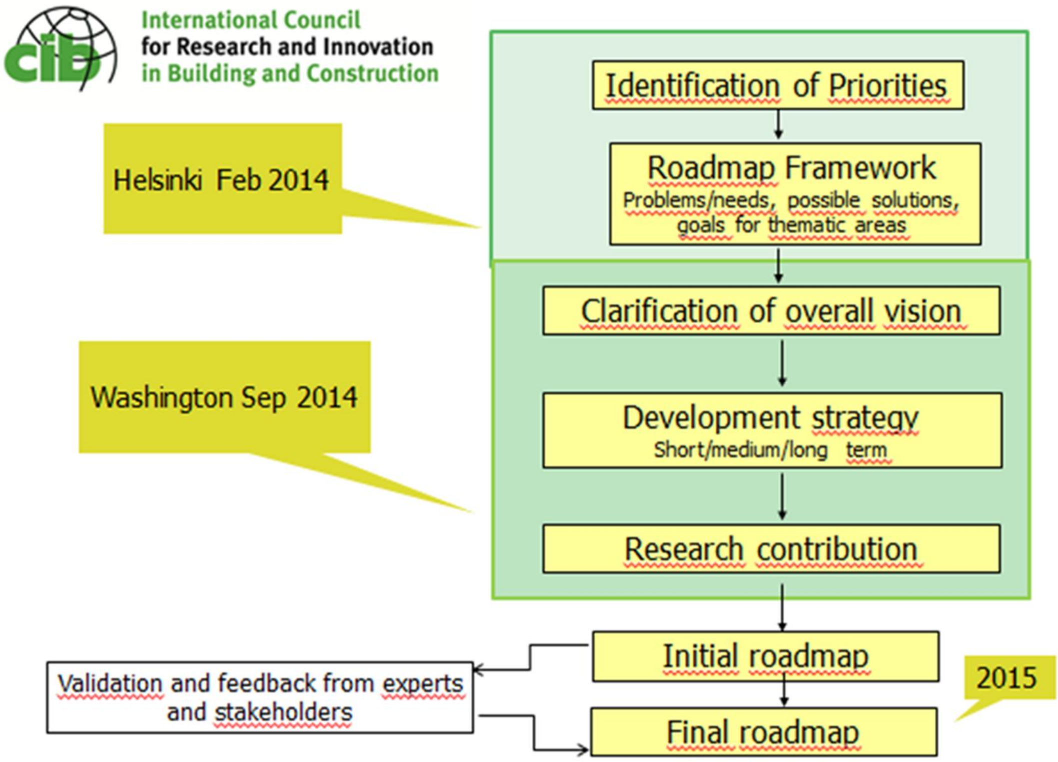

Figure 1: The interactive work process and schedule of the CIB smart city roadmap

3. Main priority areas and the CIB vision

The priority areas for the smart city roadmap were identified in the first workshop. The participants listed and discussed in three groups about choosing the priority areas. The main themes identified from the prioritisation of topics were structured into following groups:

- **Energy**: increasing the use of renewable energy, optimisation of the energy system and the management and balancing of energy supply and demand.
- **Existing and new buildings**: new solutions for renovation, living comfort and replication of building services and solutions.
- **Land use, infrastructure and asset management**: adaptive use and integration to existing systems.
- **Transport and mobility**: Easy and fast mobility, smart management systems, reducing the need and time for travelling.
- **Communities and users**: people participation, on-demand services, increasing awareness, trust and security, and good well-being.

The discussion included many cross-cutting themes, which are relevant for all priority areas. ICT solutions, interoperability and integrated planning and systems are essential elements in the smart city context. The discussion also strongly reflected cities' sustainability targets, including economic, environmental and social aspects. Especially efficient resources use and low carbon targets were considered as priority targets. One of the major changes considered was the development towards service based economy. In addition, cities adaptability and resilience was highlighted, as well as policy and governance related issues with improved collaboration and communication.

In CIB smart city workshops each theme group analysed the needs/problems from the perspectives of policy, markets, products & services and technologies. In addition each group already started to draft reasons and solutions for possible problems. In the end of that session a vision/goal for desired state was written. The group work result tables are presented below.

Commonly the tables highlight the need for technologies and services to support sustainability in cities and also the importance of technologies to support sustainable choices in people everyday life; i.e. making the sustainable choice the most convenient and easy choice without compromising well-being. The visions also highlight the new technologies for predictive, resilient and self-sustaining energy and resource management. In addition the vision states the transformation from internet of thing to internet of meaning, highlighting the importance to enrich the date to decision making to support city goals.

The detailed roadmaps for each theme can be read from CIB roadmap publication.

Analysis Framework: Energy & Buildings

	Problem or need	Reason for problem	Possible solutions	Vision (Goal)
Policies	• Distributed generation and its limits • Reliance on single energy source (fossil / centralised)	• Lack of awareness • Legacy of design: central production	• Micrgrids & islanding • Load balancing • Transactive energy: market & technology	• Clean, efficient and sustainable energy sources • Nearly zero energy buildings
Markets	• Reusing waste heat • Primary energy vs. delivered energy (process losses)	• Uncertainty • Lack of ROI for environmental protection • Variable discount rate & time value for money • Costs & pay pack time	• Size-based sliding scale pricing & taxation	• Pricing policy that provides ROI on resilience, environment etc. • Dynamic energy prising
Products or services	• Building stock inertia • Design to change user behaviour • Energy efficiency & losses	• Renovation need is huge	• Grid monitoring • Adaptive building management • User education • Real time feedback & pricing	• Smart grid & city • Adaptable and flexible structure design
Technologies	• Resilience • Accessibility and affordability	• Lack of ROI for resilience • Fluctuating supply from RES	• Response market & mechanisms	• Holistic design • Novel building materials • Different design levels: Horizontal, vertical, temporal, 3D etc.

Figure 2: Energy and buildings theme and its vision

Analysis Framework: 1) Infrastructure and asset management, and 2) Resources and waste

	Need	Reason for problem	Vision (Goal)
Policies Markets Products or services Technologies	• Transition to sustainable energy & resource efficiency • Reduce life cycle costs • Building stock management • Adaptive infrastructures • Integration of existing infrastructure with new infra	• Legacy of infrastructure and investment • Clean water scarcity	• Self-managing multi-functional infrastructure for resource efficiency and zero waste. • Smart energy management for water, waste and energy management / and smart technology • Effective urban water and waste water management • Effective waste & resource management • Zero waste

Figure 3: Land use, infrastructure and asset management theme and its vision

Analysis Framework: Transport & Land Use (T & LU)

	Problem or need	Reason for problem	Possible solutions
Policies	• Too much land use for transport and infrastructure (parking lots)	• Locations not optimally planned	• Better management coordination: Municipal to regional level • Better means for public participation in development process
Markets	• Cities develop to quickly • Population dissatisfaction with land use	• Opportunities for work are more intensive in cities -> Urbanisation • Values (interests) of populations are changing faster than development	
Products or services	• Slow development and changes in T & LU • Energy demanding solutions • Too much time	• Capital intensive development, different hinders e.g. legality and public acceptance • Lack of public transportation and un-motorized options	• Intelligent Transport System • Retrofitting current systems to become more energy efficient and fuel consuming + ITS
Technologies	• Optimal regional layout is not yet understood/explored	• Non-multidisciplinary research and collaboration -> suboptimisation	• Support for- and initiatives towards multidisciplinary research and collaborations

Figure 4: Transport and land use theme and its vision

Analysis Framework: Community & users

	Problem or need	Reason for problem	Possible solutions	Vision (Goal)
Policies	Healthy & happy citizens	• Lack of power/involvement in decision making • Land use (crime & security)	• Open communication & governance • Creative consideration in urban planning • Decision making to local level	
Markets	Set the standards • Data security • Interfaces • Requirements	• Lack of jobs	• Mapping of human resources • Distributed facilities	• Health & wellbeing • Inclusive + equal + feeling part of the society
Products or services	Citizen engagement Affordability of housing	• Lack of education & career opportunities • Affordability of adequate healthcare	• Self monitoring -> Preventive health care • Service resilience • Better control on services	
Technologies		• Lack of good quality buildings/homes	• Warning systems/ predictive monitoring of vulnerable people • Interactive infrastructure	

Figure 5: Community and users

4. Trends, drivers and vision of the business environment

Cities are facing serious challenges stemming from global megatrends:

- Urban growth and urban sprawl: urban populations are estimated to grow by 2,3 billion over the next 40 years. Immigration causes problems in many parts of the world.
- Ageing population: the number of people over the age of 60 is expected to triple by 2050. This sets concerns of sufficient workforce.
- Global warming: cities consume 75% of world's energy and produce 80% of its GHG emissions.

Under these circumstances, cities are forced to adapt and improve the whole city system and its efficiency, for example develop new energy systems and tackle social issues. The philosophy of smart cities is to see challenges as opportunities and take advantage of other trends, such as

- Digitalization: the proportion of broadband access has exploded worldwide which enables more efficient and economical service provision and internet and remote retail and services.
- Automation and servitization: more and more jobs are carried out by machines and the trend has been since a long time from goods based manufacturing economy to service and solution oriented economy.
- Technological development: e.g. intelligent transport (automatic vehicles, electric cars) and smart grids give new opportunities for cities to think about their service provision.¨

On the positive side, also 85% of innovations happen in cities. Cities are driving forces in generating economic growth. Innovation in the form of "smart city solutions" can deliver technologies, products and services that meet the dual challenges of reducing greenhouse gas emissions and delivering more efficient services.

A key goal for many cities that want to be smart is to achieve better transparency in decision making through involvement and engagement of citizens in decision making by participative and co-creative approaches, providing data publicly (open data) and providing opportunities for bottom-up initiatives.

5. Barriers

There exists various barriers that can impede or restain the realisation of the development steps proposed in this roadmap. They are into following four categories: administrative and legal barriers, technical and infrastructural barriers, economic and market barriers and social acceptance and political barriers.

One of the most challenging ones is that cities have limited and often reducing financial resources for providing governance and various services. Often it is hard to understand the real benefits and costs of investments, and evaluate their life cycle impacts in the long term. Other common barriers for many smart city developments are related to systems sub-optimisation and unclear vision. It is typical that there are many stakeholders involved from different sectors and backgrounds, which makes the integration of processes and systems complex, and communication and collaboration need lots of efforts. Another common barrier is that the relationship between data monitoring and services and the privacy and security of users' data is not clearly regulated. **Error! Reference source not found.** below summarises some of the main barriers for the main targeted development areas and main cross-cutting themes in this roadmap.

Table 1 Summary of main barriers for the targeted roadmap development areas and cross cutting themes.

Barriers	**Administrative and legal barriers**	**Technical and structural barriers**	**Economic and market barriers**	**Social acceptance and political**
Energy	Legal issues and lacking of new business models for local energy services and supply/demand matching. Development and changes are slow. Sub-optimisation.	Lots of actors makes interoperability and integration of processes and systems is complex. Limits of distributed energy (e.g. timing and fluctuation). Location affects to the accessibility and availability of RES.	High costs and long pay-pack times. Costs and efficiency still developing for some supply technologies, e.g. PV.	Legacy of design for central energy supply. Lack of common vision.
Existing and new buildings	No common semantics or standardisation for communication and data exchange.	Isolated sensor networks and subsystems Rare integration of smart products, services and technologies into wider city systems and tools.	Doubts about ROI for investments. Smart renovation solutions not cost-efficient and focus on isolated buildings	Lack of awareness Different interests of stakeholders (landlords, tenants, investors, owners, ..)

	Lack of policies for the integration of smart renovation measures Data monitoring vs services vs privacy is not clear regulated	Huge renovation need. Maintenance reactive.	rather than district integration. Building stock inertia.	Old habits.
Infrastructure	Sectorial approach; separate standards & policies for various infrastructure assets Maintenance and renovation sub-optimised. Path depedence in existing infrastucture		Long term investments vs. short term costs. Fiscal problems	Lack of asset management expertise State of stagnation without developing attitude
Mobility	Too much land use for transport and infrastructure (e.g. parking lots). Unnecessary trips.	Lack of public transportation and un-motorized options. Rarely linked to other city services.	Many cities develop uncontrollable.	Mistrust towards reliability of public transport.
Communities and users: citizens	Lack of possibility for involvement in decision making. Lack of information.	Security and privacy of data. Services, systems and interfaces that are not easy to use.	Affordability of housing. Lack of education and career opportunities.	Users resistance and mistrust towards new solutions.
Governance, policies, and land use	City decision making in silos. Development and changes are slow.	Sub-optimisation of the land-use. Inadequate evaluation of life cycle criteria.	Hard to see the impacts of the investment costs in the long term.	Dissatisfaction of people regarding the land use.
Interoperability and ICT	Data monitoring vs services vs privacy is not clear regulated	No common semantics and standardisation for communication and data exchange.	Hard to calculate the benefits of investments.	Inadequate collaboration, communication and integrated planning.

		Lack of open data.		
Resource management; environment	Sub-optimisation.	Clean water scarcity.	Lack of ROI for environmental protection.	Competition for resources.

6. Discussion and Conclusions

The global challenge is to reduce environmental impact and carbon footprint. At the same time societal development needs to be addressed and people well-being must be in focus. Pressure is growing to reduce our environmental impact and there is a parallel compelling need for business to stay globally competitive. Investment and expenditure needs for improving energy efficiency, modernizing infrastructure and creating high quality living environments are enormous. At the same time, cities have limited access to financial resources.

Globalisation has opened new markets and is requiring much more competitiveness from local industries. The advanced and modern systems deliver new services and opportunities to growing well-being. But at the same, societies have become more vulnerable to human based criminality and also to natural based catastrophes. Climate change is feeding new and unexpected phenomena requiring more robust but flexible and self-recovering systems.

The concrete threats to the urban system include natural disasters and other sudden shocks (storms, terrorism, collapse of vital technical infrastructure), vast consequences of climate change (decreasing biodiversity in the ecosystems , repeated flooding, long periods of hot and arid summer seasons, distorted population structure, escalating migratory movements, and epidemic diseases). These challenges are very different from each other as some occur suddenly (epidemics) and have relatively limited duration (collapsed infrastructure) while some affect the society slowly and may be very difficult to change or to adapt to.

Smart cities emphasize the relations between the urban flows on energy, material and people as well as governance and human behaviour. Further, the relations need to be explored in a holistic way realise cities of high resiliency and sustainability. Innovation in the form of 'smart city solutions' can deliver technologies, products and services that meet the dual challenges of reducing greenhouse gas emissions and delivering more efficient public services. Cities worldwide are modernising and becoming poles of competitive strength.

If we think about the concept of a mart city, we can easily conclude that currently the deployment of technologies and ICT solutions for energy use and production, mobility and transport is still fragmented, limited in scale and thus with low impact. A European large scale action is needed to bring the many valuable results of research and development projects together, and to focus on deployment. This can be done only by accelerating full-scale deployment of technological smart city solutions in the key areas of energy production, distribution and use, as well as in mobility and transport. ICT is the key enabler for the smart city solutions and new technologies creating interdisciplinary opportunities.

Vitality and capacity for reinvention form an essential part of a Smart City. This means that the building stock and infrastructure must be flexible according to changes in the usage needs as well as the users. A Smart City also attracts new residents, and it must be able to grow sustainable. Eco-efficiency involves recycling districts and buildings to new uses. Energy efficiency involves reducing the energy consumption of old buildings so that the energy demand of new buildings can be satisfied with the saved energy. In addition other aspects of sustainability likes social and economic aspects must be taken into account.

Choices made concerning a single building have only a limited impact. The impact can be scaled up, if the choices are made on the district level, instead. In district-level projects, it is possible to invest in innovations, product development and structural changes. With regard to energy efficiency, for example, district-level improvements and new construction solutions can achieve greater benefits than if they were implemented one building at a time.

Unlike in traditional building stock and other infrastructure, interactive data transfer is an essential part of Smart buildings. Advanced technology and economy are not enough to make a building smart. At its best, a building could promote the well-being of its residents or the people working there. At its simplest, the high quality and healthiness of the indoor air can be ensured. Taken further, the building can, for instance, monitor the condition and safety of senior citizens. At the district level, the quality of life of, for example, people with memory disorders could be improved by allowing them a wider living environment through new technology.

Modelling is an absolutely necessary tool, as the initial data produced with it can be utilised in the simulation of functionality and solutions affecting energy efficiency. Modelling produces compatible data so that a common model of the district's building stock can be generated as part of the city model.

If the development project concerns an entirely new district, the infrastructure models and building construction models can be reasonably easily combined even today. This can be done at many different levels. At its simplest, it is a question of visualising the planning options. At its most demanding, the operations and traffic flows planned for the district are included, and the best solution for the overall system selected. The task becomes somewhat more laborious, if old building stock or old infrastructure is involved. Model-compatible data of these must be obtained by means of, for example, laser scanning and ground penetrating radars, if the original plans are not available. Complete modelling of the district is necessary when the objective is a comprehensive city model.

Digitalisation and new technologies enables us to use more and more data in real time. In addition internet of things makes it possible to use, combine and enrich data from many different sources. The future city actors and stakeholders are changing internet of things to internet of meaningful information. New technologies enable also service based solutions. Future construction business is in transformation. Todays' construction of buildings and roads will change to service business like living as a service, energy as a service, X- as a service.

Future smart cities are sustainable and resilient and they are constructed from self-healing materials and systems. Zero carbon resource efficient solutions are created without compromising peoples' well-being.

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Political frame conditions for energy efficiency: context sensitivity, energy flexibility and the question of scale

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Abstract

This paper is intended to highlight some of the challenges of regulating integrated energy solutions in buildings, and so provide a better basis for both regulation and initiating innovation processes related to energy efficiency. The paper is based on a mapping of regulatory and incentive schemes and two extended case studies consisting of in depth interviews, a survey, document studies and field visits.

The paper discusses political frame conditions that are intended to promote energy efficient solutions in Norway's building stock. The starting point is that although such solutions are both feasible and financially rewarding, the practical outcomes seem to be limited. In order to understand why, we analyse the nature of current regulative instruments and two different cases of energy efficiency innovation processes by the dimensions of scale and context sensitivity. The main finding is that the very nature of projects successful in integrating heterogeneous actors, are context sensitive and small-scale. Efforts in constructing regulation schemes in order to scaling up such successful solutions are problematic due to the nature of those regulatory schemes – relying on standardisation and the measurement of distinct legal entities. If we want to move real-world energy optimization from small to large scale, one should formulate regulatory measures in such a way that they combine standardized with the development of individualized and tailored solutions.

Keywords: Energy efficiency, regulation, standardization and context

1. Introduction

Buildings account for more than 40% of global energy use in both developed and developing countries (UNEP 2009), and calculations from e.g. The Norwegian Agency for Energy Savings (ENOVA), show that there is a significant energy efficiency potential by integrating buildings' energy systems (ENOVA 2012). Although the explicit political goal is to optimize buildings' energy efficiency, the current political instruments in Norway are such that this goal is not always supported– and sometimes the policy instruments even function as an obstruction.

Many propose increased interconnection of buildings energy systems as a key response to stricter requirements for the buildings' energy and environmental performance. New technological solutions and pilot projects for low-energy and energy positive buildings have shown the feasibility of such a response. Such solutions, however, require flexibility in providing the energy needed for the operation of buildings – from grid systems (electricity and thermal) as well as from the building itself (e.g. building-based PV, wind turbines, geo-thermal, heat pump systems, bio-based CHP etc.).

Summarized, given the importance the energy demand represents, and the unexploited potential, ENOVA argues that many energy efficiency projects *should* have been implemented, and still, they are not. There is thus a *perceived* paradox in the fact that there are available solutions that are both technically feasible and financially rewarding, but are not actually realized in the market. In this paper, we argue that many preconditions, other than pure techno-economic, are important when seeking to realize energy flexible solutions for buildings.

Energy flexibility may be defined as facilitating for changing sources of energy, e.g. not locking buildings to one source only. Such flexibility is crucial in order to facilitate more renewable energy to be incorporated into energy consumption, and furthermore to match calculated potential for energy consumption with the actual energy consumption (EBC, 2014). Hence, energy flexibility in its broader sense also includes more interaction and flexibility both internally within a building, using e.g. short-term and long-term thermal storage, and interaction between buildings and/or buildings and external energy systems.

In this paper we highlight how the nature of policy instruments makes certain types of systems and systemic changes such as energy flexibility problematic. We combine an assessment of the societal and political driving forces with empirical studies of one small-scale and one large-scale case of energy efficiency innovation. By this we aim at contributing to the identification of more robust policy measures for increased energy flexibility and interaction between buildings and the energy system at multiple levels. We thereby also aim at highlighting the importance of addressing the political feasibility of the proposed measures, which may also include more shared visions and understandings across traditionally separated policy sectors.

The first case is a small-scale energy entrepreneurial project that integrates and utilizes both heat flows and CO2 outlets between companies in a food industry cluster. This case shows a very successful project in terms of energy optimizing, it takes in to account and exploit the specific contextual conditions. At the same time – as this is a context specific solution – it may not be optimal as a large scale solution for all other such clusters.

The second case is a large scale state initiated program which has lead to a significant change in the building market. This is the so called *passive house program*. The standards and means of both regulating and registering this initiative are of such a nature that it is easy for large scale adoption. But these are not context sensitive standards, and as such the solutions are not optimal for the specific sociotechnical situations.

One important observation is that the specific small scale initiatives, such as in case 1, are demonstrably successful in saving energy, while the specific houses in large scale initiatives varies a lot in such performance. At the same time – the large scale initiative has a lot more impact in the over all energy savings. We would therefore argue that if we want to move energy optimization from small to large-scale, regulatory measures should function in such a way that they combine standardized solutions with development of individualized and tailored solutions where appropriate.

2. Background – Policy framework for more energy flexible buildings

Policy instruments may be divided into three categories; regulatory, economic and informative. Regulatory instruments are *"undertaken by governmental units to influence people by means of formulated rules and directives which mandate receivers to act in accordance with what is ordered in these rules and directives"* (Bemelmans-Videc, Rist & Vedung, 1998, p. 31). Economic policy instruments involve either *"... the handing out or the taking away of material resources, be they in cash or in kind. Economic instruments make it cheaper or more expensive in terms of money, time, effort, and other valuables to pursue certain actions."* (Bemelmans-Videc et al., 1998, p. 32). Economic instruments may comprise discount campaigns, tax credits, funding, loans and grants in various forms that can be targeted at different areas, different populations, etc. Informative instruments, or "moral persuasion", cover "attempts to influence people through the transfer of knowledge, the communication of reasoned argument, and persuasion" ((Bemelmans-Videc et al., 1998), p. 33).

There are currently a number of regulative, economic and informative policy instruments relevant for energy-building interactions in Norway (summarized in the table below). This policy framework does not explicitly support solutions for increased interaction, even if there have been recent amendments in the regulation of third-party access and deliveries to district heating. Overall, energy efficiency is not a specifically well-established policy field in Norway (Knudsen and Dalen 2014, Ryghaug and Sørensen 2008). It adds complexity to an "energy efficient transition" that buildings has traditionally not constituted a uniform industrial sector and – within a Norwegian context, at least – has been anchored within and regulated from different policy fields (Rasmussen et al. 2006; Boasson 2009).

At the same time, certainly regulatory changes have been decided during recent years in Norway, pointing towards a clearer political priority of energy efficiency. An important driver behind these changes has been the stricter requirements stemming from EU-based legislation, particularly the Directive on Energy Performance of Buildings (EPBD) which (in particular) implies the compulsory phase-in of 'near-zero energy buildings' by 2020. The EU EPBD requirements are in Norway codified into the Building Code. A number of building companies have started to experiment with the new building energy standards, and several innovative projects – including energy-positive buildings – are now realized in Norway. A number of energy companies, in addition to the ICT sector, are also increasingly interested in this regard.

Table 1 Overview policy instruments for increased energy efficiency and interaction in Norway (Knudsen and Dalen 2014)

Instrument	*What*	*Governance level in Norway (national/regional/local)*	*Promotes energy efficiency and/or increased interaction*
Regulatory	**Building regulation TEK 10**	National	yes[1](thermal insulation requirements)
Regulatory	**Planning and Building Act**	National/local (municipalities set the concrete requirements)	No
Regulatory	**Plus customer arrangement**	New regulation under development: Owners of residential and non-residential buildings are supposed to achieve the right to exchange up to 100 kW surplus electricity, free of charge (e.g.bulding- integrated PV to the electricity grid)	Yes
Regulatory	**Third-party access/ deliveries to DH infrastructure**	National, amendment of the Energy Act (2013): Allowing third parties to access and deliver heat to existing district heating infrastructure, depending on the negotiation with the owner of the infrastructure. (The DH infrastructure owner is not obliged to provide access, if agreement is not reached).	yes
Regulatory	**EU Energy labelling Directive**	Norwegian Water Resources and Energy Directorate prioritize product groups for closer follow up. National regulations established on a product group base as the EU regulation progress develops into mandatory regulations. Market pull – informing buyers.	yes (market pull)
Regulatory	**EU Ecodesign Directive**	Same process as for EU Energy labelling Directive. Market push- removing prouducts from market.	yes (market push)
Regulatory	**The Energy Act**	National. Regulation of income frame for grid operators, tariff regimes for grid operators, producers and end-users of energy, including a regulation of district heating market (mandatory connecting and regulation of pricing).	Yes (energy performance certificates for buildings)
Economic	**Enova incentives**	National. Supports investments in more energy efficient heating solutions (i.e. hydronic heating, solar water heating, heat demand steering systems, geo-thermal heating), and new technological solutions.	Yes
Economic	**Innovation Norway**	National. Financial support to energy and environment R&D	Yes
Economic	**The Research Council of Norway**	Several economic instruments, such as financial support to R&D projects, and tax incentive schemes for companies conducting R&D projects.	Yes
Informative	**Energi21**	National strategy on energy technology R&D with energy efficiency as one of the prioritized areas. Priorities of the strategy to be taken into account by the RCN in the funding of R&D projects.	Yes
Informative	**Bygg21**	National strategy on buildings with sustainable, adaptable, functional buildings for the future residential and urban areas.	Yes

[1] http://www.paroc.no/Knowhow/Building-regulations/Norwegian-Building-regulations?sc_lang=en

When discussing possible solutions within a Norwegian context, it is also important to understand the societal and political factors underpinning the current situation – and consider what can be considered as politically feasible. There is a remaining barrier in the way Norwegians consider supply of energy – in the form of electricity, as cheap and abundant. Hence, the overall drivers which are substantially present in other European countries, related to higher energy prices, less security of supply and the need for phasing out fossil fuel-based production of electricity, are not present in Norway. In addition, Norwegian building prices for both residential and non-residential buildings are relatively high. Given the current prospects of increased challenges for the Norwegian economy, such concerns will grow in importance. Hence, additional costs related to energy provision for buildings may not be a very feasible path, and new projects for energy storage and interaction should also focus on and clearly communicate how they can contribute to reduced costs, in order to become more politically robust in a long-term perspective.

With the development of more interactive energy networks which are being introduced with smart grids, we can expect to see more cross-sectoral innovations, combining multiple technologies. Still, with this development comes the growing need for improved energy management systems of e.g. smart thermal grids, and new concepts for energy storage (e.g. geothermal solutions for heat/cool storage). There are challenges emerging related to the management of more integrated systems, and the coordination across traditionally separated technical systems. As mentioned in the previous chapter, these different technical systems (energy/buildings) do also represent different policy sectors with different and fragmented public authorities and different regulatory logics. A major question is how small scale and context sensitive solutions, stemming from a singular or multiple actors within e.g. the building and industrial sectors can represent alternative solutions, and to what extent these approaches can supplement and eventually influence upon the further development of the policy framework.

The following section will explore these questions further by discussing concrete cases from the Norwegian industrial sector.

3. Case studies: Implementation of policy instruments and actor induced measures

The empirical basis of the paper is two cases of building/energy innovation processes; one initiated by private actors and one as a response to governmental incentive schemes. By this the paper raises the questions as to what extent energy-flexible solutions for buildings are promoted by the current policy framework in Norway, and how pilot project actors experience this policy framework.

The case-studies are based on 30 in-depth interviews and a questionnaire. The interviewees represent industry partners, grid owners, municipalities, governmental instruments, building owners, consultants, R&D, and building contractors. We also conducted a document study of all official documents related to the establishment of the specific industry-cluster and regional energy-plans from the municipality and energy-supplier. Finally, a field-visit was done to get an impression of the cluster and energy-system of case 1. The material was transcribed and analyzed triangulating the different sources of data (Yin 2009). Drawing on the work of Burawoy (1998) and his concept of *extended case-study,* the empirical findings from the case-study is analyzed against a backdrop of Enova and Energy21 quantitative studies of barriers hindering the utilizing of surplus-heat in Norway. By doing so the case-study illuminates the perceived paradox articulated by using a barrier-model to explain the lack of innovation, and a challenging disparity between contextual optimization and regulatory standards and standardization.

3.1 Case 1: small-scale energy entrepreneurship

Our case of actor-induced initiatives constitutes heterogeneous solutions for energy efficient systems. Such projects might hold great potential for saving energy, but also for never being realized due to challenges in coordinating these innovative ideas (Johansen & Røyrvik 2014). Multiple buildings, and different kinds of production and consumption making up one system optimized by the differences of energy needs and usage characterize the case we focus on. Given that the object is the optimization of energy consumption and minimalizing impact on the environment, such projects must handle socio-technical heterogeneity – reaching beyond energy-political instruments (ibid).

The notion *collective energy-system* is used because it highlights what we consider to be the greatest innovation in this case; a shared private initiated energy-system with internal rules regarding infrastructure and trading of energy. This can be seen as opposed to a traditional energy system with a grid-owner, producer, distributor and customers. In the collective energy-system at Kviamarka the businesses have multiple roles as they are maintaining their own infrastructure, contribute with energy to the system as well as receiving from the system. The optimalization of the system is defined as a collective responsibility, even though the roles are clearly stated. The *collective energy-system* at *Kviamarka* involves surplus heat, cooling water and CO2.

Kviamarka is an alimentary cluster in a small region in Norway where five different companies have integrated their energy flows into a local sustainable energy-system in order to reduce energy-cost and make the whole region more energy-efficient. The cluster is the only industry-cluster in Norway that utilizes low-temperature heat (35 C^0) in a *collective energy-system*.

The construction of the collective energy system was initiated by the simultaneous establishment and bridging of two companies: *Tine* were building Norway's largest dairy in Kviamarka which produces a large amount of surplus heat and CO_2. To utilize this waste-energy *Miljogartneriet* were building their greenhouse next to *Tine* to utilize both the surplus heat and the CO_2 (in the photosynthesis), becoming the first greenhouse in Norway without their own energy-central. Integrating the companies' energy flows was necessary to get political approval for the development plans. When completed, this also led to a more cost-effective production.

At the time *Tine* and *Miljogartneriet* joined, the cluster already consisted of the three companies *Jaerkylling*, *Nortura* and *Prima Jæren* (all chicken producers), which at the time had to use cooling fans to get rid of their low-temperature surplus heat. By connecting to *Tine's* energy central they could save energy-costs by delivering their surplus-heat, and receive cooling water for a cheap price. By utilizing the low-temperature surplus heat from the cluster in a shared system, *Tine* can also sell this heat to the local energy-supplier which then distributes it to buildings in the nearby town, reducing the need for heating by electricity. Bridging the businesses in the cluster thus made their production more cost-effective along with reducing the whole region's eco-footprint.

In *Kviamarka* this material bridging of companies led to a huge inter-dependence amongst them; *Miljogartneriet* for example cannot maintain its daily production without the energy-input from nearby companies. Another interesting character of the collective energy-system in *Kviamarka* is how some of the agreements are informal and constituted by personal relationships between individuals in the respective companies. Ownership is distributed among the companies, they all own a part of the system and that part is necessary for the whole system to function.

The innovation in *Kviamarka* is not merely the material bridges and energy flows; it is the creation and negotiation of a collective energy-system that binds the companies together and makes them inter-dependent. In the discussion, this will help illuminating some challenges with utilizing cost-effective surplus heat that again explains the limited extent of such solutions today.

3.2 Case2: large-scale program

In the period 2010-2013, a state funding agency aiming at reducing energy consumption in the building sector on a national basis operated a programme to increase the number (proportion) of buildings houses with a *passive house quality*. The program was arranged to provide financial support to consultancy and implementation of solutions that met the criteria of the Norwegian Standard for passive houses (NS 3700 and NS 3701).

During the program period, 751 applications were granted. 182 of these were directed towards consultation within the concept development phase, while 569 were directed towards direct financial support for the implementation of solutions. During the program period several problems occurred. Some of these which may be traced back to the operationalization of the main goal of the agency into a program.

First, the translating of sufficiently low energy consumption into a standard of passive houses, seriously narrowed the scope, from a holistic measure of societal energy consumption into a number of standardized components in individual buildings. The breaking down of a holistic measure into fulfillment at a component/building level excluded solutions where for example clusters of houses in sum fulfilled the goal. As a result, the incentive promoted suboptimal energy solutions where the sum of the individual buildings – in terms of energy saving – actually underperformed clusters of buildings. A case that may serve as an example of this was a project where a series of buildings were originally planned as energy saving townhouses. Paradoxically, when it was decided that they should go for a passive house solution, the townhouse model was rejected in favor of less energy saving detached houses. The reason for this was that the conditions for financial support varied between buildings below and above $200m^2$. To be able to meet the passive house criteria, and thereby trigger the funding, the developer chose to separate each house by 40m, thus actually receiving support for less energy efficiency than originally planned.

Second, there were serious difficulties related to the measuring of saved kWh of the individual components and buildings. Thus, support was not based on real savings, but on loose estimates of saving. Third, these estimates were made in the planning phase of the projects. The applications were granted in this planning phase, and the only condition to trigger the funding was that the building was reported as completed. There were no standardized processes of control of neither the components nor building energy consumption after completion of the projects. Fourth, the funding agency records of their activities, grants and resulting energy savings were neither well maintained nor easily accessible – neither to themselves or to researchers.

Thus, the operationalization of the main goal raised concerns both regarding goal displacement and measurements. This is a case of a general paradox related to incentives and regulation: Due to decontextualisation of standards, they sometimes produce suboptimal solutions; and due to accountability regimes that permeate the public sector, one tends to produce only that which is measurable. Paradoxically, regulators do not always pay enough attention to the fact that what is measurable is not necessarily aligned with the primary goal, nor are the measurements trustworthy. We find this to be a potential problematic aspect of incentive regulated initiatives.

4. Discussion

One of the main findings of case 1 is how the integration of different businesses' energy flows implicates a number of challenges. One is that material 'bridges', that is the physical connection provided by the new infrastructure, between companies implies a need for structural bridge as well. This can be illustrated by comparing a *collective energy-system* with a traditional energy-system. A traditional energy-chain can be illustrated as a number of roles, manifested in companies responsible for performing these roles. Energy-*producers* produce energy for an energy system. Grid owners are responsible for investing in required infrastructure and maintenance. *Distributors* buy energy from the producers on the open market and sell it to *receivers*. The system is institutionalized by laws of the country and energy prices on the open marked. The expectations to the system can be characterized as a form of institutional trust (Zucker 1986) and are largely taken for granted.

Fig 1: Traditional energy-system *F Fig 2: Collective energy-system*

When establishing a collective energy-system these roles must be negotiated. This way of organizing a company's energy-flows is radically different from being connected to a 'traditional' energy-system. In addition to their normal production the businesses must take on new roles as *producers*, *distributors* and *receivers* in the collective energy-system. This involves an inter-dependence where the different actors are dependent on the other businesses' energy-flows for their daily production. The material bridging of the energy flows implies a need for structural bridging by replacing and establish the roles; producer, distributor and receiver. The responsibilities, energy-prices and ownership must be negotiated between the companies instead of being given by institutional structures. Bridging businesses' energy-flows therefore implies several challenges that must be met in order to create a collective energy-system:

1) Discover opportunities for bridging and knowledge sharing
2) Need for negotiating roles and responsibilities constituting the system
3) Emergence of inter-dependence

These challenges are all systemic and thus transcend what can be controlled, affected and regulated by instruments that focus on separate and homogenous legal entities. The very way that the industries are organized and how context specific aspects are utilized and made part of the energy system is the innovation that makes the industry cluster energy efficient. Many industry clusters could benefit from such collective energy systems, but this one exact concept would not be optimal for other clusters in different contexts – they would need to adapt to the socio-technical context that constitute their specific situation.

4.1 Scale and standardization

The political objective of energy optimization can be pursued through different regimes, with which different strengths and weaknesses are associated. Small-scale solutions can benefit from context-sensitivity and tailor-made solutions to fit local conditions of political, commercial, technological and geographical natures, through the initiatives of what we call energy entrepreneurs. The weakness of such solutions is that they are not scalable, since political, commercial, technological and geographical conditions vary from place to place, and the solutions that work well may therefore vary.

Large-scale solutions benefit from the strength that lies in decontextualized standards, and application of standard based regulatory regimes. By freeing itself from dependence on local conditions, standards work on large scales. The weakness of standardized solutions is that they are often suboptimal. In the passive house program example, the standard that applies is for single buildings (whose reference building does not exist in practice). One weakness of the standard is that it does not allow application on the system level (eg several houses combined) by upscaling. Another weakness is that the parameters used to comply with the passive house program both are difficult to measure and, moreover, not always adequate measures for the overall objective of energy optimization at society level.

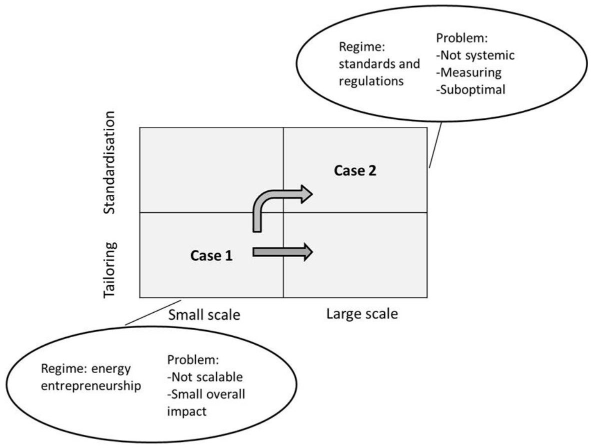

Fig 3: Scale, context and standardisation

The arrows in figure 3 indicates two possible ways of scaling up the integrated concept presented as case 1. The first solution is to standardize case 1 in terms of components and ways of measuring as it is done in case 2. We would argue that this would involve the same kinds of issues as described in case 2 as the specific solution optimal in the specific case is not similar elsewhere. The second solution is to facilitate arrangements that are both context sensitive and scalable. This is difficult in practice, and one of the central challenges energy efficiency policy is facing.

4.2 Organizational framework for smarter and increased interaction between the energy system and buildings

It is important to assess how changing trends concerning energy consumption in buildings are affected by the existing and upcoming policy framework. It is important to map and assess how certain policy instruments function and how this will impact both the level of energy efficiency in the building stock, as well as future energy consumption. This issue is also closely connected to developing smart grid solutions. Consequently, it is important to pinpoint political and regulatory factors which impact upon the very interface between energy consumption and production related to buildings, and the external energy provision towards the buildings. There are few policy analyses assessing this overall problem within a Norwegian context, implying a need for research on how policies can facilitate for transition towards increased exchange of energy surpluses and energy storage in and between buildings and building complexes.

In the the second case, the program was initiated by the regulators, the target group was conceived/operationalised as a market, and the program was shaped to influence the market – raise the demand – through incentives (subsidies). The belief was that having reached a critical mass of houses categorized as *passive,* the market would see the profitability of “passivehouses" and the incentive would no longer be needed for the market to go for such solutions. At this point, the market would thus be ready for adopting the requirements of "passivehouses " as a building standard, which could be seen as a final motif.

In the first case, on the other hand, the project was initiated by a group of actors who independent from regulators and regulations agreed to create their own market based on mutual goals and agreements. The regulators involvement in this project was merely as facilitators, without any ambition of creating new standards or of scaling up the project. This project was more actor-oriented, and relating to "market" as a composite, situated entity.

The two projects differ in many respects, not the least in scale; while the second sought to influence the market on a national scale while the second was one single project (but involving several actors). Despite this asymmetry, comparing the cases gives rise to some interesting observations:

1. The weakness of the "market-regulator" approach is that already existing inequalities in the market may be strengthened, and that the movement of the market will not be reversed when incentives are withdrawn rest on assumptions that are yet to be proved. The strength is that one make use of heterogeneous methods for stabilizing the market demand by developing new standards (Tek15) that the market has to follow.
2. The weakness of the actor-oriented approach is that it works on a small scale, and that the projects are highly dependent on mutual trust and stability of the good relations within the projects. The strength is that when the initiative comes from within the projects, the actors are willing to strive hard to realise it. Another strength is that the projects are adapted to the local context, and may thus be more efficient than more standardized projects that are initiated from regulators. In sum, many such actor-initiated projects may add up to a national portfolio that is highly adapted to local conditions, and such approaches may thus be more resilient to changing conditions over time.

5. Conclusion

One important finding from our study is that some private initiatives act as driving forces for the emergence of new solutions despite difficult circumstances substantiating regulation; while the majority of building market participants is conservative (Røyrvik et al. 2015) in the way that profitability and predictability are considered the most important thing as long as it is within the rules and regulations. This actualizes a duality, as rules and regulations both need to allow and promote private heterogeneous initiatives while also providing a clear direction for the development of the building and energy market as a whole.

Although there is an increased focus on energy efficiency in buildings, there are no explicit policy measures in place in today which directly aim at stimulating more energy storage (i.e. thermal storage in this report) and exchange between buildings. Still we have to be aware of what is politically feasible. Given the Norwegian situation with little focus on security of supply, low electricity prices – but high costs related to the building sector; there are few political incentives for 'extra-charging' Norwegian energy consumers for building owners' innovative energy measures.

We find that the policy instruments are faced with an inherent dilemma in the regulation of higher energy-efficiency: On one hand, context-sensitive regulation is necessary for energy entrepreneurs to realise creative solutions under local political, commercial, technological and geographical conditions. At the same time, context-sensitivity and energy flexibility may often be at odds with regulation based on standards, which we see as the prevailing measure for large-scale impact. We advise more research on how regulation may enable large-scale strategies to incorporate small-scale initiatives that take stock of the local context. This is challenging, since context-sensitivity and standardization tend not to not always go well together. However, we believe this is not a question of standardization or not. Rather, we believe that research aimed at addressing potential better objects of standardization than those dominating today – components, systems and buildings – may be fruitful.

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Negotiating water governance: towards cooperation in contentious groundwater recharge projects

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Abstract

Water services are an essential part of urban planning and strongly connected to the field of natural resources management (NRM). During the last few decades, Finnish community water supply has increasingly relied on groundwater as raw water source. However, inter-municipal groundwater projects have become contentious issues in Finland and several examples of prolonged projects with years of litigation can be found. A contentious groundwater project can be classified as wicked problem employing features of complexity: it is unpredictable, uncontrollable, and has several, often contradictory interpretations. In addition, several domains are intertwined in the natural, built, and socio-economic environments of the water sector. The complex nature of groundwater management was examined in two cases of prolonged *managed aquifer recharge (MAR)* conflicts in Finland by applying discourse analysis and negotiation theory. The main objective was to find new perspectives for groundwater governance by analysing the major constraints of those projects by drawing from collaborative approaches, which are widely acknowledged in the fields of urban planning and NRM. Results indicate that instrumental rationality with rationalistic planning approaches still prevails in Finnish groundwater management sector. Interaction and knowledge production based on those approaches are insufficient in responding to complex management problems, especially those with contentious features. Thus, this study suggests that the core of groundwater governance should be in collaborative rationality, while the tools can be obtained from rationalistic expert-based planning. The legitimacy for a complex groundwater project should be gained through joint knowledge production as well as mutual interaction, acknowledging stakeholders as partners who are an invaluable asset for dealing with current groundwater management problem.

Keywords: discourse analysis, groundwater governance, natural resources management, negotiation theory, urban planning

1. Introduction

Groundwater is an invaluable part of our natural, built, and socio-economic environments. However, since it is out of sight, we often forget its value and its quantity: approximately 95% of available freshwater sources, excluding those locked in polar ice caps, are underground (UNEP, 2003). During the last few decades, Finnish community water supply has increasingly relied on natural and artificially recharged groundwater as raw water source. In 2011, their combined share of the water supplied reached 66%, out of which 16% is artificially recharged[1] (Katko, 2013). However, due to geological reasons, potential groundwater areas and places for groundwater recharge are sparse. Thus, large city centers, with their increasing need for fresh water supply, are obliged to withdraw groundwater from afar, often crossing municipal borders. This may cause tensions between different jurisdictional units, generally between rural and urban areas. Indeed, there are several examples of local conflicts around the inter-municipal groundwater projects in Finland (Junes, 2013; Lyytimäki and Assmuth, 2015; Myyrä, 2007; Rossi, 2014). Projects which are justified on both technical and economic grounds have problems in gaining legitimacy among local inhabitants. Oppositions emerge and projects may go through long litigation processes.

Large-scale groundwater projects can be classified as wicked problems employing features of complexity: they are unpredictable, uncontrollable, and have several, often contradictory interpretations (Rittel and Webber, 1973; Islam and Susskind, 2013). Therefore, they pose several challenges to water managers and planners in the context of conventional groundwater management approaches. Conventional rationalistic planning cannot respond to a situation where contradictions among stakeholders and political debates may overshadow rational analysis (Sotarauta, 1996; Nolon et al., 2013). Indeed, the emerging paradigm emphasizes collaborative approaches to complex management problems in the fields of urban planning (e.g., Healey 1998, Fainstein 2000, Edelman 2007, Martinez and Olander 2015) as well as natural resources management (e.g., Singleton 2002, Conley and Moote 2003, Margerum 2011, Ostrom 1990).

This paper is based on a doctoral thesis, expected to be published in June 2016. The study aims at finding new perspectives for groundwater governance by analysing contentious cases that operate in the context of water services, thus connecting the fields of urban planning and natural resources management (NRM). Water services, which include water supply, wastewater treatment, and storm water management, are inherently bound to these fields through the multiple connections with aquatic environment, required technical infrastructures, and influence on socio-economic development. Accordingly, this research analyses the major constraints in two large scale managed aquifer recharge (MAR) projects from the perspective of collaborative governance and outlines lessons for future collaboration.

First case is situated in southwestern coastal area of Turku Region, and it started already in the 1970s as a long-distance water transfer project and was finalized in 2010. The other MAR project, situated in Tampere Region, started in 1993; the result is still open (Figure 1). More particularly, in the analysis of

[1] Later in this paper the term *managed aquifer recharge* (MAR) will be used in order to refer artificial groundwater recharge.

the two case studies, this study applies discourse analysis (Hajer, 1995) and negotiation theory (Walton and McKersie, 1965; Fisher et al. 1991; Bartos, 1995), which is the base for several consensus-oriented practices, including alternative dispute resolution (ADR) (McDonnel 1988, O'Leary and Raines 2001), consensus building (Susskind et al. 1999) and mutual gains approach (MGA) (Susskind and Field 1996, Nolon et al. 2013).

Figure 1: Geographical locations of the two case studies

In both case studies multiple materials were available. However, the primary material for the first case study was newspaper articles (approx. 400 pcs, 1999–2010), from which a discourse analysis was conducted. A discourse analysis explores the ways reality is constructed through discursive practices in texts and talk (Nikander, 2008). In this case, the study analyses the argumentation used in newspaper articles and recognizes the ways these texts constructed and maintained discourses around the MAR project. Second case included 28 semi-structured interviews and a conflict assessment process with a workshop which convened representatives of almost every stakeholder group. The results of conflict assessment were viewed through negotiation theory (see Kurki and others, 2015 as well as Kurki and Katko, 2015 for more details about the case studies and the analysing processes). Overall, the analyses of these two case studies clarified the visible tip of the iceberg of conflicts as well as the large invisible entity, which is often forgotten beneath the surface.

2. Results

In Finland, municipalities have a responsibility to organize water services. Increasing challenges of water quality requirements, aging infrastructure, and decreasing fiscal resources have furthered collaboration between municipalities. In both case studies, municipalities joined forces in order to produce enough good quality fresh water for domestic and industrial use in an efficient, economic, and ecologically sustainable manner. Accordingly, in both regions, a municipally owned water company was established with its main task to plan and implement an MAR project in order to achieve this goal.

Managed aquifer recharge (MAR), also known as artificial groundwater recharge, is a technological innovation where natural system of water purification is exploited as part of water supply system. It has been used for decades, mainly as a water treatment method in boreal areas (Kolehmainen, 2008), whereas in arid and semi-arid regions for freshwater storage (National Research Council, 2008; Shahbaz et al., 2008) and in reuse of storm- or wastewater (Barnett et al., 2000). This method is widely used and gains continuously increasing attention inside groundwater management discussions and practices, especially in terms of technical, economic and legislative considerations (Bloetscher, 2014; Dillon et al., 2010). However, a comprehensive framework for MAR is lacking. This study presents such a framework, which acknowledges the complexity of water systems as well as perspectives of collaborative governance.

2.1 A comprehensive framework for MAR

Water is inherently bound to our natural, built, and socio-economic environments. Conventional water management approaches often underestimate the first or third domain, or address all three of them but as separate entities. However, for example, Swyngedouw (2004) describes their interconnected relationship where social practices are predicated upon and conditioned by the circulation of water into, through, and out of the city. According to Linton and Budds (2014), the hybrid nature of water means that it is simultaneously both a natural and a physical element, as well as a social one.

Accordingly, Figure 2 presents a comprehensive framework for MAR where all three environments are acknowledged. From a technological point of view, the framework of an MAR project consists of three main components. First, the base of an MAR project is in its *local conditions*, which are characterized by the natural as well as physical environments. Second, the needs of the community arise from the local conditions and together they define the *purpose of MAR*, which in Finland is generally water treatment. The communal needs are clearly part of socio-economic environment, and interconnected with economics and legislation, which all affect the implementation of an MAR system. Third, the local conditions and purpose of MAR together influence the selection of *infiltration options* which consist of technical design parameters needed for an MAR system, thus being strongly connected to the built environment.

Finally, the outcome of an MAR project is the chain from water intake to infiltration and end use. In this chain, all three environments are present. Raw water is taken from its natural environment; infiltration options represent the physical, built environment with water transfer pipes, excavated basins, and constructed recharge wells; and finally, the processed water is delivered to the community, to the socio-economic environment. Through this process, the material form of water is modified, but also local conditions and social structures change along the way. Thus, once an MAR system is established, it does not remain stable. Instead, the system is dynamic in its spatial and temporal dimensions, and new socio-natural configurations emerge (Linton and Budds 2014). Consequently, the system involves several characteristics of complexity: nonlinearity, unpredictability, and uncontrollability.

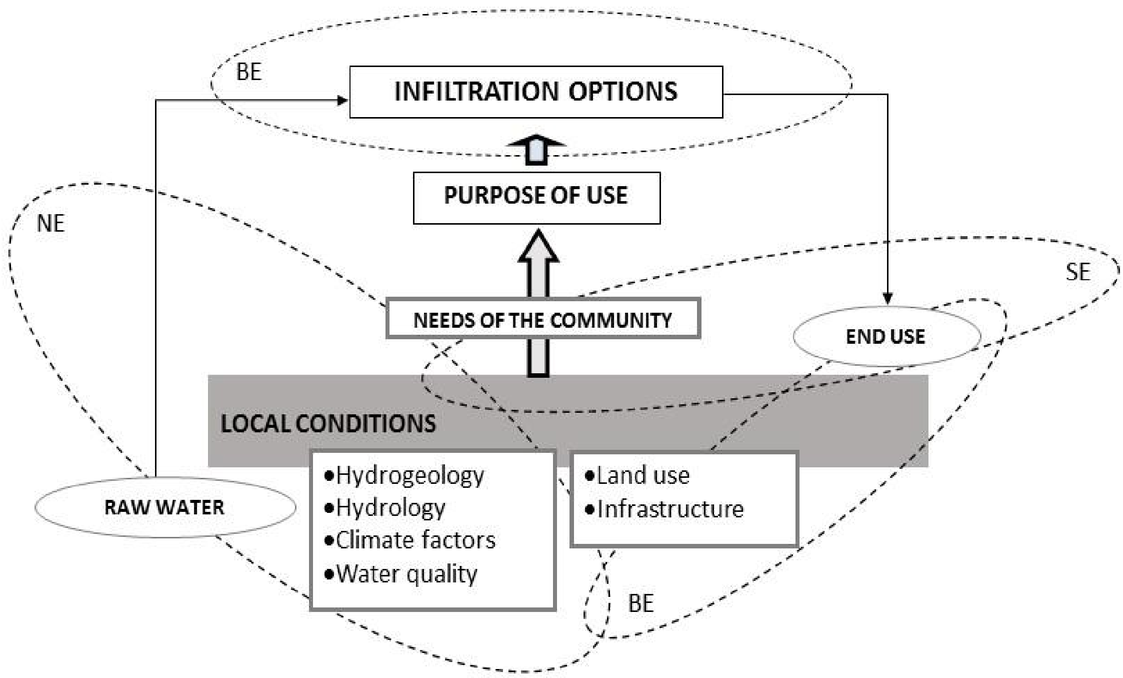

Figure 2: A comprehensive framework for MAR and interrelations between natural environment (NE), built environment (BE), and socio-economic environment (SE) (modified from Kurki et al. 2013)

In groundwater governance and especially in MAR cases, a strong connection to land use and spatial planning should be acknowledged (see Hartman and Spit, 2014). An MAR project has indirect impacts on land use through it potentially causing restrictions for other land use activities as well as direct impacts through constructed pipeline network and infiltration areas. However, groundwater issues also involve a mental feature in connection to land use: an underground resource is often regarded as a property of the landowner, even though according to Finnish legislation groundwater cannot be owned by anyone. Accordingly, MAR conflicts can be also regarded as land use conflicts, thus intertwining the features of common-pool and non-common-pool resources. This may cause mental confusion, which forwards the contradictions related to groundwater projects.

2.2 Major constraints in groundwater governance

The complex nature of an MAR system was not recognized in the two cases. Instead, they were managed as merely technical problems, to be solved by using a sufficient amount of expert knowledge. The definition of a problem derived from a mechanistic worldview where a system can be taken apart, the details of those parts analysed, and feasible partial solutions being thereby found (see Islam and Susskind, 2013). Especially the social dimension of the system was not adequately acknowledged. Therefore, interaction between various parties failed and a conflict emerged. Drawing from negotiation theory and discursive framework, the paper presents the discursive order and the major constraints observed within the two contentious MAR projects.

In both cases, strong positioning of various parties was formed during the decades of dispute, leading finally into a deadlock where the only aim of the opponents (composed mainly of local residents) was to turn down the project, and the only aim of the proponents (the water company owned by the municipalities) was to implement it. Discourse analysis, clarified how a strong environmental discourse was formed around the MAR projects. It was constructed and maintained by several parties: while the opponents addressed the possible environmental threat that an MAR plant would bring to the area, the proponents claimed that MAR technology is an environmentally friendly way to produce drinking water. In fact, environmental discourse dominated the visible structures of social orders and overshadowed a latent but important regional policy discourse.

The regional policy discourse was formed around a concern for local economy, that it would be threatened by the MAR projects since they would cause tightening land-use requirements and environmental restrictions for local economic activities. This does not mean that the environmental arguments of local inhabitants were false, but it does indicate that the real interests and values are hidden under strong positions that actors take (Susskind, 1999). Accordingly, one major constraint of the two projects was that the actors concentrated on their predefined goals through their fixed positions and did not acknowledge the underlying interests of the other side. This kind of competitive mindset was accompanied by interaction based on zero-sum game and hard bargaining where the main purpose is to defend one’s own goals with as minor concessions as possible and to maximize the share of the fixed amount of benefit (Bartos, 1995; Fisher et al., 1991).

Another constraint is related to the knowledge production process. Knowledge is one of the fundamental elements for building legitimacy in complex processes. It is, however, also a medium for clashing claims. Expert knowledge was acknowledged as a sole legitimate source of information, but expert-based arguments from the water managers and planners did not calm down the opposition; instead, they worked as a fuel for even stronger counter-argumentation. This indicates the presence of instrumental rationality, which is in line with the idea that contradictions can be solved by increasing the amount of expert knowledge. Yet, this assumption is questioned by several scholars (Nelkin, 1979; Pellizzoni, 2003; van Buuren, 2009) and also by this research.

Finally, the results indicate that conventional groundwater management approaches, which derive from instrumental rationality, could not respond to the problems that operate in a complex environment. Although collaborative efforts were implemented, they were used only as casual tools without really relying on collaborative rationality.

2.3 Collaborative groundwater governance

The analysis of two MAR projects brought up several challenges in planning and implementing complex groundwater projects. In order to answer those challenges, this section presents some comparisons between conventional groundwater management and collaborative groundwater governance. These frameworks are drawn from two sources: on one hand, from literature on collaborative governance, including multiple case studies, theoretical considerations, and pragmatic guidebooks; and on the other hand, from those lessons that we can draw from the pitfalls of the two case studies. However, complex problems do not fit into any single governance model, which often offer too simplified a picture of the world (Ostrom 1990). Every situation is different; thus, practitioners need to translate solutions derived from scientific findings into the confused context of the policy world, where natural, built, and socio-economic environments need to be considered. While no universally correct answers are available, this study indicates some directions towards collaborative groundwater governance.

Whereas the goal of conventional groundwater management is to achieve outcomes that fulfill technical, legislative, and environmental requirements, in collaborative groundwater governance the whole process is defined by legitimation. Legitimacy here is understood as tacit approval (Häikiö 2007) where actors recognize, approve, and support the process, practices, and outcomes. It needs to be gained from the perspective of all three domains that are ultimately present in groundwater processes: natural, built, and socio-economic environments.

While analysing the major constraints faced by the MAR projects, two significant aspects arose above others in the process of legitimation: interaction and knowledge production. Failed interaction can form an insurmountable barrier between parties, whereas successful interaction can construct a bridge even between contentious interests of various parties. Accordingly, interaction based on zero-sum game involves an idea of fixed amount of benefit that needs to be allocated among the stakeholders (Islam and Susskind, 2013). Parties negotiate from the perspective of their positions rather than of their interests; thus, this creates only winners and losers, and fosters mistrust and hostility. However, in collaborative groundwater governance, interests of every party should be acknowledged and brought to the negotiation table. That way, parties can come out from behind their positions and are able to search for creative solutions and new potential options for reaching mutual gains.

Knowledge production, which is inherently bound to the interaction between parties, is in conventional groundwater management driven by an assumption of perfect and objective information that can be obtained by expert analysis. However, in complex cases this assumption leads to a deadlock. Disagreement about the facts also prevails among the experts themselves (Jarvis, 2014). Indeed, MAR projects form fruitful ground for a kind of duelling expert syndrome. Therefore, it is vital to find legitimate ways to gather the knowledge base, which then forms a cornerstone for the collectively produced truth about the problem. A legitimate knowledge base is created together with experts and stakeholders in a joint knowledge production process, where expertise is exploited as a fundamental source of knowledge but it is complemented with local, experiential, and other forms of non-scientific knowledge (see Ehrmann and Stinson, 1999; Jasanoff and Martello, 2004; van Buuren, 2009).

In these settings, the role of water manager changes from the holder of the only legitimate source of knowledge to a facilitator or even a mediator who has the key to expert-based knowledge as well as to the sources of collective knowledge production. Water manager could also be a conveyor whose main task is to construct and maintain collaborative process and to ensure that every relevant stakeholder is gathered around the negotiation table.

3. Conclusions

Water services are strongly bound to the fields of urban planning as well as natural resources management (NRM). They are often considered as separate fields of inquiry, but they both are an intrinsic part of societal development and thus inherently bound to each other. In addition, urban planning and NRM both involve planning with complexity as well as interactions inside natural, built, and socio-economic environments. From the perspective of governance, both fields widely acknowledge the contribution of collaborative approaches in planning practices.

The objective of this study was to find new perspectives for groundwater governance by analysing two contentious MAR projects and the major constraints from the perspective of collaborative governance. Groundwater conflicts are less frequently analysed than those around surface water projects (Jarvis, 2014). Furthermore, the rather abundant water resources of Finland constitute a very interesting context for studying water conflicts. Although the southwestern coastal area lack adequate water resources in terms of water quality and quantity, from global perspective the rhetoric of water scarcity loses its argumentative power. Indeed, the two case studies support the argument presented in a report published by OECD (2011): water issues are not primarily a result of water scarcity, but rather they indicate significant challenges in the field of water governance.

The two case studies showed how conflicts were formed around two elements: interaction and knowledge production. Having competitive mindsets, the parties' interaction was based on zero-sum game and the discussion was dominated by arguing about facts instead of acknowledging various interests and the complexity of the problem. In addition, the knowledge production process relied on instrumental rationality where the only legitimate source of knowledge is expert knowledge and the causal effects form the basis of the analysis. Complex problems do not, however, follow the logic of a machine: a machine can be classified as a complicated problem with its multiple interactions, but it does not involve unpredictable and uncontrollable elements as societal issues do in their complex appearance.

A complex system should be considered as a whole rather than as a sum of its parts. To complexity we need to answer with complexity: instead of trying to resist and control the system, we can adopt to complexity through collaborative approaches, which can be seen as complex adaptive systems themselves (Innes and Booher, 2010). Collaborative governance framework acknowledges the uncontrollable and unpredictable nature of groundwater management problems and tries to find mutual gains and win-win options for cooperation by stepping away from strong positions and addressing stakeholders' interests instead of predefined goals. Here, the complex nature of the system is seen as source of adaptation rather than control.

Yet, if we use new tools in an old manner, the result will probably remain the same. Thus, the *core* of groundwater governance should be in collaborative rationality, while the tools can be obtained from rationalistic expert-based planning; not vice versa, as the examples derived from the two case studies show. The legitimacy for the project should be gained through joint knowledge production as well as interaction, where stakeholders are viewed as partners who are an invaluable asset for dealing with current groundwater management problems.

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Innovation towards low energy buildings and the role of intermediaries in the transition - Review of Scholarly Case Studies in Europe

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Abstract

As buildings throughout their lifecycle account for circa 40% of total energy use in Europe, reducing energy use of the building stock is a key task. This task is, however, complicated by a range of factors, including slow renewal and renovation rates of buildings, multiple non-coordinated actors, conservative building practices, and limited competence to innovate. Drawing from academic literature published during 2005-2015, this paper carries out a case study review of low energy innovations in the European residential building sector, analysing their focus and drivers. Specific attention is paid to the roles that intermediary actors have in facilitating innovation processes and in creating new opportunities. The article addresses the following research questions: What is the current status and range of innovation and diffusion in the field described in zero carbon and/or low energy innovation scholarly case studies in Europe? What have been identified as the key factors influencing the development and diffusion of innovations in these case studies? And, what are the nature, type and influence of intermediaries contributing to the low energy building transition? The analysis of the case studies is informed by innovation studies, and specifically by the concepts of the multi-level perspective on socio-technical change and strategic niche management. We find that the qualitative case study literature on low energy building innovation is limited, particularly in the context of existing building stock. Environmental concerns, eco-social values, EU and national policies, and increasing energy prices have been the key drivers, while local authority agents as intermediaries have been important in several innovation processes. On the other hand, market, health and design related drivers were surprisingly rare.

Keywords: low energy building, building energy efficiency, built environment, innovation intermediary, innovation

1. Introduction

System level innovation has been called for to achieve reduction in the energy use of buildings (e.g. Mlecnik, 2013) that at present amounts to circa 40% of the total energy use and over 30% of greenhouse gas emissions in Europe (Meeus et al., 2012). In the context of achieving significant low energy transition in the building and housing sector, both diffusion of existing technologies as well as the emergence and diffusion of novel system and architectural innovations for residential buildings (e.g. Mlecnik, 2013) are needed. System innovation refers to the integration of *several independent innovations* (e.g. technical products, applications, services) to work together to perform new functions or to improve performance as a whole (Cainarca et al., 1989), while architectural innovation is defined as novel *combinations of existing technologies* and components in a novel way (Henderson and Clark, 2004). These differ from modular innovation that is typically one specific technology (Henderson and Clark, 2004), such as better windows or building-integrated solar panels.

The renewal rate of buildings is extremely slow (e.g. Meeus et al., 2012). Changes to the building stock are relatively rare, and thus at those times when buildings are addressed via renovation or new build, system innovation is important to generate maximum improvement. Innovation and diffusion in the sector are, however, difficult due to a variety of factors making the current regime very stable. Despite country specific variation in the nature of the building stock, building related practices, cultural preferences, regulatory context, building industries and climatic conditions, many commonalities have also been found. The building sector often consists of a multitude of actors who have not structurally coordinated their activities (e.g. Tambach et al., 2010; Killip, 2013) and who do not have competence or resources to innovate independently (Mlecnik, 2013). The building sector is often conservative, especially regarding renovation processes, building materials and work habits (e.g. Davies and Osmani, 2011; Killip, 2013). Also, devising solutions to the high energy problem is difficult due to heterogeneous building ownership and housing arrangements (e.g. Meeus et al., 2012). Additionally, some countries, such as the UK, face tendencies towards mere incremental innovation (Lees and Sexton, 2014) with a building industry that is unwilling to deviate from traditional masonry methods and work habits (Tambach et al., 2010; Davies and Osmani, 2011; Killip, 2013) and often lacks specialist skills (Killip, 2013). "Contrary to this situation, sustainable buildings require (to a varying extent) high-tech components, which are supplied by specialized companies (building control technologies, windows, heating systems, use of solar energy, transparent insulation materials, heat recovery systems, etc.)" (Rohracher, 2001, p. 138).

Drawing from the above it is clear that achieving systemic – or even architectural – innovation in the building sector is challenging both in terms of (1) creating networks and gaining support for the emergence of niche innovations as well as (2) disrupting the high energy institutions and practices of the existing socio-technical regime. Many scholars have explored the topic in different local and national contexts in Denmark (Holm et al., 2011), Belgium (Mlecnik, 2010, 2013), Finland (Heiskanen and Lovio, 2010; Pässilä et al., 2015), Slovenia (Broto, 2012) and the UK (Lovell, 2007; Fawcett, 2014), while overarching analyses are rare (with the exception of Meeus et al., 2012). Therefore, we undertake a systematic review of the literature, focusing on case studies, to explore the status, drivers and barriers for low energy building innovation in Europe.

Taking a long-term transitions perspective, we connect to two core theories in the field of sustainability transitions (cf. Markard et al., 2012): the multilevel perspective (e.g. Geels, 2002) and strategic niche management (e.g. Smith and Raven, 2012). These theories are used for building an analytical framework for the systematic review (cf. Petticrew and Roberts, 2006) of case studies to draw broader lessons on the role of niche, regime and landscape factors in these processes. In addition, we pay particular attention to whether specific intermediary actors (cf. Hargreaves et al., 2013; Kivimaa, 2014) have been present in facilitating the innovation processes and in what ways. Innovation intermediaries, i.e. "actors who create spaces and opportunities for appropriation and generation of emerging technical or cultural products by others who might be described as developers and users" (Stewart and Hyysalo, 2008: 296), have been envisaged as keystone players in the ecosystems where innovations develop (Clarysse et al., 2014), and they could be crucial also in building sector innovation.

The article addresses the following research questions:

1. What is the current status and range of innovation and diffusion in the field described in zero carbon and/or low energy innovation scholarly case studies in Europe?
2. What have been identified as the key factors influencing the development and diffusion of innovations in these case studies?
3. And, what are the nature, type and influence of intermediaries contributing to the low energy building transition?

Section 2 presents the theory informing our analyses, followed by a description of the research approach and method in Section 3. Section 4 presents the findings of the case study review. Section 5 discusses and concludes the paper.

2. Sustainability transitions and intermediaries

2.1 Multilevel perspective and strategic niche management

The literature on sustainability transitions addresses the problem and dynamics of how to transform existing socio-technical systems to more sustainable configurations. The socio-technical approach implies radical changes not only in technology but also in the surrounding actor-networks, policies and institutions, and people's habits, practices and culture (e.g. Markard et al., 2012). While the sustainability transitions approach entails a range of theories, the multilevel perspective (MLP) and strategic niche management (SNM) have been some of the most frequently applied. In the MLP, transition is depicted through interaction between changes in three levels: the landscape, socio-technical regime, and niche (e.g. Geels, 2002, 2011; Smith et al., 2010). The socio-technical regime refers to the fairly persistent deep structure formed of dominant technologies, infrastructures, formal and cognitive rules including public institutions and policies, and the prevailing networks of actors with their practices, beliefs and habits. As opposed to, for example, car-based mobility regimes, Rohracher (2001, p.143) has described building regimes as "rather loosely coupled systems depending on the interaction of various professions (architects, planners, building services, etc.)", building codes, that regulate the technical standards of buildings, providing "a rather wide framework defining minimum standards—especially with respect to criteria of sustainability (energy use, waste, durability, materials used, etc.).". The building regime is composed of the dominant construction industry as well as maintenance and repair practices, markets and business models in both new build and renovation, regulation and policies influencing the building infrastructure, planning and building control practices, as well as how people perceive buildings and live in them (Figure 1).

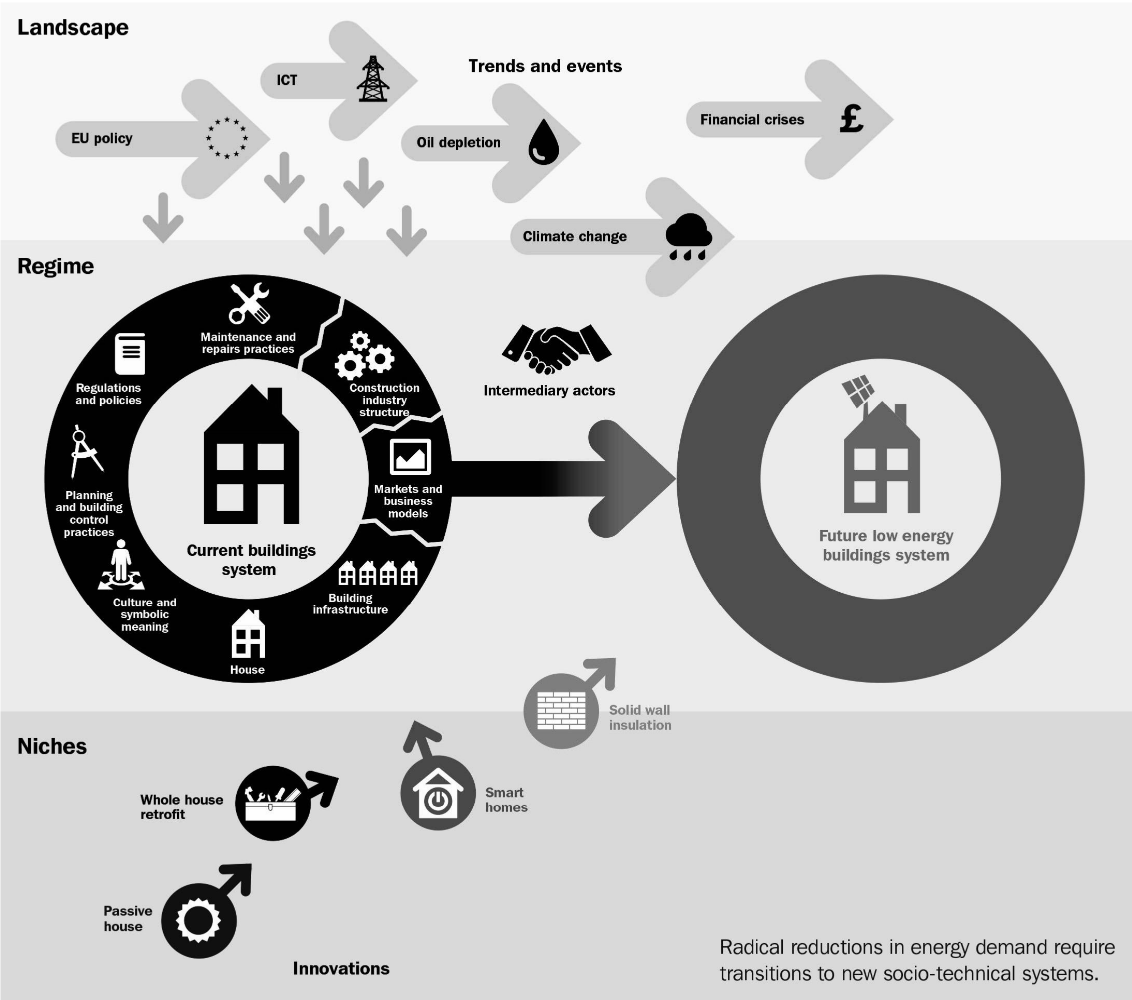

Figure 1: Niches, regimes and landscape in building low energy transition (CIED, 2015))

While incremental innovation is regarded to occur within the context of the existing socio-technical regime, radical innovation activities occur in niches that are associated with initially unstable socio-technical configurations (Kemp et al., 2001; Hoogma et al., 2002). According to SNM, niches provide spaces of protection for radical innovations (Smith and Raven, 2012). In the building sector, concepts such as passive houses and smart homes (Figure 1) can be regarded as radical innovations that develop in niches and have not diffused yet to mainstream building regimes. Processes of articulating expectations, creation of new networks and sharing learning have been identified as key for successful niche development (Hoogma et al., 2002; Schot and Geels, 2008). These processes facilitate the emergence and diffusion of innovations, making them more likely to embed into and gradually change the dominating regime (Smith and Raven, 2012).

The landscape level is the hardest to influence, existing largely beyond regime and niche influence (e.g. Geels and Schot, 2007) and includes the broader context in which a socio-technical system, such as the building sector, is situated in. It is formed of macro-economic, macro-political and cultural forces, patterns and development trends, such as climate change and the financial crisis (Figure 1) creating pressure for changing socio-technical regimes and opening for new innovation niches. The concepts in Figure 1 were used to guide the systematic case review.

2.2 Innovation intermediaries in transitions

In innovation studies, intermediaries are perceived as crucial actors facilitating innovation processes (Howells, 2006; Boon et al., 2011). An innovation intermediary has been defined as "[a]n organization or body that acts as an agent or broker in any aspect of the innovation process between two or more parties" (Howells, 2006). The transitions literature recognises that actors and agency are important (e.g. Meadowcroft, 2011). Yet intermediary actors have received little attention, although van Lente et al. (2003) argued over a decade ago that 'systemic intermediaries' are important for long-term and complex changes, including transitions to sustainability. A few previous studies have shown that intermediary actors can facilitate the SNM processes in a variety of ways (Hargreaves et al., 2013; Kivimaa, 2014).

Much of the previous literature on innovation intermediaries focuses on arbitration between the developers of innovations and their users (e.g. Howells, 2006; Stewart and Hyysalo, 2008). Individual studies of a range of actors that could be considered as intermediaries have been published, including consultants (Bessant and Rush, 1995) and university technology transfer agencies (Macho-Stadler et al., 2007). In addition, innovation centres, science parks and innovation financing agencies have been listed as potential intermediaries in innovation processes (e.g. Howells, 2006; Polzin et al., 2015). The previous literature on innovation intermediaries focuses also on intermediation in the emergence and first adoption – rather than diffusion – of innovations. Often the range or intermediaries addressed have narrowly focused on direct innovation oriented actors and not all actors with potential effects on innovation. Alternative types of innovation intermediaries, such as internet market places or energy service companies have been less explored.

A variety of actors operate in the building sector that could act as potential "low energy" innovation intermediaries. In previous literature, for example, architects (Fischer and Guy, 2009; Davies and Osmani, 2011), building managers (Grandclement et al., 2015) and regulators (Holm et al., 2011) have been identified to play potential intermediary roles, while their influence in low energy transition is by no means certain. For example, Davies and Osmani (2011, p. 1692) have found that there are no legislative drivers to motivate architects to "*positively engage in low carbon housing refurbishment design*" and at present architecture companies do not generally take this on as a dominant activity. In other countries, organisations such as foundations (Kivimaa, 2014) and innovation platforms (Mlecnik, 2013) have been identified to intermediate successfully in advancing low energy housing innovation. In addition, Parag and Janda (2014) have examined religious congregations, building professionals, and commercial building communities from the perspective of intermediation in low energy innovation.

3. Research approach and method

The research approach taken in the paper was a systematic review (Petticrew and Roberts, 2006) of case studies using Scopus, in a qualitative manner. Following Gerring (2004), we understood a case to mean an empirical study describing a process of low energy building innovation, involving measures such as residential housing refurbishments and zero carbon new build homes.

We first limited the year of publication search to 2007-2015, a year after the introduction of Directive 2006/32/EC on energy end-use efficiency and energy services (later repealed by the Directive 2012/27/EU on energy efficiency). The search was limited to peer-reviewed journal articles for ease of access and replicability. The contents of the abstracts of 93 hits were analysed using the following inclusion and exclusion criteria: (1) articles outside the discipline of social sciences and humanities were excluded; (2) to have a connection to innovation studies, the article had to contain the word 'innovation' somewhere in the article title, abstract or keywords; (3) to have a common geographical (and political) frame of reference articles outside the EU were excluded from the analysis; (4) to be included in the review, the article had to contain an empirical case study describing a process of low energy building innovation. The case study review, thus, only included so-called 'uncontrolled' real life case studies. A caveat of such case study review is that "[u]ncontrolled studies are more susceptible to bias than studies with control groups, so their results should be treated with caution" (Petticrew and Roberts, 2006: 65-66).

"Innovation" was used as a search word in all the 40 search term combinations due to our explicit focus on innovation case studies, and innovation being a very widely diffused word. Each abstract appearing in the Scopus searches was read through to see whether the content really related to what we were searching for. As the initial review only resulted in 18 peer-reviewed journal articles, we extended the review to hand searching the bibliographies of the initially identified 18 sources (cf. Petticrew and Roberts, 2006). In addition, we extended the review of journal articles to a ten year range from 2005 – 2015. Due to our focus on 'current status', we viewed a review of the past 10 years more than sufficient. The purpose of the systematic case study review was to examine events anticipating and subsequent to the EU policy on energy end-use efficiency and energy services. Hand searching the bibliographies of the 18 articles and analysing the contents of those articles that had the theme 'buildings' or 'homes' in the title and matching the above inclusion/exclusion criteria resulted in 2 further relevant articles and 2 cases for the review. Despite extending our search, we, thus, ended up only with 20 peer reviewed journal articles that we subjected to systematic content analysis. Seven articles were subsequently excluded as the more detailed analysis revealed the non-existence of case studies. The 13 articles included in the review contained a total of 25 case studies; five cases described in more than one source article.

Two researchers coded each article first separately following a joint excel categorisation building generic innovation study categorisations of innovation, literature on intermediation and the MLP.

4. Findings

4.1 Overview of the innovation cases

Although in practice multiple demonstration projects and pilots around low energy new builds and retrofits have been carried out all over Europe, our review finds that very few have been subjected to academic scrutiny and in-depth qualitative analysis from an innovation studies angle. This is besides the wealth of research on the technical qualities, economics, architectural design, domestication, and the policy and politics of low energy buildings. What is also surprising is that what can be classified as qualitative case studies of low energy building innovations or projects promoting them, were found to concentrate only in five EU member states (Belgium, Denmark, Finland, Slovenia, UK). Our attempts to identify scholarly papers addressing these innovations in what can be regarded as front runner countries, such as Austria or Sweden, were unsuccessful.

The cases were predominantly focused on new build, as only three of the 25 cases related to the existing building stock. The nature of innovation in the cases was varied, including piloting sites for ecological living (n=4), architectural innovation resulting in new buildings combining a range of energy efficiency and renewable energy measures (n=7), large scale energy efficient housing development or refurbishment involving systemic and architectural innovation (n=4), innovative processes showcasing and promoting the commercial application of new low energy housing concepts (n=6), creating a new low energy house business model (n=2), adopting modular innovation by mainstream building companies (n=1), and conducting a renovation project towards a passive house standard (n=1).

In all but one case, a variety of different motivations and drivers were evident, and several cases had more than one key driver. The key drivers can be broadly divided to the following eight categories (in the order of importance):

- *Environmental drivers* (e.g. green values, environmental concerns, climate change)
- *Eco-social drivers* (e.g. eco-social movements, communal living, alternative lifestyles)
- *Policy drivers* (e.g. local, government and EU policy, Local Agenda 21 movement)
- *Financial drivers* (e.g. 1970s oil crisis, high energy bills and desire to reduce them)
- *Knowledge drivers* (e.g. a lack of know-how, influence of previous research programmes)
- *Market drivers* (e.g. existing or expected market demand)
- *Health & comfort drivers* (e.g. living in healthy homes)
- *Design drivers* (e.g. aesthetics, desired space)

Environmental drivers were evident in the majority of the cases (n=21), including cases initiated by individuals who had strong green values and were motivated by environmental concerns and climate change or aiming to pioneer in low carbon buildings. Interestingly, quite a few cases originated back to eco-oriented societal movements and sustainable housing activists in the 1970s, and a total of 20 cases had what we classified as *eco-social drivers*. These also included drivers such as the desire to enable alternative lifestyles, create communal living, follow the principles of sustainable development and provide fair housing.

In 13 out of 25 cases, *policy* was one of the drivers in the form of influence from international, national and local policy measures. The articles mentioned the Kyoto Protocol, EU level decisions, national policy agendas and Local Agenda 21 as policies driving innovation. Moreover, Quitzau et al. (2012) mentioned a gap between policy intention and policy implementation as a key driver for one project. If policy actors are included in the analysis, eighty percent of the cases had some favourable support from public authorities or policy. In 13 out of 25 cases, local authorities had a significant influence either through supportive individuals within the local authority (n=5); municipal housing fund acting as the key actor (n=6), municipal eco- and energy requirements for new buildings within district area planning (n=1) and land sold to a non-highest but energy efficiency oriented bidder by the local council (n=1) – in only one of these cases a specific policy instrument acted as a driver. Equally in 13 out of 25 cases, national policy was influential, only six cases (all based in Ljubljana, Slovenia) combining local and national influence. In majority of cases a mix of policies played a role ranging from RD&D and deployment subsidies through innovative competitions to building codes and planning regulations. Building regulations have clearly been important (n=11), while equally over a half of the cases have been initiated without the guiding influence of building regulations. Policy changes *during* the innovation processes have also influenced, for example, energy efficiency subsidies running out during a budget year delaying one project with a year, or a project initially beginning without policy influence having to alter its optimal design type due to the introduction of new building requirements (Pässilä et al., 2015)

In 12 out of 25 cases one of the initiating factors was *financial*, largely driven by high energy bills and the desire to reduce energy costs. For example, in six cases, there was a clear motive to provide lower energy bills for social housing tenants to ensure that they were able to pay their rents and hence secure income for the social housing landlord (Broto, 2012). In four cases, *knowledge drivers* were identified, including cases where existing knowledge played a key role (e.g. a planning team with high capacity and previous research programmes' findings on energy efficient buildings) and cases that were driven by lack of knowledge (e.g. lack of know-how of energy efficient building and lack of innovativeness in the housing industry). *Health & comfort drivers* were evident in two cases: one architect-owner aspired to create a healthy home as his child had asthma (Mlecnik, 2010), while in another case one of the key motives was to create not only energy efficient houses but also healthy living environments (Jensen and Gram-Hanssen, 2008). Similarly *market drivers* were identified in two cases, one experiencing (niche) market demand for passive houses and in another the company aimed to be a frontrunner expecting future market demand (Mlecnik, 2010; Pässilä et al., 2015). Finally, *design* features were evident as a driver in two cases, including the desire to have not only sustainable but also aesthetically pleasing housing in one case, and the desire to create a better space for living in another (Mlecnik, 2010; Pässilä et al., 2015). The analysis shows that while there was a range of drivers identified for the cases, environmental, eco-social, policy and financial drivers featured most often, while knowledge, market, health & comfort and design were less evident.

4.2 Roles, functions & activities of intermediaries

Intermediary actors were explicitly mentioned in relation to four case studies, while our analysis identified that intermediary actors were in effect involved in 14 out of 25 cases. This does not necessarily mean that there were no such actors involved in the other cases, as findings only reflect the style in which the cases were written. Particularly the eco-village developments appear rather independent with little influence from intermediary actors (Smith, 2007; Lovell, 2008; Holm et al., 2011). Intermediary actors represent 10 different organisations, five operating locally and five nationally. Five types are represented: local authority agents, business network organisations (trade bodies), independent groups/foundations, a public housing fund, and a government energy efficiency agency.

In nearly half of the cases local authorities seem to be key players in the low energy housing innovation processes, including local authority's energy manager (Lovell, 2008), municipal planners (Quitzau et al., 2012) and a public housing fund (Broto, 2012). When local authority agents have acted as intermediaries, they have (1) *facilitated concrete building projects* by connecting actors (networking), speeding up planning and permitting processes (learning) while also aiming to influence local politicians (articulating expectations) (e.g. Lovell, 2007); (2) *aimed to create niche markets* for new low energy housing innovations through developing planning policies and building requirements in exemplary districts (articulating expectations), searching for new technological and policy designs suited to these districts (learning) and bringing together entrepreneurs and constructing companies (networking) to showcase these innovations (articulating expectations) (e.g. Holm et al., 2011; Quitzau, 2012); and (3) *implemented new practices in publically owned building stock by showcasing developments* based on a vision of a pioneer low carbon city (articulating expectations), bringing together land, knowledge and financial resources and creating new partnerships to realise these developments (networking), and learning from the practices and adoption of new technologies by tenants (learning) (Broto, 2012).

Interestingly in other contexts, other (intermediary) actors have taken similar roles to those described above. For example, an independent Local Agenda 21 group facilitated a similar market creation process in Herfølge, Denmark, as the local authority had taken in Stenlose Syd, Denmark (Holm et al., 2011). Other actors, such as a government-owned energy-efficiency company or a foundation, have supported processes to create new business models for low energy housing by organising competitions for new housing designs (articulating visions), connecting actors such as architects, house buildings and buyers (networking), and managing these processes including information dissemination, knowledge building and adjusting goals (learning) (Heiskanen and Lovio, 2010; Pässilä et al., 2015). These kinds of actors are important in as that they can reach a geographically wider scope and are less dependent on (local) values, politics and interests. In only two cases business network organisations were described to take intermediary roles (Pan and Cooper, 2011; Mlecnik, 2013). In Belgium, a passive house platform performed a range of activities, including articulating opportunities for companies and demonstrating passive house designs (articulating expectations), providing opportunities for partnering, aiding in finding and applying for resources, brokering negotiations with project partners (networking) and organising visits and workshops (learning) (Mlecnik, 2013).

5. Conclusions

Our systemic review of case studies on low energy housing innovations demonstrates that scholarly research on this topic is limited. Particularly innovation studies on low energy in the context of existing building stock barely exist with the exception of two articles. This, thus, demonstrates a need to qualitatively explore the processes, drivers and barriers to innovations, and intermediary actors, in whole house retrofits. The review shows that a local authority or national policy were supportive elements in over a half of the cases. National policy particularly influences through building regulations but also RD&D subsidies. Building regulations have been important, especially as they have usually been repeatedly tightened, sometimes altering project goals, if changing during the innovation process. This indicates that not only the existence of supportive policies but their dynamics with innovation is crucial, calling for further research. Besides policy, generically environmental concerns and eco-social values have been key drivers for these developments. In addition, financial drivers, including increasing energy prices and the opportunity to cut bills, have played a major role. Knowledge, market, health and comfort, and design drivers were surprisingly rare as drivers in the studied innovation processes. This may indicate that a lack of a more holistic picture, i.e. system or architectural innovation, can be the outcome when drivers are such that limit focus to a particular aspect of the environment – such as energy – or immediate financial savings. Improved focus on the synergies between energy efficiency, health, comfort and design could lead to more systemic innovation in the sector.

Equally to public policy influence, intermediary actors were present in over half of the cases. In most cases a local authority agent (1) facilitated a construction process, (2) aimed to create a market for new technological solutions, or (3) implemented new technological designs through social housing stock. Only in a few cases other types of intermediaries, such as independent organisations, independent foundations or network platforms of businesses were shown to play a role. This calls for more specific studies focusing on the range of intermediary actors that take part in different phases of the innovation process. This includes also the identification of crucial intermediary functions in both supporting the emergence of innovation niches and the expansion or empowering of those niches within/to the socio-technical building regime.

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A smart future housing in Egypt for all-
a challenge or an opportunity?

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Abstract

Egypt's population has recently reached 90 Million inhabitants. A figure that is expected to double in the coming 20-30 years. With around 60% of the population less than 30 years old and the anticipation of demographic change; Egypt should be prepared to accommodate the various needs. Nevertheless, the current built environment in Egypt does not seem to accommodate people's current socio-economic needs; and no plans are evident that the anticipated demographic change is taken into consideration.

This paper is part of an ongoing research project[1] to investigate current built environment challenges and opportunities in Egypt, with particular emphasis on housing. Literature review, supported by an exploratory case study, was adopted to define current challenges and potentials, in an attempt to define ingredients needed for a smart future housing for all. An informal area was selected for the case study to demonstrate the functional interventions by individuals to fulfil their day-to-day needs.

For 60 years now, public housing in Egypt has always adopted a top-down approach. However, housing supply by the Government and private sector combined, to date, is failing to meet market housing demand. The consequences of which are illegal informal developments and/or illegal transformation of the original 'formal' developments. This would not only burden the infra-structure and consequently affect people's physical health, but may also elevate psychological distress and aggression. Nevertheless, despite the negative impacts, informal developments' interventions seem to, unintentionally, bear basic principles of universal design such as multi-use of residential spaces and mixed-use buildings. Hence, could be considered 'smart'. A building does not necessarily require sophisticated technologies to be 'smart' as long as it adapts to people's current and future needs. Therefore, there is an opportunity to achieve smart housing for all, if current informal interventions could be capitalised on and deployed properly and legitimately in housing projects.

Keywords: Adaptability, demographic change, Egypt, smart housing, universal design,

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1. Background

In light of the rapid change and transformation of social, political, economic aspects, in addition to the technological advancement; urban planning approaches and techniques should cope with and govern the unprecedented pace of change in the Egyptian society. Hence, the call for smart urban planning (reinventing planning, 2006) to prevent chaotic developments to take over formal planning.

Egypt population density is reported to be 1,066 per km^2; whereas in Cairo, the capital, the density exceeds 46,000 per km^2. With the increased number of population in Egypt, currently more than 90 Million, the Government is being challenged to alleviate a complex problem that has never been resolved since the 1950s; namely the provision of housing that is affordable, and yet adapts to people's various needs.

While there is no official figure confirming the number of housing units needed annually, it is argued that at least 300,000 units are needed (Real Estate, 2012). In comparison to the UK, housing market demand is estimated around 232,000 – 300,000 units/year (Gorgolewski, 2003; Barlow et al., 2002; Parliament, 2015). However, considering cultural, social, and demographic variations among Egypt and the UK; the estimated annual need of 300,000 units in Egypt do not seem to be a relevant figure. Even if this anticipated figure was true, Egypt is far from being able to meet this market demand. According to CAPMAS (2015) housing units achieved in the year 2013/14, by both public and private sectors, account for around 146,000 units in comparison to 136,000 units back in 2012/13 which is less than half of the estimated need. The distribution of the supplied units includes 55% economic housing; whereas low cost housing was only 3.2%. Nevertheless, the definition of low cost and economic housing is not clear in the CAPMAS report.

In Greater Cairo, according to Colliers (2015), an average of 90,000 – 100,000 units are required annually to meet the demand generated by new households. Though, it was recorded that only 45,000 units enter the market every year, i.e. only half of what is required could barely be met. Thus, suggesting the already existing gap to amount to 6 Million households and the annual demand to rise to 500,000 units by 2020 (Figure 1).

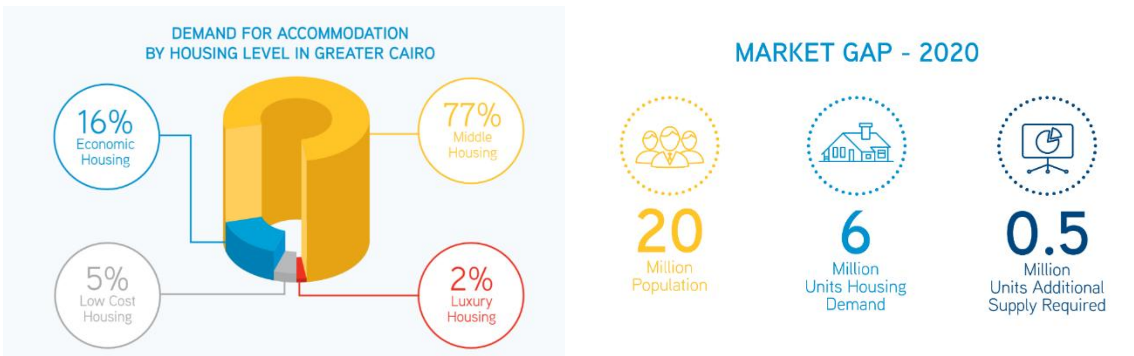

Figure 1: Demand for accommodation by housing level in greater Cairo (Colliers, 2015)

The persistent inability of successive Governments to meet housing demand may have arguably resulted in the unprecedented pace of informal developments continuously taking place.

2. Housing challenges in Egypt

The main focus of extant literature over the past decades was, to a large extent, mainly concerned with the affordability of units and financial capabilities of households (which undoubtedly is very important). There is, however, no clear evidence on investigating the reciprocal effect of the built environment, in general and informal developments in particular, with regards to not only the physical but also the psychological health of Egyptians, the anticipated demographic change, and impaired mobility.

2.1 Chaotic development and impact on health

Due to the inability of successive Governments to meet housing demand and further provide affordable and adaptable housing; individual chaotic interventions has taken over planned development throughout the past 60 years to date. Chaos is manifested in residential buildings being built illegally and informally in any space available with no attention to regulation, to building codes, nor to health and safety measures. The illegal construction is arguably spreading at a pace unprecedented in the past five years (Nadim et al., 2014). The ramification of this blatant infringement of public spaces, the crowdness, and poor environmental conditions in housing projects are serious implications not only on the physical but also on the mental health of individuals. No empirical studies could be identified within the Egyptian context; however, several international literatures investigated the association of built environments with mental health (Evans, 2003; Guite et al., 2006). According to Evans (2003) for example, the number of people per room, and noise may elevate psychological distress, hypertension, high blood pressure, heart disease, hearing impairment, stress levels, reduced ability on concentration, and disturbed sleep (Stansfeld and Matheson, 2003). Furthermore, malodorous air pollutants intensify negative impact; and some toxins (e.g. lead and solvents) may cause behavioural disorders such as self-regulatory ability and aggression (Stansfeld and Matheson, 2003; Evans, 2003). Notwithstanding these issues, Evans (2003) argues that insufficient daylight is strongly associated with increased depressive symptoms. This is further supported by Guite et al. (2006) who confirmed the association between the physical environment and mental well-being attributing the important negative impacts to noise, sense of over-crowding at home and in open spaces, in addition to fear of crime.

2.2 Demographic change and impaired mobility

The population growth rate in Egypt has been decreasing since the period 1980-1985, where it stood at 2.28 per cent. Then it reached 1.56 per cent in the period 1995-2000 and slightly increased afterwards to 1.68 per cent in the period 2005-2010. Currently, the growth rate is being reported at around 2%. However, this is expected to decline to reach 1.4% in the period 2020-2025 and reaches 1.1% in 2045-2050 (UN, 2015). Furthermore, the proportion of the elderly population (65+) has been increasing and was estimated to be 5.9% in 2015 and anticipated to double to reach 12.3% by 2050 suggesting a demographic change (Figure 2). However, according to CPAMAS (2015), the percentage in 2015 has already reached 6.9% (6 Million people equally distributed among both genders), i.e. is 1% more than estimated. In the same context, UNFPA (2015) demographic report concluded that Egypt should get prepared to deal with an aging population and the consequent increase in the dependency ratio.

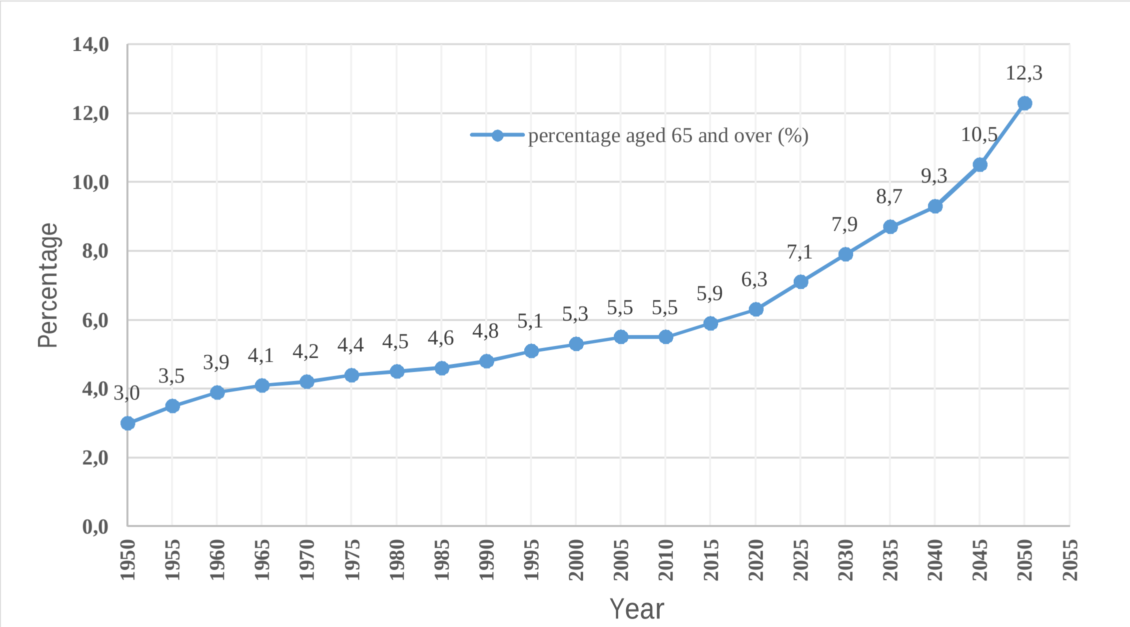

Figure 2: Trend of Egypt's Elderly Population, 1950-2050 (UN, 2015)

In addition to the increased number of elderly (CAPMAS,2015), another 7% of the population - amounting to around 6 million - have some sort of impairment CAPMAS (2006). Thus, there is a considerable percentage of Egyptians who are not taken into consideration when planning and designing the built environment. These, currently, underprivileged segments of the society, are not the only ones suffering, but their families and friends as well; a figure that could easily impact 20 Million people who may have relatives or friends not being able to move around freely, neither indoors or outdoors.

The Egyptian built environment in general arguably needs houses, neighbourhoods, and whole communities to accommodate all abilities across the lifespan. This requires better planning and arrangement of uses, streets, paths, public spaces, and transportation systems (Nasar and Evans-Cowley, 2007). The impairment law in Egypt (chapter five, clause 27 and 28) requires that all new builds and open spaces, in addition to the existing environment, to be adjusted to be friendly to people with all different impairments. Furthermore, 5% of the subsidised housing is set to be made available for those with different abilities. Nevertheless, no real evidence on ground could be recorded with regards to adjusting current and/or new build.

While in Egypt there is no evidence of any proactive measures to deal with the aging population, the developed world is being very active in this respect. In the UK, for example, and as a response to the demographic change, a policy goal has been put to meet the housing needs of an ageing society. In this context, the UK regards population aging as an opportunity rather than a threat as it is anticipated to boost the social, civic, and economic capital of the community (ILC, 2008). Furthermore, the US consider the future design, structure, and function of their housing, neighbourhoods, and communities as a central issue to an aging population. The strategy is therefore to develop healthy communities that would engage everyone and foster intergenerational experiences (Cisneros et al., 2012). One of the innovations suggested for older people who wish to continue working in a small, self-employed setting is the live-work concept (Kallash and Kruse, 2012); where the dwelling would include a workspace. Suggesting that mixed uses create settings were older people can comfortably pursue careers (Cisneros et al., 2012).

According to the World Health Organisation (WHO) an age friendly city is ‘friendly for all ages’ and not just 'elderly-friendly'. It should be clean, have well-maintained (green) spaces with adequate toilet facilities, pedestrian-friendly walkways, outdoor seating, smooth well-maintained pavements, sufficient pedestrian crossings and street lighting, etc. (Smedley, 2015). It is argued that making homes and the environment safe for the elderly would arguable make them safer for the younger people as well (Cisneros et al., 2012).

3. Universal design and smart buildings

Universal design is a concept aimed to make daily functioning easy for the general population. The key principles to universal design can be categorised under equitable use, flexibility in use, simple and intuitive products, tolerance of error, low physical effort, and size and space (Cisneros, 2012). These may be further interpreted to address accessibility, visibility, functionality, and movement in a space (Figure 3). Another important term associated with ‘universal design’ is ‘visitability’; a movement, that investigates components and minimum features and standards to make buildings accessible to people with mobility impairment (Cisneros, 2012) such as:

- open floor plans, i.e. minimising subdivisions,
- reducing number of hallways,
- making rooms more open to accommodate a variety of abilities.
- a front door to accommodate a wheelchair
- a sink with a knee space for independent use of the kitchen
- plenty of under cabinet and task lighting,
- accessible lighting outlets, and electrical switches
- front-loading washing machines
- bathroom accessible shower design

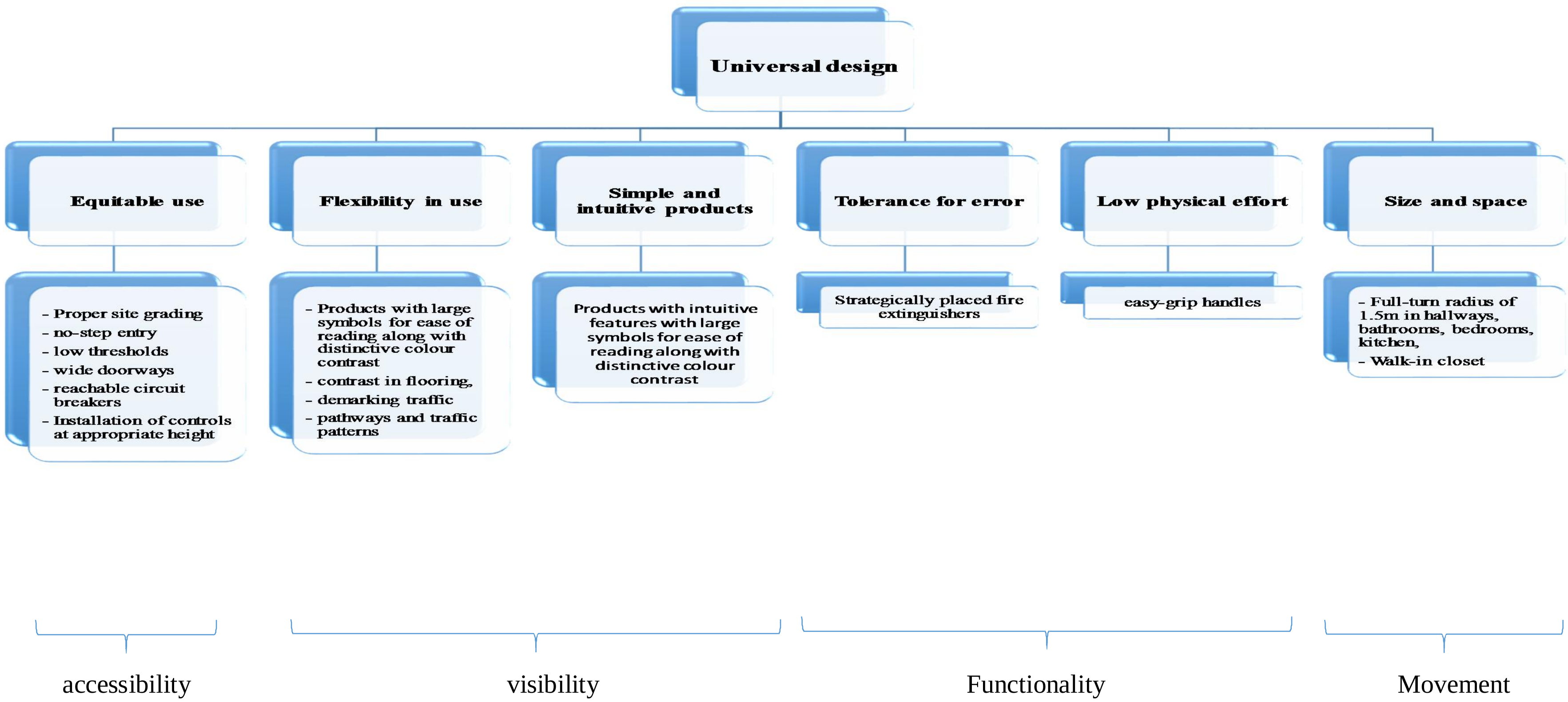

Figure 3: Universal Design principles (adapted from Cisneros, 2012)

4. Informal housing in Egypt – The exploratory case study

This exploratory study investigates an informal area in Greater Cairo in order to define major dwelling and the immediate surroundings concerns, and the respective interventions to accommodate basic needs. The reason for selecting an informal area, is that informal areas represent two thirds of Greater Cairo's built environment; hence, may be considered a representative exemplar for pure functional solutions to people's everyday needs. The investigation took a form of semi-structured meetings, to define, in depth, people's perceptions with regards to the area they live in, in general, with particular emphasis on their dwellings and the immediate surroundings. The aim was to have various age groups and different physical abilities. An announcement of the meetings was made through an active NGO in the area, and the participants are those who voluntarily joined the meetings. In total, four groups were represented, the elderly (6, three with severe joint problems), youth (4), university students (4), and contractors (2). The meetings aimed to conclude dwelling spatial organisation (plan) and the various associated functions, the vertical circulation (entrances, stairs, and roofs), and any informal transformation that took place on ground floors.

The informal area, under investigation, encompasses both residential blocks built by the Government back in the 1970's and informal buildings that are being built to date. It is an old area and was originally an agricultural land with a few houses; which along the years, gradually became an informal urban settlement with multi-storey buildings, and the agricultural area eventually disappeared (GIZ, 2013). The Family average size is six including both parents; where women largely work in various jobs to contribute to family income (GIZ, 2013). A study published by an NGO in the area, while not confirming the number of people with impaired mobility in the area, concluded that 72% of people with some kind of impairment are illiterate, and only 6% managed to get higher education. Unemployment rate, furthermore, reached 87% arguing that current local work market is 'repelling' 1/3 of the people with some kind of impairment (Abdelbaki, 2015).

The Government built blocks' areas range between 60-70m^2 including two to three rooms, constituting of a ground floor and four typical floors. Informal buildings, however, provide a bigger range of areas in order to accommodate the different financial abilities. There are those that may exceed 100 m^2 and those even smaller than 40m^2. Some of these informal buildings may have 12 typical floors. As a result of the relatively small unit areas and the large number of family members; spaces are used for multi-functions particularly the reception/entrance, children bedrooms, and even the corridors/halls (Figure 4).

4.1 The residential unit

Egyptian families are generally conservative, therefore a complete separation between family private spaces and spaces to receive guests has to be achieved in the unit. In some cases, areas to receive guests are never used by family members to keep them in good condition. There is no clear pattern between the different participants with regards to the multi-use of spaces. In some cases, the entrance may be used for eating, receiving guests, watching TV, and even studying. The hall/corridor may house the washing machine, storage spaces, and the fridge. Furthermore, the children bedroom may be used as a family living space and a reception for close relatives. The kitchen and toilets are relatively small to accommodate any other activities. There was a case where cooking could take place in the main bedroom; however, in most cases main bedrooms are not used for any other functions. In general, the type of functions used depends on the size of the individual rooms as well as the overall dwelling area, i.e. depends on the financial capabilities of households.

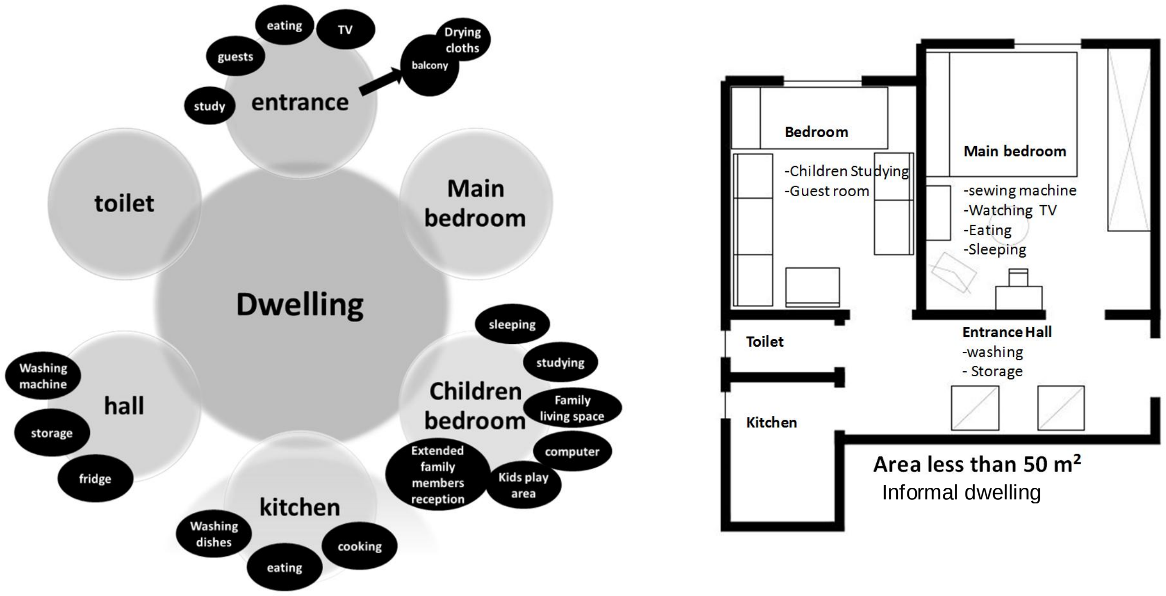

Figure 4: Dwelling spaces various multi-uses to accommodate every day needs in small areas

4.2 Mixed-use transformation/ developments

Another prominent feature in informal developments, is the transformation of primarily ground floors in Government built buildings into other non-residential activities, whether these are commercial, industrial, or even raising livestock. The informal buildings on the other hand, include a four-meter-high ground floor reserved for non-residential activities from the outset. This, while is intended for generating income and employment, is perhaps more importantly intended for raising the first residential unit at least four meters above the street level for not to be accessible from the street level for security reasons. In addition, the building entrance is raised one meter above street level, to ensure that when Government pave streets, the entrance would not 'sink' below street level. This is intended to protect the building entrance from sewage overflow that is common in the area. Nevertheless, the increasing number of steps at the entrance, puts further burden on the elderly, and those with impaired mobility; especially that the riser could be as high as 50cm. The roofs in general, are used for ditching scraps, and in very limited cases are used for raising chicken or sheep, or planting vegetables.

These non-residential activities (largely on ground floors), while generating income to owners and create jobs; they nevertheless, burden the infra-structure such as water, sewer, and congest streets etc. In addition, the different activities may result in bad odour due to the different industrial and/or organic waste. Nevertheless, the majority of participants did not mind non-residential activities on the ground floor, as long as it did not harm the residents wellbeing and comfort, and did not cause higher rental fees for residents.

5. Discussion

Egypt has always been challenged by the provision of affordable housing; while seeming to overlook, or neglect the provision of adaptable housing that would respond to various socio-economic needs for the past 60 years. In addition, it is not evident that plans are set to accommodate anticipated demographic change and the increased dependency ratio.

While housing provided by the Government promote complete functional separation of uses; informal interventions are largely based on mixing residential and non-residential functions. Despite the negative impact on infra-structure and people’s physical and mental wellbeing (section 2.1), benefits could also be recorded. Mixed-uses may have the benefits of enabling people with a range of incomes and backgrounds to reside side by side; and thus, help foster greater social equity and integration (Friedman, 2012). In addition, building homes for seniors along with dwellings for young households may further attract extended families and create a mutual support system. Notwithstanding this, design approaches adapting to changing demographics and lifestyles arguably include live-work dwellings, support aging in place, and multigenerational, small size, and adaptable housing (Friedman, 2012).

In light of the above, an important question should be raised, namely: are smart buildings exclusive to developed countries; or could buildings still be ‘smart’ with less or no sophisticated technology? Before attempting to answer this question two terms are investigated, namely ‘smart building’ and ‘technology’.

Smart building, is usually referring to a building being intelligent i.e. it encompasses various technologies, such as data network, voice network, power management, video surveillance, fire alarm, HVAC control, lighting control, access control etc. with the different systems having the capability to communicate for a much efficient use of the building (Sinopoli, 2006). Other interpretation of smart building may encompass (although still associated with the integrated systems) responsive and adaptive envelopes and material that respond to the internal and external environment, green roofs, inclusion of Photo Voltaic, etc. It is, however, important to investigate the extent to which homes could be smart, without the inclusion of sophisticated technologies (Friedman, 2012). This is of particular importance to developing countries.

‘Smart’, as an adjective, is usually associated with either intelligent people or a technology that is intelligent i.e. responds to the end users’ needs and make their experience as efficient as possible. The term ‘technology’ may refer to a new product and/or a process (Laborde and Sanvido, 1994). In this context, it can be argued that a ‘design’ may refer to a product (if it is noun) or to a process (if it is a verb); and in both cases a ‘design’ is associated with a new ‘creation’. Therefore, a design may be considered a ‘technology’ that could be ‘smart’, as long as it is able to respond and adapt to current as well as to future dwellers’ needs. Since, universal design principles aim at a design that could be easily adapted to current as well as to future needs, accommodating all ages and mobility; it could result in ‘smart’ buildings. Thus, it could be concluded that ‘smart’ buildings could be achieved by simply achieving a universal design; and not necessarily to encompass sophisticated technologies.

6. Conclusion

Egypt is currently facing huge housing challenges to solve a problem that successive Government failed to solve for the past 60 years. Currently, with more than 90 Million inhabitants, and around 300,000 housing units needed annually, the anticipated 6 Million gap in housing provision by 2020, and the expected demographic change; the housing problem seem to exacerbate due to the multi-variate complexity. The inability to provide affordable and adaptable housing, has led to individual chaotic developments that do not pay attention to or abide by building codes and regulations. This may lead to physical as well as mental/psychological implications.

This paper investigated the housing challenge in Egypt, and the implication of informal developments on people's health and well-being. The paper acknowledges the importance of informal developments to satisfy socio-economic needs; but also highlighted the negative impacts of such informal chaotic development. However, it was concluded, that despite the negative implications of informal developments, they imply some sort of 'smartness', particularly that these depend on the provision of mixed-uses, include extended families, are small in size, and allow adaptability of spaces.

In conclusion, there is an opportunity to provide a smart future housing in Egypt by mitigating negative challenges of informal developments and capitalise on the positive. The result of this paper will feed into the second phase of the research to provide scenarios for future housing that takes into account the socio-economic, demographic change, as well as technological advancements.

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Regional Energy Model -Based Approach to Identify New Business Opportunities While Increasing Energy Efficiency

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Abstract

The importance of reduction of energy use in tackling climate change is widely recognized. The greenhouse gas (GHG) emissions of energy production are high, while the biggest share of energy consumption belongs to the built environment and industry. Various regulations and treaties create pressure for reducing GHG emissions on both regional and national level.

The energy sector provides significant potential for tackling climate change. However, achieving the goals will require changing the traditional energy systems of the society. Here, introduction of renewable energy sources, as well as increasing the efficiency of energy production, transmission and consumption, are needed. Major changes in regional energy systems are most likely to occur in the near future, an important one being the increasing of self-production of energy, where actors traditionally considered as consumers of energy will become also producers. The upcoming changes will create challenges for decision-making related to the development of energy systems, as traditional approaches will become insufficient to operate under the new conditions. The changed patterns of regional energy systems also create new business opportunities, and the recognition of them is important to integrate into the decision-making processes in order to support sustainable development of the energy system in the region.

This study proposes a regional energy model -based approach to identify new business opportunities in changing conditions and to support sustainable development of the energy system. The framework of the approach requires modelling the current state of the energy system of particular region. This includes identification of the different actors within the energy system and the energy flows between them. Such an approach makes it possible to compare different future development scenarios and evaluate them in terms of environmental, economic and other targets. The approach can help the different actors within the energy system (energy production, industry, buildings, services, etc.) to develop their operations by providing them with holistic information on the current state of the energy system, possible development paths, future energy demands, realization of sustainability targets, as well as emerging new business opportunities.

Keywords: Energy efficiency, Regional model, Business opportunities, Decision-making

1. Introduction

The role of energy use in tackling climate change is widely recognized as extremely important due to the high greenhouse gas (GHG) emissions of energy production. The energy consumption of the built environment and industry is high. These sectors are responsible for 96% of energy end-use and 86% of GHG emissions in Finland (Sitra 2010). Emerging regulations and treaties create pressures for reducing GHG emissions on both regional and national level by posing emission reduction, energy efficiency and other targets. Economic issues are often the major challenge in achieving the required GHG reductions.

The energy sector provides great potential for tackling climate change. However, achieving the targets requires changing the traditional energy systems of the society. During the urbanization and industrialization period, energy production solutions concentrated on large centralized fossil fuel based production units. The increased pressure to achieve a low-carbon society and energy self-sufficiency requires transition from fossil fuels towards local renewable energy sources (Motiva, 2010). Also increase of energy efficiency in the processes of energy production, transition and consumption, is required (Saidur, 2010; Abdelaziz et al., 2011; IEA, 2012). One important change will come due to increase of the decentralized self-production of energy. This change is in Finland driven by such factors as fast technological development and new building codes, which support the utilization of locally produced renewables (Ministry of Justice, Finland, 2011). This means that traditional energy consumers such as households or private companies, can become producers (Nielsen & Moller, 2012; Li, et al., 2013). Such a change can result in a decrease of the demand for centrally produced energy (Persson & Werner 2011). The changing energy system will create challenges for future energy planning, as traditional approaches will become insufficient. However new business opportunities would also emerge, and it is important to integrate the recognition of these into the decision-making in order to support sustainable development of the energy system of the region (Viholainen, et al., 2016). Therefore, the creation of simple methodologies to provide information on sustainability of the current state and optional development scenarios of the regional energy system is required.

This paper presents an approach for including sustainability aspects systematically in the decision-making process related to the development of a regional energy system while paying attention to the local conditions of the region in question. The approach is based on the recognition of individual functional characteristics of the energy system of the region and identification of the mechanisms affecting the realization of regional sustainability targets. This includes charting the regional energy system by identification of the actors (centralized producers, transition network operators, consumers and prosumers), as well as the roles and interests of the actors, the pattern of energy flows within the system, and the mechanisms affecting the energy-related decision-making of the actors. Finnish conditions are used as an example.

2. Methodology

The municipality is the only permanent operator within the regional energy system, and it plays the role of the upholder in the region. The primary responsibility of the development of the regional energy system, as well as the realization of international and national sustainability targets lies on the municipal administration. International and national sustainability targets create pressure for the municipal administration in the form of legislative norms and binding targets. In order to achieve the sustainability targets in the most efficient way, municipal decision-making should incorporate a comprehensive analysis of local region-specific conditions, including economic, environmental and social aspects. Knowing the potential and challenges of sustainability within the region helps the municipality to establish a local sustainability policy and targets that would drive the development of the energy system while supporting the realization of international and national targets. Establishing an adequate local sustainability policy and targets forms a solid base for sustainable development of the regional energy system.

The municipal administration controls the development of the energy system towards the chosen sustainability targets by applying various policy instruments, which can be regulatory, economic or some other instruments. To understand which policy instrument would be the most efficient one to achieve the sustainability targets, the impact of various regulatory actions on the energy system and the targets should be evaluated thoroughly and transparently (see Figure 1). Here we can consider the municipal administration as a supervisor of the process (development of the regional energy system) sending control inputs (regulatory and economic policy instruments) into the system while receiving surveillance feedback (indicator data) from the system and comparing the indicator data with the parameters required by the local sustainability policy. The appropriate indicators should be selected carefully to provide the required specific information on the performance of the energy system. The sustainability indicators should be chosen according to region-specific conditions, but should cover economic, environmental and social aspects as well.

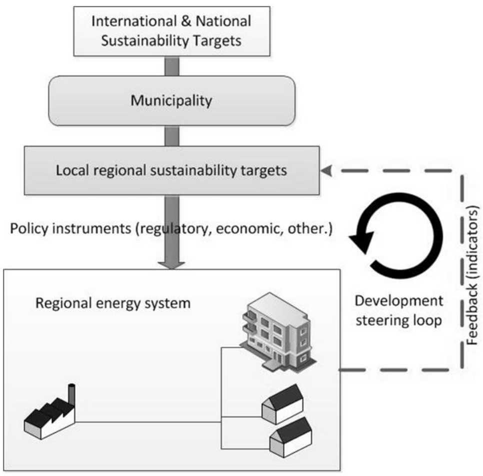

Figure 1: Steering of the development of the regional energy system

The evaluation process described above requires good understanding of the energy system in question. In order to understand the current situation of the energy system and to be able to predict the further development of the system, it is essential to recognize issues like the mechanisms that affect the formation of heat energy demand, how energy demand affects energy production, what influence different scenarios have on the sustainability indicators, and with what kind of mechanisms the municipality can steer the development. It is necessary to map the different actors operating within the energy system, as well as the energy flows between the actors. The roles and interests of the different actors and the issues affecting the energy related decision-making of the actors should be recognized. This will help to incorporate the interests of the different actors in the decision-making process, creating better operating conditions and helping with the realization of new business opportunities under the changing circumstances. The information required for mapping the local energy system can be gathered by various means, such as collecting data from the actors, energy modelling of different processes within the energy system, etc.

3. Regional sustainability approach

In this study, a common approach for systematical steering of the development of the energy system towards international, national and local sustainability targets is developed. The common framework for the incorporation of sustainability issues into the development process of a regional energy system is presented in Figure 2. The approach starts with the identification of the regional sustainability policy established by the municipality based on national and international treaties, the legislative framework and local conditions within the region. The regional sustainability policy incorporates environmental, social and economic targets for the future development of the region in question. These targets should be identified clearly from the very beginning of the decision-making process.

The second step in the approach is charting the functioning of the regional energy system. This starts with identification of the actors (centralized producers, distribution network operators, consumers and prosumers) operating within the chosen region, as well as the pattern of energy flows between the identified actors. Also issues affecting the energy-related decision-making of these actors, such as economic interests, preferences etc., need to be identified. The municipality can be considered as one of the actors, as it regulates the development of the energy system. The common pattern of the regional energy system, including the roles of different actors is presented in Figure 2 below.

The next important step is the recognition of indicators (key measures) that would help to estimate the actual development of the energy system towards the regional sustainability policy and targets. Each actor within the energy system is important for contributing on their own behalf to regional sustainability, so appropriate indicators should be identified for each class of actors. The indicators should incorporate at least environmental, economic and social issues. Also other local policy-specific indicators can be included in the approach. All indicators should be selected on a case-specific basis in order to illustrate the particular local sustainability targets in the best possible manner. Studying the functioning of the local energy system will help the decision-makers to understand how energy demand is formed, what mechanisms affect the formation of energy demand, how energy production and transition is affected by changes in the energy demand, and how these issues affect the sustainability indicators.

The presented approach makes it possible to evaluate different possible energy system development scenarios in terms of sustainability targets. Based on regulatory input and sustainability indicator output analysis, optimal steering instruments can be chosen that will support the development of the regional energy system towards the realization of local sustainability targets. Including the regional sustainability approach in the process of regional development would help to incorporate the interests of the different actors in the energy system into decision-making. Also challenges and new emerging business opportunities can be recognized and taken into account while steering the local development towards sustainability.

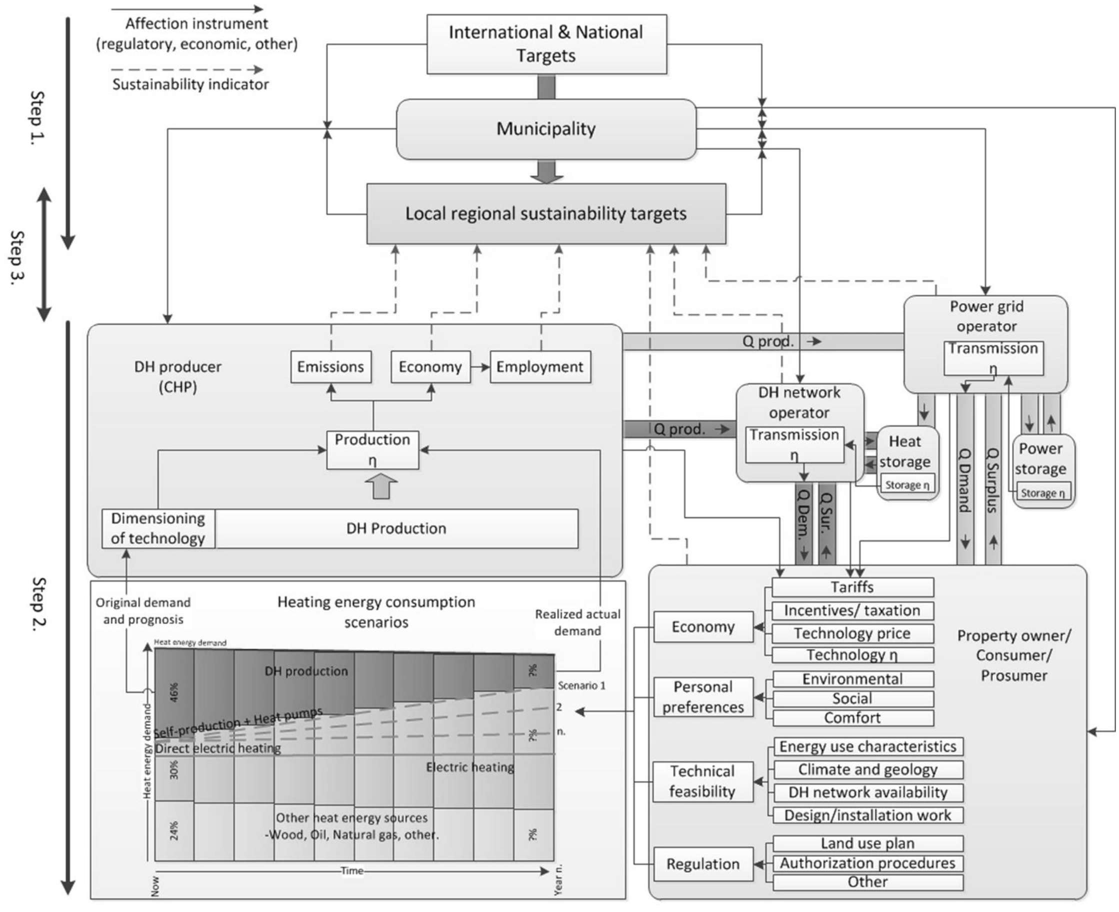

Figure 2: Regional sustainability approach

3.1 Charting of the regional energy system

3.1.1 Consumer or prosumer

The consumer is the operator of a building of a particular purpose. Buildings, in turn, are where the energy demand for the region is formed. The operators and the purpose of the buildings vary, as the buildings can be domestic, commercial, industrial, or municipal. Traditionally, building operators have been considered as energy consumers, but due to technological development and economic factors, self-production of energy is increasing. Self-produced energy is either used on site to cover the energy demand of the operator, or it can be sold to the regional energy distribution operator. Within the energy system, these actors can no more be considered traditional consumers due to changed role and interests, but are rather a so called prosumers. The impact of increasing self-production and prosumers on future energy demand can be major. The main interest of the energy consumer is to cover the required heat and power demand with the cheapest possible energy, while prosumers are interested in getting a maximal price for the energy sold to the distributors. Also both consumers and prosumers wish the energy services to be provided reliably and with minimal effort.

Selecting the heating method is a big decision the operator of the building has to make. In addition, the operator can decide whether to self-produce energy on site and to what extent, and whether to sell the energy or not. For the operator these decisions have a long-lasting effect, since the chosen technology will be in use for decades. The decision-making is driven by such factors as economic issues, local conditions on site and the characteristics of the heating systems, while the decisions made dictate how the actual heat demand of the region will look like (see Figure 2). Notice that the demands presented in Figure 2 are symbolic and may not represent the actual future development. The appropriate solution is chosen on the basis of optimization of the various criteria, and some compromises have to be made.

Economy is one of the most important decision-making parameters when deciding on the heating method and energy self-production. The economic viability of the heating method is determined by heat energy tariffs, energy taxation, the price of technology, and possible incentives supporting particular technologies. The tariffs concern energy sale, purchase and transition determined by the local energy producers and distribution network operators. Taxation and incentive policies are the core methods in the realization of the regional sustainability policy.

Another important factor is the heating system -related personal preferences of the building operator. This encompasses personal requirements for comfort, namely ease of use, the quality of services, operational reliability, safety, etc. Also priorities in terms of social and environmental issues might play an important role. In this case, the realization of the regional sustainability policy can be boosted by rising social and environmental awareness of local residents.

Every property and building has its individual conditions and characteristics that affect the technical feasibility of each heating or energy production method. Some circumstances may limit out or favor the utilization of particular technologies. For instance, the characteristics of energy use vary significantly depending on the purpose of use of the building. One important energy use parameter is energy demand and its daily and annual variation. Site-specific climatic and geological conditions are detrimental for such systems as solar and geothermal heat production. Another important site-specific condition is the vicinity of a district heating (DH) network. It is rational to consider utilizing district heat whenever a DH network is available because of uncomplicated use, low need for maintenance, and competitive energy tariffs. The connection fee to DH is determined by the distance between the property and the DH network (Motiva, 2015).

Finally, the selection of the heating method is affected by the local regulatory framework that incorporates international and national laws and policies, as well as municipality-specific policies. In some cases the municipality can make the connection to the DH network obligatory by a local land use plan if a DH network is available, and if this will serve the local sustainability policy. In

Finland, the building operator can, however, derogate from this obligation if the building has low energy demand or the owner proposes a more efficient renewable heat source -based heating system (Ijäs, 2015). Some municipality-specific regulations related to geothermal heat extraction in groundwater areas and in the vicinity of water intake stations may apply (Town of Lahti 2015).

3.1.2 Centralized energy producer

Centralized energy producers operate large-scale energy production plants producing heat and power for the needs of multiple customers (consumers/prosumers). Centralized energy producers are important contributors to the local sustainability targets of the municipality, as well as national and international targets. The coverage of centralized heat production can be on the level of a neighborhood, the whole municipality, or even neighboring municipalities. Centralized power production is connected to the national grid. The core interest of centralized energy producers is maintaining and increasing the profitability of their activities. Here, understanding the upcoming changes in the energy system is important in order to be able to adapt to the changes and utilize the emerging new business opportunities while managing the risks.

At the moment, centralized energy production is competitive. For example district heating (DH) accounts for 46% of the total heating market in Finland (Finnish Energy, 2015). However, competition is expected to grow. Self-production and ground thermal pump solutions are becoming the main competitors. Also the national and international regulatory framework and emission targets affect the competitiveness of centrally produced energy. Among these are emission trading, the Industrial Emissions directive with new nitrogen sulfur and particle emission limits, new national building codes promoting local renewable energy, and energy taxation. The new energy taxation measures which took effect in 2011 reduced the competitiveness of DH considerably, especially in the case of producers utilizing fossil fuels, like oil, coal and natural gas (Pöyry, 2011).

The future development of energy demand formation will affect the operation efficiency and profitability of the existing centralized energy production capacity greatly. Investments into energy producing technology are typically long. Investment decisions are made based on the market situation and the best available future market development prognosis at the moment of decision-making, see Figure 2. Technology sizing and fuel selections are optimized on the basis of the best available market knowledge at the time. The long duration of investments create a challenge for heat energy producers to adopt to new conditions in the case of unexpectedly high market fluctuation. For example a considerable drop in DH heat energy demand can lead to a decrease of production efficiency in some oversized production plants. This in turn can lead to decreased economy of production and a need for premature replacement investments of energy production technology. Decreased production efficiency also increases nominal GHG emissions of production, which is a drawback for the national and regional sustainability targets.

The main challenge for the centralized energy producer is identifying the optimal development scenario for the activities from the point of view of profitability of operations. The core scenarios to compare are whether the energy production capacity should be kept the same, increased or reduced, which fuels should be used for production, what should be the price for energy, and how energy services should be tailored to suit the customers' needs best. Here understanding the mechanisms affecting the development of energy demand, as well as the influence of the regulatory framework, is required. Production capacity sizing decisions depend strongly on the energy demand. The main factor affecting the formation of energy demand is the consumer.

3.1.3 Energy distribution network operator

Energy distribution network operators connect energy production with consumption. Basically, they operate two types of distribution networks, the district heating network and the electric power grid. The interests of the distribution network operator can vary, depending on the ownership of the network and other issues. The common interest of privately owned energy distribution network operators is profitability. However, if the operator is owned by the local municipality, the strategy is selected based on the municipality's sustainability targets. Here, in addition to maximization of municipal incomes, also a non-profit strategy can be applied with accent on the provision of necessary energy distribution services to local consumers. The profitability of energy distribution networks depends on the formation of energy demand and other preferences of energy consumers and prosumers in terms of the quality of the energy services. The transition efficiency of distribution networks depends on various transition losses and sub-system efficiencies. The introduction of energy storages can increase the overall transition efficiency. The efficiency of energy distribution can have a significant impact on primary energy consumption, and has thus major importance in terms of regional sustainability targets. The higher the heat losses during energy transition are, the more primary energy is required to cover the heat demand of the consumer (Vinokurov & Luoranen 2015). Traditionally, distribution networks have been designed to connect large centralized energy producers with residential, municipal or industrial consumers. However, the continuous increase in self-production requires some changes in the traditional design, because the energy produced by distributed solutions needs to be fed into network. Also the measuring of energy consumption and production should be improved, and appropriate tariffs for both the purchase and selling of energy should be introduced.

3.1.4 Municipality

The municipality monitors and steers the development of the region in accordance with sustainability targets. The common interests of the municipality are ensuring the welfare of its residents, developing the economic attractiveness of the region, and providing the residents with services in an economically and environmentally sustainable way. On the regional level, decision-making related with the development of energy systems is highly affected by the national energy legislation and local energy policy. National-level regulation is for example carried out by target-oriented energy taxation. In Finland this means that for example the tax for fuel used in heat energy production is based on the energy content and GHG emissions of the fuel (Finnish Energy, 2011). The local energy policy is regulated by the municipality, and its framework is based on international and national energy-related targets, while paying attention to local municipality - specific sustainability targets related to the local climate, and social and economic, etc. conditions. There are different mechanisms the municipality can use to support the realization of the regional energy plan. These are economic incentives that boost the introduction of a technology, such as renewable energy solutions, promoted by the energy plan. Another instrument is a land use planning system carried out by the municipality. The land use plan determines the future of the region by defining issues like what must be preserved, what can be built and where, and how the construction can take place. In some cases, the heating method to be used can be defined by the plan among other features, thus affecting the development of the local energy system (Ministry of the Environment of Finland, 2013). Here, a settled strategy of the regional energy plan plays an important role. For instance, if the municipality targets to decrease GHG emissions by investing in a costly centralized heating plant using biofuel, it might be rational to support DH system connections. Again, if because of different local conditions, biofuel is not easily available, it might be beneficiary to invest on different heating methods, for example on distributed production utilizing ground thermal heat pump technology. The revision of the local energy policy in the light of the changing conditions, and in some cases the change of policy might be beneficiary. Here comprehensive understanding of the current situation of the energy system and the effects brought by optional development scenarios is crucial.

3.1.5 New business opportunities

Identifying the local actors, the relationships between them, and their interests, as well as the energy flows within the region will help to understand the current situation of the regional energy system in the light of the local sustainability policy, and thus the current development trend can be estimated. In addition, different optional development scenarios can be compared and it becomes possible to identify the optimal scenario that will support the realization of the local sustainability targets best. The approach presented here will also reveal the issues that are required to achieve the chosen targets, among these the challenges and new business possibilities for the different actors in the energy system.

One of the major future challenges for energy planning is the growing competition between DH and renewables-based self-production and geothermal heat pump technology. This situation will also create new business opportunities, however. For example, the continuously developing self-production systems and incentives promoting renewable local energy sources will increase the viability of energy self-production. Here the traditional consumer has the opportunity to become a producer of energy, selling energy to the distributor and receiving economic benefit.

The centralized energy producer can find an opportunity by providing a new energy service that includes the realization of centralized solar or geothermal heat production in the scale of a neighborhood, and providing energy to local consumers at an appropriate tariff. This can bring competitiveness for the centralized producer, as the consumer will receive locally produced renewable energy while being spared from laborious planning, construction and service, these being the responsibility of the centralized producer. This can be an actual development, especially when the competition with self-production is increasing.

For the energy distribution network operator, the main future challenge is to recognize upcoming changes in customers' demands and to adapt to them. In terms of increasing self-production, the new business opportunity can be increasing the purchase of self-produced energy from prosumers and selling it to consumers who require energy at that moment. This would require changes in the network, but it could also create new incomes and ensure the demand for energy transition activities even if the demand for centrally produced energy were decreased.

New business possibilities can be provided also to other actors than those operating within the energy system. The analysis like one presented in this approach requires the collection and procession of a large amount of data and interpretation of the results, which is a task requiring certain professional expertise. This process should be controlled by the municipality, but depending on the available resources, these task can be fully or partially outsourced to specialized consulting agencies. This will create a demand for new consulting services. Also the business opportunities of technology producers will expand. For example, a major increase in renewables-based self-production will require new efficient heat storage technologies in the market.

4. Discussion

The required emission reductions can be achieved by introducing local renewable energy sources and by increasing the efficiency of energy production, transition and utilization, and thus a regional approach is needed. These measures would require changes in the traditional energy system that has been designed to rely on large centralized energy production plants utilizing mainly fossil fuels. Increasing the decentralized production of energy by utilizing renewable energy sources provides a possibility to achieve local emission-free energy production. However, this will create new challenges for energy planning, since traditional energy systems have not been designed for decentralized energy production, and changes are required. Among the core challenges are the decreasing demand for centrally produced energy and issues related to feeding decentrally produced energy into the distribution network.

Achieving sustainability targets requires changes that will affect all the actors operating within the local energy system, creating new challenges, but also new sustainable business opportunities. Municipalities as overseeing authorities and responsible for steering the regional development have to acknowledge the present and upcoming challenges and opportunities and incorporate these into the decision-making process related to the development of the regional energy system. The approach presented in this paper is based on understanding the functionality of the local energy system by charting the different actors, energy flows and mechanisms in the system affecting the energy-related operations of the actors. The approach will help to understand the current state of the regional energy system in terms of sustainability, as well as to evaluate possible development scenarios. Following the presented framework will help to identify existing and upcoming challenges and new emerging business opportunities and incorporate the interests of different actors operating within the energy system into the decision-making. This can support local economic growth and increase the energy security of the region by increased local energy resource utilization while creating more local jobs. By understanding the mechanisms affecting the realization of sustainability targets, the decision-maker can choose the appropriate steering mechanisms to develop the energy system in accordance with the local policy.

The approach presented here is not intended to perform as a detailed energy analysis, but rather to provide guidelines for gaining a comprehensive overall picture on the current state and possible development scenarios of the energy system in terms of local sustainability targets. It is important to acknowledge that the presented approach is a common framework for systematic realization of regional energy analysis. Each region has specific conditions in terms of sustainability targets, actors, energy resource availability, climatic conditions, etc. These conditions should be taken into account when applying the framework. For example, the sustainability indicators should be selected according to region-specific sustainability targets. The approach may be accompanied with more advanced economic, environmental and social examinations, such as Life-Cycle Analysis, energy modeling, etc.

5. Conclusions

Transition from traditional fossil fuel -based energy production towards the utilization of local renewable energy sources as well as an increase in the efficiency of energy production, distribution and utilization are important steps in achieving regional sustainability targets. These measures require changes in the traditional regional energy system, creating challenges as well as new opportunities for energy planning. If appropriately implemented, these changes can decrease the overall emissions while increasing energy security and economic wellbeing in the region.

This paper has presented an approach to identify and incorporate the interests, challenges and opportunities of different actors within the energy system systematically into the decision-making process related to regional development and energy planning. The approach is based on the identification of local conditions, such as actual actors with their interests, energy flows, local sustainability targets and case-specific sustainability indicators. This can give the decision-makers an overall view on the current state of the energy system, and help them to compare the effect of optional future development scenarios on the overall sustainability of the region. Therefore, the selection of the optimal development steering actions can be tailored to suit the region-specific conditions and needs.

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The Água Branca Urban Retrofit Project in São Paulo: Comparative Analysis to Paris Nord-Est Project

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Abstract

With the constant growth of the world population, and limited resources on the planet, as well as the pursuit of better living conditions without consumption increase, it is necessary to create new methods of utilization of the urban structure ever built. Infrastructure constraints currently include ageing, underutilized and inadequate existing facilities, as well as a lack of integration in planning, design and management strategies for future infrastructure development in long-term scenarios. The urban retrofitting, one of the solutions to this problem, is usually defined as the occupation of degraded areas in town – such as misused, abandoned and/or empty ones –, making the transition from city actual situation to its future vision. This transition, or urban retrofit itself, shows comprehensive nature and large scale, integrated nature and a clearly defined set of goals and metrics for monitoring. Urban retrofitting presents great advantage over creating new urban developments and infrastructures, in point of view of urban sustainability. Therefore, this paper presents a comparative analysis of two case studies, urban retrofitting projects. The first one is the urban operation Água Branca, in the city of São Paulo, an area with substantial transformations in the urban municipality, since 1995, in order to provide a more densely populated neighbourhood, with mixed use, inclusion and social diversity. The second project is the Opération Paris Nord-Est, northern suburbs of Paris, started in 2002 with the purpose of transforming this outlying area in a new economic and urban centre, through retrofitting existing infrastructure and promoting mixed-use, commercial and residential. The research method included a literature and documents review, consultations, interviews and technical visits. The result is a comparison of two retrofit projects, in São Paulo and Paris urban contexts, in terms of similarities and differences between priorities, perspectives, guidelines and urban policies, using urban indicators to quantify comparisons, such as: area for construction, population density, floor area ratio and green space areas, and listing respective advantages and disadvantages of urban retrofitting implementation process.

Keywords: Urban Sustainability, Urban Retrofitting, Urban Renovation, Urban Redevelopment

1 Introduction

The United Nations Human Settlements Programme (UN-Habitat, 2009) identified eight major trends in the integration of the green agendas in cities, that focus on: “developing renewable energy; striving for carbon-neutral cities; developing distributed power and water systems; increasing photosynthetic spaces as part of green infrastructure; improving eco-efficiency; increasing sense of place; developing sustainable transport; and developing cities without slums”. More recently, Newton (2013) highlights a number of critical issues for cities, that are likely to intensify by mid-century unless concerted interventions commence, which are: “climate change, resource constraints, population change, urbanization and intensification of urban development, ageing infrastructure, socio-demographic change, urban economic base and financial uncertainty”.

In order to reach those objectives, many projects have been proposed, such as retrofitting ones, that uses older buildings and develops a range of ecological and/or technical adaptations. The concept of urban retrofitting or re-engineering has gained ground globally in recent years, with a sustainable approach. Sustainable urban retrofitting regards the “directed alteration of the fabric, forms or systems which comprise the built environment in order to improve energy, water and waste efficiencies” (Dixon and Eames, 2013). However, for cities, larger-scale and more integrated and sustainable systems or enterprises are needed. According to Living Cities (2010), the defining characteristics of a larger-scale retrofit system are these: comprehensive scale, integrated, sufficient and sustainable funding, deliberate and systematic strategy for engaging and benefitting lower-income people, and robust performance management system with a set of clearly defined goals and metrics for monitoring.

Newton (2013) says that “urban regeneration, renewal, redevelopment, rebuilding, renovation, restoration and retrofit are all terms that have been used somewhat interchangeably in the literature to describe the processes aimed at revitalizing the existing built environment, local communities and local economies”. They encapsulate the multiple dimensions represented in urban redevelopment, including scope, ownership and governance.

Therefore, the urban retrofitting is usually defined as the occupation of degraded areas in town – such as misused, abandoned and/or empty ones –, making the transition from city actual situation to its future vision, in long term scenarios. This transition, or urban retrofit itself, shows comprehensive nature and large scale, integrated nature and a clearly defined set of goals and metrics for monitoring. Urban retrofitting projects are a set of interventions in order to adapt the urban area to improve its sustainability, not only at present time, facing current demands and problems, but also for future population and needs. Usually these projects cover former urban areas, around public transportation stations, or industrial areas, i.e. environmentally fragile lands, empty or not. Retrofitting adaptations involve a whole range of issues related to urban sustainability, such as: housing, energy, water, waste, walkability, existing buildings.

Urban retrofitting presents great advantage over creating new urban developments and infrastructures, in point of view of urban sustainability. Expanding cities towards occupying natural lands and greenfields, improving environmental and ecological impacts on building new urban infrastructure, seems to be a less sustainable alternative facing developing urban areas with wide configurations and uses, in order to occupy decayed areas and brownfields.

In fact, in a period of economic crisis, rather than thinking of large incremental development plans, it is wiser to suggest urban retrofitting operations conceived as the punctual nodes of a longer term re-planning, as they have the potential to generate new identity processes at the urban scale (Ferrante and Semprini, 2011). Dismantling and re-building cities is not a realistic option and abandoning urban areas is not a preferable alternative.

Furthermore, the retrofit of a neighbourhood must be coherent with the city as a whole. It needs to tackle the local issues of the area as well as the more global challenges of the city, such as car congestion, pollution or flooding risks. This is why urban retrofit operations are often encapsulated in each other, creating a strategic director plan for the city future.

2 Methodology

The aim of this paper is to study urban retrofit processes, so this research presents a comparative analysis of two case studies, urban retrofitting projects, a comparative case, here preferable to a single in-depth case because the analysis also assess how these two retrofit projects address the challenges of each respective background, the city where each one belongs to.

The first urban retrofitting project is the urban operation Água Branca, in the city of São Paulo, an area with substantial transformations in the urban municipality, since 1995, in order to provide a more densely populated neighbourhood, with mixed use, inclusion and social diversity. The analysis determined how the retrofitting project could improve the living conditions in the area, by bringing balance and dynamism to this uneven and unequal yet pivotal neighbourhood, and meet the challenges of São Paulo, a giant and ever growing metropolis in a developing country, Brazil.

The second project is the *Opération* Paris Nord-Est, northern suburbs of Paris, started in 2002 with the purpose of transforming this outlying area in a new economic and urban centre, through retrofitting existing infrastructure and promoting mixed-use, commercial and residential. The research determined how this project, located in Paris, a more ancient and more slowly growing metropolis of a developed country, is different from the previous one, both in the urban issues at stake and the proposed solutions.

Many urban projects are under development in São Paulo municipality, but the urban operations demonstrate affinity to urban retrofitting concept, since they present neighbourhood and district scale, long term implementation and agreement to strategic plans and future city scenarios. According to the Ministry of Cities (Ministério das Cidades, 2008), the urban operation concept was influenced, to a certain extent, by international experiences, such *Zones D'Aménagement Concerte – ZAC*, or joint development zones, that appeared in France in 1970s. French ZACs assumed more state interference, by means of direct actions for urbanization, mobilization and recovering the value of local real estate for community, submitting private capital to public interests and priorities. However, in Brazil, urban operations appeared in other line, more linked to negotiation of urban laws exceptions by the State, in order to get resources to urban development actions.

The research method included a literature and documents review, consultations, interviews and technical visits. The current situation of both neighbourhoods was analyzed as a whole, by highlighting their population, economic data and drainage issues. The both urban retrofitting plans show present and future situations, under main guidelines and urban policies involved in the process. Some urban indicators and parameters were selected to assess comparisons.

The objectives of urban retrofit can be quite different from a country to another. Western countries must cope with ageing building stock and urban infrastructures and cities while developing countries need to retrofit informal and unplanned urban developments to tackle the issues of poverty, housing, economic growth, energy insecurities and climate change. We will compare Água Branca with a French retrofitting project to see if the objectives of urban retrofit are always very different.

2.1 The urban operation Água Branca

In 2010, the *Prefeitura do Município de São Paulo*, or São Paulo Municipality, presented a report entitled “SP 2040: the city we want” (PMSP, 2012), that diagnoses current situation and foresees scenarios for 2040. São Paulo is the biggest city in South America, with over 11 million of inhabitants and 20 million in the metropolitan area, and it is still growing at a rapid pace, with an increase of 1,65 per cent per year for the period 1991-2010 in the metropolitan area (PMSP, 2012). The city is coping with multiple challenges, which make urban planning increasingly difficult for the city council. How urban planners will tackle these challenges will prove very useful to improve living conditions for the 85 per cent of Brazilians who live in the cities.

As in Brazil as a whole, economic inequality is significant in São Paulo: 15 per cent of the population live in favelas, shanty towns mainly located in the outskirts of the city (PMSP, 2012). Meanwhile, the richest inhabitants live in the city centre, often in “condominiums”, luxurious and highly-guarded residences. PMSP (2012) presents a trend scenario for 2040, with a projection of current problems. City population is estimated to around 12,1 million inhabitants in 2040, while metropolitan region population will reach 22,5 million inhabitants.

The joint urban operation Água Branca, or *Operação Urbana Consorciada – OUC Água Branca*, was select for study because is a project under development, initiated in 1995. With easy access, Água Branca is located in the Municipality of São Paulo, within the main beltway. It extends over 540 hectares along the south side of the Tietê River (PMSP, 2014). The Água Branca area was designated for a retrofit operation because it was located in the city center and the displacement of industries left it unbalanced. The significant amount of public transportation, namely train and metro, was also a reason of the retrofit of the area. In 2010, the population of the Água Branca area is 29.815 inhabitants, and the population density is 55 inhabitants per hectare, which means that it is not densely populated (EMURB, 2009) comparing to population density in São Paulo metropolitan area, that is 75 inhabitants per hectare. The objective is to significantly increase this number, with an objective of 86.289 inhabitants, i.e. a sharp increase of 189% in the population (EMURB, 2009). Sectors with former industrial lands with no inhabitants will be largely transformed, by creation of many streets and major housing projects.

The following figures represent an aerial view of the Água Branca neighbourhood and the urban plan of the retrofit, and the following table is a synthesis of the changes brought to Água Branca by the retrofit.

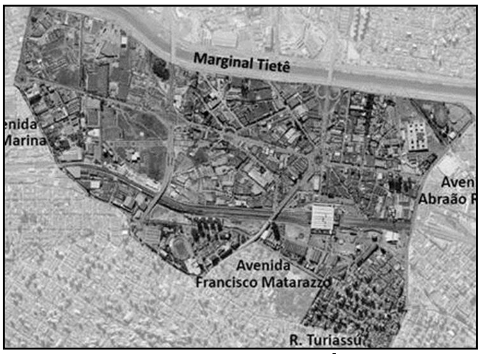

Figure 1: Aerial view of the Água Branca neighborhood (PMSP, 2014)

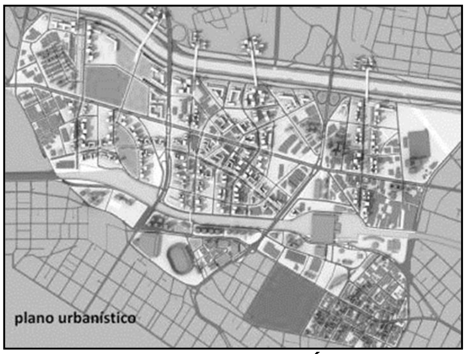

Figure 2: Urban plan - Água Branca neighborhood (PMSP, 2014)

Table 1: Numerical synthesis of the changes brought by the Água Branca operation

Data	***Água Branca in 2014***	***Future Água Branca (after project implementation)***
Total Area	*540 ha*	*540 ha*
Population Density	*61 inhab/ha*	*177 inhab/na*
Empty Areas	*50 ha*	*0*
Residential Area Stock	*30 ha 5100 unities*	*0*
Non-Residential Area Stock	*51,2 ha*	*0*
Green Space Areas	*10 ha*	*42 ha*
Green Space Areas (% of total area)	*7%*	*19%*
Road System Area (% of total area)	*16%*	*25%*

Adapted from EMURB (2009), PMSP (2014) and WALM (2009)

2.2 The Paris Nord-Est Project

According to *Préfecture de Paris* (2010), or Paris Municipality, *Gran Projet Renouvellement Urbain* – G.P.R.U., or Big Urban Renewal Project, initiated on March 2001, in order to improve structure and quality of life in eleven priority neighbourhoods, remotes from city center, covering 200.000 residents and seven districts, through participative actions, public consultations and long term projects, including the urban revitalization and renewal of a big area in North-East region of Paris.

One of the eleven neighbourhoods, the Paris Nord-Est project was initiated in 2002 by the city council, following the significant retrofit of the nearby neighbourhood of the *Plaine Saint-Denis*, in the northern suburbs of Paris, which has recently become a very dynamic economic area. The area of the project covers 220 hectares, alongside the *Boulevard Periphérique,* which represents the limit between Paris and its northern suburbs (*Préfecture de Paris*, 2014).

The aim of the project is to transform an outlying area into a new economic and urban center by retrofitting decaying infrastructures and by benefiting more efficiently from existing infrastructures such as the *Boulevard Periphérique* or the A1 Motorway. Paris Nord-Est will become a more mixed area, with offices, facilities and housing. All the parts of the retrofit are expected to be completed by 2020.

Paris Nord-Est area is characterized by the considerable presence of networks, with the railways from both *Gare du Nord* and *Gare de l'Est*, the A1 motorway, the *Peripheral Boulevard* – which may be regarded as the physical limit of the city of Paris –, the *Boulevard des Maréchaux* – a boulevard that also encircles the city center), and the Saint-Denis canal. Despite its large area, the area is seen as undervalued and landlocked. Currently, Paris Nord-Est has only 13 000 inhabitants and 16 000 jobs (*Préfecture de Paris*, 2014).

The objective of the urban retrofit is to revitalize this pivotal neighbourhood by creating 25 000 new jobs and by allowing the settlement of 10 000 new inhabitants (*Préfecture de Paris*, 2014). The priorities of the retrofit are:

- to improve quality of life throughout the area by requalifying public spaces and the main infrastructures (boulevards, public squares, "*portes*" of Paris, canals)
- to open up the neighbourhood by benefiting more from the proximity of important networks
- to create new economic cores within the Paris metropolis with activities, shops, rail freight and urban services that will create jobs for the inhabitants of this disadvantaged neighbourhood

According to *Préfecture de Paris* (2007), new built area will cover 1.1 million of square meters (110 ha). During this retrofit, approximately 233 000 square meters (21% of the built area) will be destroyed to make space for new buildings. There will also be around 27 hectares of green spaces once the retrofit is over. The current situation and the proposed plan are shown at following figures, and the following table is a synthesis of the changes brought to Paris Nord-Est by the retrofit.

Figure 3: Aerial view of the Paris Nord-Est area (Préfecture de Paris, 2014)

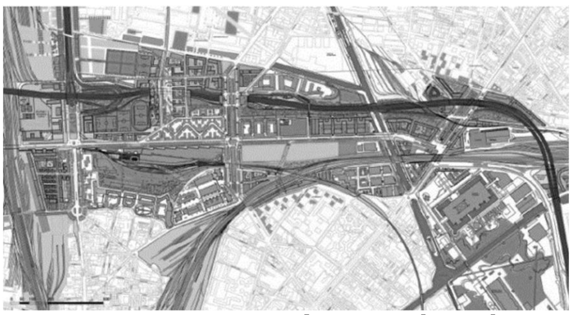

Figure 4: Paris Nord-Est – Urban Plan (Préfecture de Paris, 2014)

Table 2: Numerical synthesis of the changes brought by the Paris Nord-Est Project

Data	***Paris Nord-Est in 2013***	***Future Paris Nord-Est (after project implementation)***
Total Area	*220 ha*	*220 ha*
Population Density	*59 inhab/ha*	*105 inhab/na*
Empty Areas	*23,3 ha*	*0*
Residential Area Stock	*44 ha (50% to social housing)*	*0*
Non-Residential Area Stock	*66 ha*	*0*
Green Space Areas	*11 ha*	*27 ha*
Green Space Areas (% of total area)	*5%*	*12%*

Adapted from Préfecture de Paris (2007) *and Préfecture de Paris* (2014)

Paris Nord-Est is already a socially-mixed area, with a large share of low-income households. The project takes this into account with a minimum objective of 50% of social housing on the new housing projects (*Préfecture de Paris*, 2007).

The retrofit aims also at increasing the population density in the various sectors of the project. On the former railways, there are only few inhabitants: the increase in population density will be thus very important. However, in the south of Paris Nord-Est, the urban fabric is already densely built and populated. Nevertheless, studies are being made to assess with precision where improvements in construction and population density are still possible.

3 Results

From the comparative analysis between Água Branca and Paris Nord-Est projects, urban indicators were identified and, however, provide results with common points and differences between both projects. These indicators and parameters are presented and discussed below.

3.1 Land use characteristics

The following table compares some current urban parameters of land use, showing occupancy and dimensions, both in São Paulo city and Paris. Main areas of São Paulo were selected due they better represent Água Branca project areas.

Table 3: Urban parameters of some areas in São Paulo and Paris

City	***Area***	***Floor Area Ratio***			***Maximum Building Height (m)***	***Minimum Front Setback (m)***
		Minimum	***Basic***	***Maximum***		
São Paulo	*High Density Area*	*0,05*	*2,00*	*2,50*	*no limits*	*5*
	Polar Centre Area	*0,20*	*2,00*	*4,00*	*no limits*	*5*
Paris	*Centre*	*none*	*1,50*	*3,00*	*between 35 and 42*	*between 6 and 8*

Adapted from IAURIF (2005) and PMSP (2004)

3.2 Area for construction

Table 4 shows differences between destination of news areas for construction of each one of the comparative projects. Both projects have comparable total area for new constructions, but the destination of Paris Nord-Est project is more balanced than Água Branca. Area destined for new housing is also larger in Paris.

Table 4: Destination of new areas for construction of Água Branca and Paris Nord-Est Projects

Destination of new areas for construction	Água Branca		Paris Nord-Est	
	ha	% of total	ha	% of total
Housing	30	25	44	40
Equipments	24	20	11	10
Business Activities	24	20	55	50
Others	90	35		
Total	**120**	**100**	**110**	**100**

Adapted from PMSP (2014) and Préfecture de Paris (2013)

3.3 Population Density

The following table shows the evolution of population densities in Água Branca and in Paris Nord-Est projects, as well as in São Paulo city and in Paris. Paris, with current 201,6 inhabitants per hectare is a much more densely populated city than São Paulo, with 73,8 inhabitants per hectare. This will not change much over time.

Table 5: Population densities evolution in Água Branca and Paris Nord-Est Projects, and in São Paulo and Paris

Population Density (inhab/ha)	Água Branca	São Paulo	Paris Nord-Est	Paris
Current	61,0	73,8	59,1	201,6
Future	177,0	78,3	104,5	209,8
Increase	190%	6%	76%	4%

Adapted from WALM (2009) and Préfecture de Paris (2007)

Água Branca will see its population density almost triple, overcoming the population density in Paris Nord-Est, despite that the last will increase by 76%. This difference in population density of both projects can be explained by the different potential of each neighbourhood. In Água Branca, the majority of the area is occupied by former industrial lots, which can easily be retrofitted. In Paris Nord-Est, however, railways occupy a significant amount of space, which limit the population increase over the whole neighbourhood.

3.4 Floor Area Ratio

In both neighbourhoods, the floor area ratio will increase where an increase in population density is projected. The buildings will be higher and denser to house more people and jobs. The two neighbourhoods possess empty land, where the increase in floor area ratio will be the most significant.

In Água Branca, some social housing projects with a floor area ratio over 3 will be built in areas where the floor area ratio used to be 1,00. Along the up-righting axes, the increase in floor area ratio will also be significant, thanks also to the maximum housing quota scheme and to the curbing of parking places.

In Paris Nord-Est, the increase in floor area ratio will be easy along the former railways and on the former industrial lands. Yet, in the south of Paris Nord-Est, it will be more difficult to find spaces for a potential increase in floor area ratio, since the area is already densely built. Additional constructions will be decided on a case by case basis. Below is an example of a detected potential for a new construction, although the floor area ratio of the lot is already 2,38 (*Préfecture de Paris*, 2013).

3.5 Green Space Areas

The following table shows the green spaces in the current and future neighbourhoods. There will be a significant increase in the total green spaces in both neighbourhoods, in the end of urban retrofitting projects.

Table 6: Green spaces evolution in Água Branca and Paris Nord-Est Projects

Green Spaces	**Água Branca**		**Paris Nord-Est**	
	ha	**% of total**	**ha**	**% do total**
Current	10	2	11	5
Future	42	8	27	12
Increase	6%		7%	

Adapted from PMSP (2014) and Préfecture de Paris (2013)

Água Branca will see its total green spaces quadruple due to the retrofit, creating projected new parks. In Paris Nord-Est, green spaces will represent 12 % of the area once the retrofit is over, which is quite significant. In Paris, the percentage of green spaces is 17%, which includes two forests: Bois de Vincennes and Bois de Boulogne (*Préfecture de Paris*, 2013).

4 Discussion

The issues tackled by both retrofit operations are the same as Água Branca and Paris Nord-Est are two quite similar neighbourhoods: they both include large former industrial lots, with obsolete infrastructures. Despite their strategic location within the city, they are both undervalued and landlocked. They also have a low density of population.

As Água Branca, Paris Nord-Est is an undervalued neighbourhood because it is landlocked and there are many dilapidated infrastructures. Moreover, the neighbourhood is dislocated due to the railways and the *Boulevard Périphérique*. In order to open up the neighbourhood, 6 transversal paths will be renewed or created (*Préfecture de Paris*, 2007). These paths through the neighbourhood will bring dynamism and visual references to the neighbourhood, like the up-righting axes of Água Branca (PMSP, 2014), connecting it to the surrounding areas.

The local issues of both neighbourhood explain why these two urban retrofit projects, located in two very different cities, have many similarities. The objective to create a more densely populated neighbourhood is the same, as is the goal to induce a socially-mixed neighbourhood with social housing and incentives for low-income households. There is also a common focus on green spaces: both neighbourhoods will see a significant increase in the total areas of green space and in the number of trees along the main streets. Moreover, the two projects tend to enhance the landscape in the same way with several linear parks to create new visual references within the neighbourhood. The main objective of both projects is to create a more compact and liveable city.

Increasing the areas of green spaces is regarded as a way of enhancing the landscape of the neighbourhood and to improve the living conditions in the area. Moreover, green spaces restore the physical cohesion of the neighbourhood. In Paris Nord-Est project, at the end of the retrofit, there will be 27 hectares of green spaces. There will also be a linear park along the second pathway, between *Charles Hermite* and *Plaine Commune* (*Préfecture de Paris*, 2014). It will have the same function as the linear parks in Água Branca, enhancing the landscape for pedestrians and bicycles alike (PMSP, 2014). In Paris Nord-Est project, the comparison between former and future green space distribution highlights how the city of Paris manages to retrofit sectors that used to be dedicated to the main urban services such as railways. The conservation of the empty spaces created by the railways and their transformation into parks is a unique opportunity for the city, as it allows all the public spaces in the sector to spread from there. The *Jardin d'Eole* becomes one of the largest green area in the whole 18th *arrondissement* (district).

The comparative analysis shows that both projects want to fulfil the demands of their citizens by making their life better and more comfortable, improving the landscape, and reducing economic inequalities. It indicates how necessary it is to understand the habits and the behaviour of the citizens, and how important the projects have to cope with politics and institutions.

Differences appear in the way retrofits need to change the cities. In Paris, the large-scale objective is to revive a developed metropolis which may lack dynamism by focusing on its neglected and landlocked territories while, in São Paulo, the main challenge is to guide an uncontrolled urban dynamism and sprawl, by bringing more coherence and more density to the city and more balance to social inequalities. This may explain why the Paris Nord-Est project is more focused on job creation to boost the neighbourhood whereas the Água Branca operation is more centered on providing a larger housing offer to the city.

Moreover, some of the priorities of each project are different. For instance, Água Branca needs improvements to its drainage system due to flooding risks, which are much lower in Paris. Furthermore, as congestion issues are much greater and cars were always given the priority in São Paulo, the urban retrofit project of Água Branca tackles car traffic by curbing parking places with a new dedicated policy and by encouraging bicycle use and pedestrian circulation. In the meantime, the curbing of car use is already well in place in Paris, where many city dwellers often don't need to own a car because of an efficient, extensive public transport network.

Besides the analysis of urban indicators and parameters, it is important to know the context about urbanism and historic, political and cultural issues of both cities. São Paulo and Paris, are utterly different. The notion of adaptability is necessary and it must be understood that every solution of urban retrofitting needs to be considered from a more global point of view before being implemented. Moreover, Água Branca Operation and Paris Nord-Est show that societal and political support are inevitable requirements. As transitions like urban retrofitting processes have characteristics as sufficient and sustainable funding, and deliberate and systematic strategy for engaging and benefitting lower-income people (Living Cities, 2010), this is important to consider the political dynamics of their host cities and regions. And the temporal dimension of urban retrofitting transitions requires further policy attention.

These two retrofit projects analysed in this paper, the joint urban operation Água Branca and Paris Nord-Est, both adapt their priorities to their city's current main issues. Nevertheless, they have surprisingly close objectives regarding social inclusion in the neighbourhood, green area expansion and increased construction density.

5 Conclusion

The urban operation Água Branca is an ambitious urban retrofit project that aims at creating a whole new neighbourhood, which will be more compact and liveable. This retrofit must not only tackle the inherent problems of the neighbourhood, such as flooding risks, but also São Paulo's main urban issues, such as social and economic inequalities and congestion. It does so by resorting to classical urban ideas as well as resorting to new urban policies. It copes with São Paulo's significant economic inequalities by creating a more socially-mixed neighbourhood not only through incentives for social housing but also through a maximum quota per housing unit scheme that allows more low and middle-income households to come to live in the neighbourhood. Besides, thanks to a new policy that curbs parking places, it tackles São Paulo's notorious car traffic by increasing the area of green spaces and by expanding sideways to give the city back to its inhabitants.

Urban parameters help to assess the change brought to the neighbourhood by the retrofit. The division of lots, the extension of green spaces and of streets should also help to create a more liveable area. Land use and ratios are crucial to determine how the area is transforming thanks to the retrofit. Thus, the densification of the area needs to be regarded as an obstacle in the urban sprawl of São Paulo.

The comparison analysis with the Paris Nord-Est project shows that urban retrofit projects tend to have surprisingly similar objectives throughout the world, even though they must be adapted to the issues of the area. It also highlights the fact that the retrofits of neighbourhood always take into account the larger urban picture and the issues of the city in which these neighbourhoods are located. Moreover, drawing comparisons between these two retrofits, located respectively in a developed country and in a developing one, may give new interesting ideas to both urban retrofitting projects.

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Global Sustainable Perspectives X3: North America, Europe, and Africa

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Abstract

Sustainable practices differ considerably within nations and are significantly more dramatically apparent when a contrast is made amongst nations from three major continents. As well, if one does not look carefully at the criteria for sustainable terms, one can be easily misled in the meaning of sustainability. The paper will show how a collaborative effort with three educators in three institutions working within their standard rating systems reveals the challenges of sustainability indicators – carbon footprint / ecological footprint. The indicators for each educator are presented and analysed as one bases of comparison. The ethics of the differences were explored through the value systems that are embedded in each of the rating system. The ethical perspective the authors hypothesize brings about a needed and robust political discussion first with intentions for cooperation and collaborations in the future for a sustainable built environment that is equitable and achievable at the most significant level. The sustainable rating systems were analysed and compared for effectiveness with a rubric that will suggest plans for adaptation to other regions, both locally and globally. Common ground, or clarity, in the rating systems were illustrated with suggestions for productive collaborations that could benefit the larger ethical dimensions within the future of the built environment.

Keywords: Built Environment, Carbon footprint (CFP), Ecological footprint (EFP), Sustainability

1. Introduction

When the three authors of this paper undertook to research the differences in individual carbon footprints (CFP) of three different countries; a key assumption (#1) was that there would be major differences in each country's respective average CFP. Naturally, as perceptions and assumptions go, it was expected that the Netherlands would have the lowest CFP, followed by South Africa and then the United States of America (USA). However, this was not the case, because infrastructure and or state sponsored programs are factored into individual footprints. More interesting was the fact that there was not a greater difference than was expected. Understanding the criteria used to create a carbon foot print assessment reveals important nuances that will help understand how one can make a difference. The carbon emission data from the World Bank development indicators in terms of metric tons per capital show that South Africa has the least emissions at 9.3 whereas the USA has the highest among the three countries at 17 and emission data for the Netherlands follows that of South Africa at 10.1 (World Bank, 2015).

The motivation and the overarching question that the authors wanted to address in doing this comparative study is "how do you change the individual CFP of a nation" if it were known that there are others who have a greater CFP and they are not willing or able to lower their footprint. As well the authors believe governments can more easily impact the built environment, construction, and buildings, because the many stakeholders involved in the construction process are often tied to government policies. That is, lending agencies, regulatory agencies, legislation for public project are frequently incentivized quite often require public monies and thereby more easily made to follow the "enlightened public self-interest" standards. Construction amounts to 40% of all energy needs consumed in the USA (Kibert, 2013) of which many projects are funded through public agencies imposing standards that are more global. Focusing on the individual footprint would have greater variability, although an office building is an office building whether in Netherlands, USA or South Africa.

The next major assumption (#2) was that this motivating factor was related to knowledge, awareness and willingness to do so. But the study shows that these factors were not the main factors that are necessarily changing CFP. The next section is a concise description of the research process. This is followed by the findings on CFP and ecological footprints (EFP) of the educators. In the discussion section, the nuances of the findings are conceptualised in terms of sustainability in the built environment and the complexities that are associated with the ideas related to sustainability and changing behaviours.

2. Synopsis of the Desktop Study

The paper is based on a study of secondary sources / information for their contents and explanations (Krippendorff, 2013). The study began with a visit to the website of the World Bank Group as indicated in this section of the paper. The authors looked at the data concerning CO_2 emissions (metric tons per capita) Indicator Metadata. Using the World Bank definition on the website - "Carbon dioxide emissions are those stemming from the burning of fossil fuels and the manufacture of cement. They include carbon dioxide produced during consumption of solid, liquid, and gas fuels and gas flaring"; this study view CFP as the greenhouse gas (GHG) emission to the environment by a person or an organization.

Based on the World Bank data of the Netherlands, South Africa, and USA mentioned earlier and the illustration of Figure 1, the authors were able to learn that the differences between these nations that are located in three separate continents were not as dramatic. For instance, the USA is not only on the top of the scale globally, and even the nations are not so far apart when you consider the lowest and highest CO_2 footprint nations (World Bank, 2015).

Figure 1: SA, NL, USA and two most extreme nations

The information on the development indicators of the World Bank (2015) is insightful as shown in Table 1. The indices on the World Bank (2015) website show the rating for 195 nations. The data indicate that 60 nations have less than 1.0 index, 110 nations have $1.0 \geq 10.0 \leq$, 21 nations have $10.0 \geq 20.0 \leq$, and only 8 nations have $20.0 \geq 44.0 \leq$. It is notable that people or population is not indicative of the extent of carbon emissions from a country. Table 1 shows that the top nations have fewer populations whereas the low emitters have large people living within their borders. At best, it can be argued that the lifestyle of the overall people may have marginal influences on carbon emission, while the main factor may be the type of industries servicing an economy. This is evident as the top emitters run economies that depend on fossil fuel while the least emitters are basically less industrialised countries in Africa.

To put this argument in perspective, although the indices for both South Africa and the Netherlands are close (9.3 and 10.1 respectively); there is a wide gap in the number of people living in both countries. According to the fact book of the Central Intelligence Agency (CIA) of the USA, the population of South Africa is 53,675,563 and that of the Netherlands is 16,947,904 as at July 2015. These figures are even far behind the population of the USA, which stood at 321,368,864. In fact, the populated nations of China and India have 6.7 and 1.7 indices respectively. These illustrations support the argument that the main driver of growth and environmental degradation is not population per se, but consumption patterns and levels multiplied by the number of consumers, especially in developed economies (Toth and Szigeti, 2015). These disparities between the carbon emission indices and population imply that individual behaviours are yet to significantly impact the amount of emissions from a country. In other words, the calculation of CFP should go beyond individual behaviour and focus on a more comprehensive form of information that may be captured in an EFP calculator.

Table 1: A summarised CO_2 2011-2015 emission indicators (metric tons per capital)

Top 10			Bottom 10		
Country	Index	People	Country	Index	People
Qatar	44.0	2,194,817	Burundi	0.0	10,742,276
Trinidad and Tobago	37.1	1,222,363	Chad	0.0	11,631,456
Kuwait	28.1	2,788,534	Burkina Faso	0.1	18,931,686
Brunei Darussalam	24.4	429,646	Eritrea	0.1	6,527,689
Aruba	23.9	112,162	Ethiopia	0.1	99,465,819
Luxembourg	20.9	570,252	Malawi	0.1	17,964,697
United Arab Emirates	20.4	5,779,760	Mali	0.1	16,955,536
Oman	20.2	3,286,936	Rwanda	0.1	12,661,733
Saudi Arabia	18.1	27,752,316	Niger	0.1	18,045,729
Bahrain	17.9	1,346,613	Guinea-Bissau	0.1	1,726,170

Sources: World Bank (2015); CIA Fact book (2015)

To give strength to the initial purpose of the research, the authors submitted personal information into CFP calculators. The authors selected the calculators based on a Google search for the top-three visited CFP calculators in each country to select the most used calculator. However, the search results for individual author differs and more worrisome is that a common top calculator is only available to residents of USA alone. Thus, a common calculator for CFP for the three authors was not identified. The story is not the same with the EFP calculator, which allow the authors to take similar test that allows consistent comparison between their countries. The decision to take a test based on EFP is also born out of the fact that CFP is a component of EFP. Although EFP and the CFP are matrices for measuring the impact of routine human activity on the environment, both matrices differ in their scope, expression of impact values, and the perspectives of calculations. For example, the CFP takes into account only the activities related to GHG (Weidema et al., 2008), which are directly influenced by fossil fuel burning, and indirectly by electricity consumption.

Graphs	Country	Data Quality	HDI	Per Capita GDP	Region	Income Group	Total Ecological Footprint [gha per capita]	Total biocapacity [gha per capita]	Biocapacity (Deficit) or Reserve [gha per capita]
	Netherlands	6	0.91	$ 46,309	EU - 27	HI	4.5	1.1	(3.3)
	South Africa	6	0.65	$ 11,910	Africa	UM	2.5	1.1	(1.4)
	United States of America	6	0.91	$ 49,746	North America	HI	6.8	3.7	(3.1)

Figure 2: Snapshot of national ecological footprint of three countries (source: GFN, 2015)

The CFP thus gives the raw amount of carbon emission in tonnes per year as an output. In contrast, the EFP describes the entire activities a person is involved in, and the resources utilized as well as the wastage generated through such activities. It measures how much of the biosphere's annual regenerative capacity is required to renew the natural resources used by a defined population in a given year (Venetoulis and Talberth, 2008). The EFP gives values of the land and water area that is needed to replace the resources consumed – these directly affect the built environment in terms of construction and use of materials in the industry. In brief, the CFP metric aims to reduce the impact on the environment by reducing global warming and evading catastrophes while the EFP takes all problems of the environment as a whole and target sustainable development as a goal.

3. Ecological footprint exploration – national metrics

This distinction between the CFP and the EFP and the need to use a consistent tool by the authors lead to the use of the calculator of the Global Footprint Network (GFN). The calculator, www.footprintnetwork.org/en/index.php/GFN/page/personal_footprint/, was used to compute the individual footprint of the authors and their home countries. The terminologies of GFN (2015) calculator include biocapacity, which serves as a lens that shows the capacity of biosphere to regenerate and provide for life; and the global hectare (gha), which is a biologically production hectare with world average productivity.

When the behaviour of those deemed sustainable friendly and environmentally most conservative, yet maintain levels of consumption in excess of the global standards by a factor as much as two (ScienceDaily, 2008) one has to be concerned with motivation. Factors such as military, infrastructure and roads, public expenditures etc., that increase the average CFP may attribute to the attitude.

4. Ecological footprint exploration– personal metrics

When the authors calculated their individual EFP, the data shown in Table 2 and Table 3 were produced through the GFN calculator. In Table 2, impact refers to the activities that impact personal footprint. For instance, if everyone lived like Anton, humanity would need 3.0 planet earths to provide enough resources, and to support the lifestyle of Anton, it takes 6.3 global acres of the earth's productive area that include all the six EFP components. Among these components, CFP of Anton has been estimated to be 18.4 tons.

In addition, Table 3 shows the breakdown of the personal EFP of the authors. In ranking order, services, shelter, food, goods, and mobility constitute the percentage contributions of activities, which make up the EFP of Anton.

For the author resident in South Africa with a family of four and an SUV for mobility, impact is rated at 2.4 and to keep the lifestyle going, 4.4 global acres of the earth's productive area shall be required. It is however notable that the test undertaken in South Africa did not produce the CO_2 emission estimate for Fidelis. Although the authors answered very similar questions on the GFN calculator, the calculation of the metrics may be country dependent, hence the lack of CO_2 data for the South African author. As illustrated in Table 3, food and shelter contribute the most to the personal footprint of Fidelis. In other words, if Fidelis is to reduce his EFP, these are the parts that he should influence.

Table 2: Comparative personal ecological footprints of authors

Author	Country	Impact	Support	CO_2 (tons)
Anton	Holland	3.0	6.3	18.4
Fidelis	South Africa	2.4	4.4	-
Erich	USA	4.4	19.8	22.0

Source: Authors

The American author also undertook the same test on the GFN portal to produce the data displayed in Table 2 and Table 3. The data is self-reported into the calculator and depending on the circumstances of how one view their circumstances can make a significant difference in the score. For example, the American author lives in a different location from his family due to his employment. His household compared to the Dutch author with same number of children, which consists a total of five residences and five cars and whereas the Dutch author has one residence and two vehicles, but the criteria based on the calculator inputs did not account for these differences, which then would make dramatic changes in the comparative scores. The Dutch motivation may be associated with the fact that the government taxes Co_2 unfriendly and subsidize Co_2 friendly practices in manufacturing, travel, design and construction. These are successful in changing consumer's behavior. Owning / using a car in the Netherlands is approximately three times more expensive as in the USA, and the public transportation system is partially financed by private vehicle taxes and the same logic is applied to Co_2 emissions of buildings.

Table 3: Comparative personal ecological footprints of authors – break down in ranking format

Criterion	Anton	Fidelis	Erich
Food	3	1	3
Shelter	2	2	4
Mobility	5	3	5
Goods	4	4	2
Services	1	5	1

Source: Authors

5. Discussion

In "*Footprints to nowhere*" (Giampietro and Saltelli, 2014) cast doubts on the ability of EFP and CFP metrics to accurately capture the complexity of human progress in term of sustainability. In fact Beynon and Munday (2008) have attempt to demonstrate the imprecision and uncertainty in the EFP estimation. The thrust of the doubts of Giampietro and Saltelli (2014) pertain to the semantics and syntax of what these metrics represent and the downsides of using them for policy making. Despite the fact that these doubts have elicited debates from the scientific community (van den Bergh and Grazi, 2015), 'business as usual' mode of production and development cannot continue in perpetuity. In the context of the built environment, which is represented by cities and urban areas, there is a clear case to address climate change through mitigation and adaptation (McManus, 2015), which is inclusive of regeneration. The built environment of rapid urbanisation has spawned traffic fatalities, pollution of all forms, and endemic threats to human well-being (Herzog, 2015). Thus, sustainable development is a key issue for developing countries such as South Africa, who need to achieve poverty alleviation, infrastructure development, shelter for all and higher consumer expectations within added constrains imposed by ecological limits of the biosphere (Moran et al., 2008). With major carbon emissions from both existing buildings and infrastructure and on-site construction (Construction Industry Development Board, 2009), South Africa requires development without a corresponding increase in per capital demand on ecosystem resources (Moran et al. 2008). The ethics / moral of this paradigm is that most developed nations have achieved their development without such constrains - why should other nations follow a separate developmental path? In terms of the built environment, changing the behaviour of individual clients, designers and contractors, including their employees would lower the CFP through the choices that are made (Emuze, 2015).

By definition, sustainability is global, complex, comprehensive, and involves everyone, everywhere, all the time. A multi-perspectival approach review of sustainability is witnessed in the organization, Triple Pundit. Taking into considerations people, planet, and profit in regards to sustainable practices globally (TriplePundit, 2015). Responsible leadership is an ethical approach that considers all constituents of a society and serves as a model in which leadership does not necessitate a strong top down approach to assure responsible conduct but engages at all levels of a society. Such an organization would be constituted of interrelationships that involve wide participation in robust public debate that forms a "broad and durable political consensus devised and implemented by partnerships among private firms, non-governmental organizations, municipal agencies, utilities, community groups, neighborhood groups and individuals" in other words, everyone (Hawken, Lovins, and Hunter-Lovins, 2000).

An interesting suggestion made by Rakhorst (2012) in the Dutch translation of the book Cradle to Cradle (McDonough and Braungart, 2002) is not to try to achieve a decrease in the things we do badly, but to try to achieve to increase the thing we do good, and green. From a pedagogical point of view, this is in alignment with a behavioristic view (Skinner, 1976). Behaviorism is the philosophy which assumes that behavior is a consequence of environmental histories of reinforcement. If the positive outcome of Carbon neutral behavior is visible, direct and sensed as resulting from one's own choices it is easier reinforced that if the outcome's positive effect is delayed, and not experienced as the result of one's own doing. Of course this is going to be a difficult task in a society where we buy ready made products and the relation between the final product and the amount of energy needed for production is far from clear. Perhaps making this relation between resources and products more transparent again can contribute in change.

6. Conclusions

The original intent of this research was to provide a comparative text based on CFP of each author in which the data would be understood based on equitable criteria. Then followed by an analyses of the rating systems to provide a basis for "sustainable" practices. However, as data were gathered, it became apparent that the most frequently used CFP calculator was not viable in the authors' location because of the national bias of the CFP calculator criteria (bad).

The assumption that an understanding of the CFP (good) and knowledge of how to reduce it would be sufficient motivation for lowering the footprint was not confirmed. CFP calculators which are not globally applicable, have value in that they engage individuals in the understanding of sustainable practices at the personal level.

Those individuals with the largest footprint may not feel compelled to change the consumption patterns required to be sustainable because of the differing values (ugly) of the more affluent, regardless of nation, when using a CFP calculator.

While this realization confounded original intent of the authors, it begins to clarify the complexity that is not readily apparent when making broad and sweeping statements about sustainability, typical of such terms as "green" or "sustainable". The prospects for change and improvement need to be carefully understood and this study begins to get the more complex issues that entail, policy, politics and ethics, at varying levels of social responsibility.

Responsible behaviour at all levels of social endeavours is a fundamental necessity for sustainable initiatives to be effective and genuine. A more critical understanding emerges when you are willing to see things from additional perspectives. From the scale of the individual to the scale of nations, if one looks to means for reducing footprint globally people are on ethical grounds to a sustainable future. It is a matter of "scale" that the CFP calculator can stimulate concern among individuals and their ability to make a difference. Oversimplification of sustainability can and has led to misunderstanding and or dismissive attitudes about the need to be responsible. Complexity and differences in evaluative criteria can provide conflicting data. The issues of how one impacts a carbon footprint are variable depending on location, history of development, population and infrastructure.

Therein lies the need for governments to provide leadership by showing courage, cooperation, fairness and moral fortitude in finding ways to change patterns to practice global enlightened self-interest for a sustainable future, as demonstrated in the COP 21 climate change summit held in Paris the week of November 20, 2015 where 40,000 delegations from 195 countries met to discuss a globally binding, nation flexible, equitable, comprehensive and durable agreement that reduces greenhouse gases emissions. The leadership of nations can serve as motivation for individuals to follow in their choices to be more sustainable, as the German Chancellor Angela Merkel remarks suggest, "billions of people pinning their hopes on what we do in Paris…Let us do everything we can not to dash those hopes," (CNN, 2015).

Awareness of consequence is a mitigating factor in creating change in personal as well as national behaviours, subjecting oneself to a CFC measure that can be comparable is a good first step in beginning a dialog between citizens and a practice that moves one towards global responsibility. It was the authors' experience that comparing own footprints and trying to genuinely explain the differences made each author more critical of the complexities and speaking to issues related to sustainability. The authors encourage involvement of other people in the same. *"Make it your business to draw out the best in others by being an exemplar yourself." ~ Epictetus*

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Modelling construction industries internationally, using the UK benchmark model

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Abstract

Numerous countries produce data on the size, growth and performance of construction. Unfortunately, there is little consistency in the way construction is measured in different countries. This makes comparing and aggregating construction data difficult if not impossible. In the absence of an internationally consistent measure of construction, the UK benchmark model is intended as a first iteration of an approach to gather existing data and compare it based on common measures. The modelled data consists of total construction output, construction output by type, employment and skills and trade and output of specialist firms. This data will be useful for making comparisons with other international construction data and can be used to estimate comparisons of construction productivity and identify countries with the strongest construction industries, which may be useful in discovering countries where construction best practice exists. However, important limitations of the UK benchmark model are seen as pointing the way to further improvements of the benchmarking approach. The purpose of this paper is to set out the scope of the data that can be modelled using the UK as a benchmark and highlighting the weaknesses of the model that need to be taken into account in order to improve future international construction industry data comparisons.

Keywords: UK benchmark model, international comparison of construction, construction data, Gross Fixed Capital Formation

1. Introduction

Following the United Nations Climate Change Conference held in Paris, the Conference of Parties 21, (COP 21), in 2015 there emerged broad international agreement on the effect of climate change, (Clark and Stothard, 2015) These climate changes can be expected to impact on the construction sectors of all countries for a variety of reasons. As sea levels rise and populations are forced to move inland, where regional agriculture is no longer viable and people move into cities, expanding the size of urban populations, the implications for the global construction sector is likely to be great. The need to plan for these population movements places an obligation on policy makers to assess the amount of construction needed and the capacity of the international construction sector to meet these challenges. Economic, social, political and construction industry considerations are likely to play a major part in determining the ability of political elites to manage a peaceful, productive and creative standard of living for the global population. The scale of the problem could not be higher and the challenge greater.

If one accepts that unless policies for dealing with the consequences of climate change are developed, the cost of not acting is likely to be greater than attempting to plan for the changes when political and international tensions increase still further. Stern (2008) recognised the risks of climate change in terms of acting to mitigate risk by reducing CO_2 emissions, which he equated with the kind of decisions taken when designing buildings and infrastructure. There is therefore a need to measure the extent of the problem on a global scale and this involves assessing the size, extent and location of global construction activities. To assist in this process, the purpose of this paper is to set out the scope of the data that can be modelled using the UK as a benchmark, while highlighting the weaknesses of the model that need to be taken into account in order to improve future international construction industry data comparisons that could be used to measure built environment changes as a consequence of climate change.

There is therefore an urgent need to confront the issues on a global scale. Unfortunately, there is as yet no way of comparing or aggregating national construction industries in any detail in a way suitable to estimate the potential global demand for housing, buildings and infrastructure and the capacity of the world construction industry to meet that demand. The training of labour, the materials needed and the plant and equipment as well as the costs to be managed by the public sector are all necessary to establish the scale of the problem and the policies required.

As a first step, comparable estimates of national construction industries are needed. Such information will also be of use to the private sector in terms of indicating and anticipating market changes in different countries. The public sector can also begin planning procedures, skill training requirements and the assessment of national construction industry capacities to meet demand. International bodies and funders also need the data to ensure sufficient finance is available in a timely and planned manner.

As national data is not always available in a consistent form and as it is invariably difficult to make comparisons of the national data, the use of a model is suggested to simplify the process of aggregating and comparing construction in different countries. For this reason the UK benchmark model is described here with a view to illustrating the type and scope of data that may be discussed.

2. The UK benchmark model

If one adopts a pedantic approach to construction data, it will always be possible to find fault with the conclusions. Therefore in order to measure construction on a national scale let alone a global scale, it is necessary to make sweeping assumptions based on experience, knowledge and alternative sources of information. The errors and estimates built into all construction data of necessity means the data is invariably inaccurate and imprecise.

When confronted with a battery of statistics, decision-makers may respond in a spectrum ranging from accepting the data without question, to being highly sceptical of the figures and rejecting the exercise as almost a waste of time. As usual a reasoned response lies somewhere between these two extreme positions. When one examines the data in detail, how it is defined and how it is gathered, the task of capturing meaningful results becomes even more challenging. Take for example, House (2013), who describes the composition of residential data in Gross Fixed Capital Formation (GFCF) compared to housing in construction output data. Although at a cursory glance these time series may appear to be attempting to measure the same thing, they differ in several ways.

Table 1: Components of GFCF dwellings and the construction aggregate housing

GFCF dwellings	*Construction aggregate components*
New build	
New dwellings	New build output
Private housing	Private new housing
Public housing	Public new housing
Housing fees	
Self builds	
Work on existing stock`	
Dwellings improvement	All repairs and maintenance (housing total)
Contracted improvements	
Hidden improvements	
DIY improvements	

Source: House, G., (2013) Conceptual differences between an aggregate of construction output measures and the GFCF dwellings measure, Office for National Statistics

To begin with, GFCF data covers the United Kingdom whereas the construction data only covers Great Britain. Moreover, Table 1 compares the housing components of GFCF and construction output data. While the construction output data includes all repair and maintenance, the GFCF data uses "improvements" that add to the value of buildings, of which 27% of work on existing stock (see Table 2) is classed as hidden improvements, which are based on estimates of unrecorded work or firms or individuals outside the construction industry. The GFCF figure is a measure of expenditure and includes tax and charges, which are not included in the construction output measure. The result of these differences is that one would expect the GFCF construction figures to be greater than the construction industry output figures based on the survey of construction contractors.

Table 2: Components and percentage share of GFCF dwelling components

Component of dwellings in GFCF	% of total	% of new	% of improvement
New dwellings	52		
of which public housing		17	
of which housing fees		0.7	
of which total private housing		82.3	
Dwellings improvement	48		
of which hidden improvements			27
of which DIY improvements			5
of which contract improvements			68

Source: House, G., (2013) Conceptual differences between an aggregate of construction output measures and the GFCF dwellings measure, Office for National Statistics

As estimates of hidden construction are 27% of improvements or approximately 14% of total dwellings output, it is not surprising that even official data is open to criticism and doubt. The figures are what the profession of statisticians presents and the methods used are not always understood or transparent as far as the user is concerned.

The value of annual UK construction output used in the model described here, called the UK Benchmark Model (UKBM), makes use of the official UK Office for National Statistics data. It is not necessarily accurate but may be the best estimate available. This means that it can be used to inform debate and can be used to model the construction industry, provided there is a degree of understanding that the data may not be entirely accurate. To some extent it would be preferable to have a range lying within say a

5% or 10% confidence interval rather than a single figure lying within the range. Nevertheless official data is presented with single estimates. The UKBM should be viewed as only a first iteration. The purpose of which is to communicate the scope of the research it is proposed to develop over the next two years in TG81 Global Construction Data.

The principle of the UKBM is to take the data for the UK as a guide to a number of ratios in other countries on the assumption that in the absence of evidence to the contrary, the UK ratios are indicative of the equivalent ratios in other countries. These UK ratios are used as coefficients of the national GFCF and aggregate national construction output estimates to find the total size and breakdown of national construction industries.

The following section begins by listing the official tables used in the UKBM model. They can be found in the websites of the UK Office for National Statistics and the UN Statistics Division. These form the source of data for modelling construction output enabling an analysis of types of output, type and size distribution of firms, skills and employment of construction labour. We then describe how the tables are used to build the UKBM model.

3. Finding the data for the UKBM model

To build this first iteration, Table 3 lists the tables used in the UKBM model.

Table 3 Sources of data of the UKBM model

Publisher	*Table title*
1 Construction Statistics Annual UK Office for National Statistics	Table 2b Construction output: volume non-seasonally adjusted – by sector
2 Construction Statistics Annual UK Office for National Statistics	Table 2.4 Value of construction output by type of work
3 Construction Statistics Annual UK Office for National Statistics	Table 2.8 Private contractors: Value of work done, by trade of firm and type of work
4 Construction Statistics Annual UK Office for National Statistics	Table 2.9 Private contractors: Value of work done by size of firm and trade of firm Values are in current prices.
5 Construction Statistics Annual UK Office for National Statistics	Table 3.4 Number of firms by size and trade of firm
6 National Income Accounts Office for National Statistics	Table G8, Gross Fixed Capital Formation by sector and type of asset
7 UN Statistics http://unstats.un.org/unsd/snaama/dnlList.asp	UN Data Table "GDP and its breakdown at constant 2005 prices in US Dollars" (All countries)

Because it is difficult to locate specific spreadsheets in the UN database, the following advice is given. For the purposes of accessing data for the UKBM model, the UN url is given in Table 3 above for the UN Data Table. This will direct the reader to the UN National Accounts Main Aggregates Database. From there, select "GDP and its breakdown at constant 2005 prices in US Dollars." From the list select the country and then "Gross fixed capital formation (including acquisitions less disposals of valuables)" for the country selected.

4. The UKBM model

The purpose of the UKBM is to find a consistent international measure of construction output and other construction variables, such as the size of markets for various building types, number and types of firms, numbers employed and skills. This will provide a data base of estimates of the size and growth rates of all national building industries, a breakdown of different types of buildings and structures, the number and types of firms, numbers employed and skills. This will in turn provide time series of various national and sub-national variables, including estimates of capacity, size of markets and growth rates.

The basic UKBM model estimates total annual construction output and size of types of work. A second model, not discussed here, will model firms, skills and employment. What follows is a statement of the method used to build the model.

In order to link the construction industry measures of the national construction industries of all countries, GFCF is used as this is comparable for all countries and is published by the UN Statistics Department. The theoretical definition of GFCF is the value of capital formation before depreciation. The GFCF figure includes new build dwellings and other new buildings and new build structures but the size of the construction industry is measured as the total of new build *and* repair and maintenance. As repair and maintenance (R&M) is maintenance of existing buildings it is a form of depreciation or capital consumption, which is not included in GFCF in principle. We therefore assume only new build is included in GFCF. To include repair and maintenance to find total construction output, an adjustment to the built element of GFCF is needed. The UK benchmark model therefore adjusts the new build construction element of GFCF by adding an estimate of R&M. This is achieved using the following steps:

1. To find the average ratio of new build to total build 1997-2014 access Table 2b “Construction output: volume non-seasonally adjusted – by sector” in the Office for National Statistics construction statistics series.
2. Use the inverse of the ratio in step 1 to multiply each year’s total built element in GFCF in Table G8 “UK GFCF by sector and type of asset” not seasonally adjusted, chained volume reference year = 2011. This forms an estimate of annual total construction, including R&M.
3. Use total UK construction calculated in step 2 to estimate the average ratio of the total construction to UK GFCF between 1997 and 2014 or any other appropriate years.

4. Use the average ratio found in step 3 as the co-efficient of the UN annual GFCF for specific countries selected in the UN table entitled “GDP/breakdown at constant 2005 prices in US Dollars (all countries)”. This is the UK benchmark estimate of the value of specific country’s annual construction outputs.

The size of construction for any country can be modelled from UN GFCF using the ratio of the UK built element in UK GFCF over UK GFCF as a benchmark co-efficient. The modelled data given here is construction output 1970 to 2013. This is based on the average ratio of new build to total UK construction output data for 1997 to 2014, the average ratio of the UK built component of GFCF over GFCF for the period from 1997 to 2014 and UN GFCF data for 1970 to 2013.

4.1 Limitations of the UKBM model

According to the OECD, (2014) gross capital formation includes spending on additions to fixed assets, such as the construction of roads, railways, offices, industrial buildings, hospitals and residential dwellings. According to the OECD, data on construction capital formation is equivalent to data on construction activities. The reliability of data, the OECD warns, depends on the quality of government accounting systems and these are often weak in developing countries. Measures of fixed capital formation by households and firms, especially by small enterprises, can be inaccurate.

The UKBM model assumes the ratios of the UK can be transferred and applied to other countries. However, the UK is not necessarily representative of the countries shown. According to OECD (2014), Table 4 compares buildings and structures as a percentage of GFCF in 31 countries for the years 2001 and 2011.

Table 4: Change in percentage of built component of GFCF 2001 and 2011 for 31 countries.

Country	*2001*	*2011*
Australia	47.35	58.49
Austria	53.73	51.92
Belgium	46.91	54.91
Czech Republic	45.56	50.07
Denmark	49.56	50.89
Estonia	50.24	50.50
Finland	61.19	68.22
France	57.06	62.34
Germany	54.31	55.65
Greece	65.19	52.64
Hungary	50.26	52.12
Iceland	61.20	54.34
Ireland	68.99	53.65
Israel	49.78	52.08
Italy	47.89	52.14
Japan	50.96	47.08
Korea	57.44	57.96
Luxembourg	51.83	56.77
Netherlands	56.55	56.26
New Zealand	47.47	55.56
Norway	63.17	69.00
Poland	56.20	62.04
Portugal	62.23	61.41
Slovak Republic	46.86	45.14
Slovenia	52.20	49.71
Spain	66.35	62.39
Sweden	38.03	43.52
Switzerland	41.07	45.33
United Kingdom	*55.27*	*64.11*
United States	43.72	37.25
South Africa	33.74	48.47

Source: National Accounts at a Glance 2014 - © OECD 2014, Chapter 3 Table 10.2. Gross fixed capital formation by asset Version 1 - Last updated: 30-Jan-2014

Examination of the data shows that the average based on the geometric means of the countries in Table 4 in 2001 and 2011 were 52.00 and 53.79 respectively. The UK stood at 3.27 above the mean in 2001 and 10.32 in 2011. This meant that the UK was 0.39 of 1 standard deviation above the mean in 2001 and 1.44 standard deviations above the mean in 2011. This represents a large relative share increase of GFCF of the UK construction industry compared to the construction industries of the other OECD countries listed and implies that the UK industry was not typical of the relative performance of the other countries in 2011.

Figure 1 shows the change in the size of construction compared to GFCF in 7 mature economies at a similar stage of development to that of the UK. The performance of the UK construction industry relative to investment in plant and machinery shows that in the UK the share of construction in GFCF grew faster in the UK than it did in the other comparable economies. This of course could be due to changes in the amounts invested in plant and equipment as much as increasing investment in construction in the UK. At the very least it reflects changes taking place in all these economies following the global financial crisis which began in 2007.

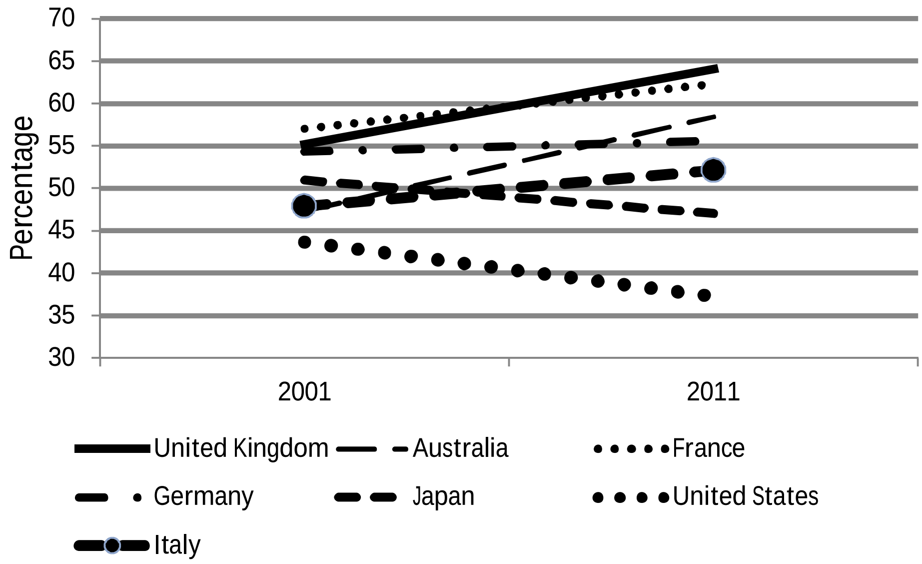

Figure 1: Changes in percentage of built component in GFCF 2001 – 11 of 7 selected countries

Source data for Figures 1-5: National Accounts at a Glance 2014 - © OECD 2014, Chapter 3 Table 10.2. Gross fixed capital formation by asset Version 1 - Last updated: 30-Jan-2014

Figure 2 shows the UK to have a greater proportion of construction in GFCF than the average for the other 31 countries compared in Table 4 or even the 7 selected countries shown in Figure 1. This data shows that the performance of the UK during the period between 2007 and 2011 may have influenced the results rather than the performance of the construction industry alone. The UK economy recovered and managed to recover faster than the other countries during an exceptional economic crisis. Further research is needed to assess the performance of construction in detail over a longer period.

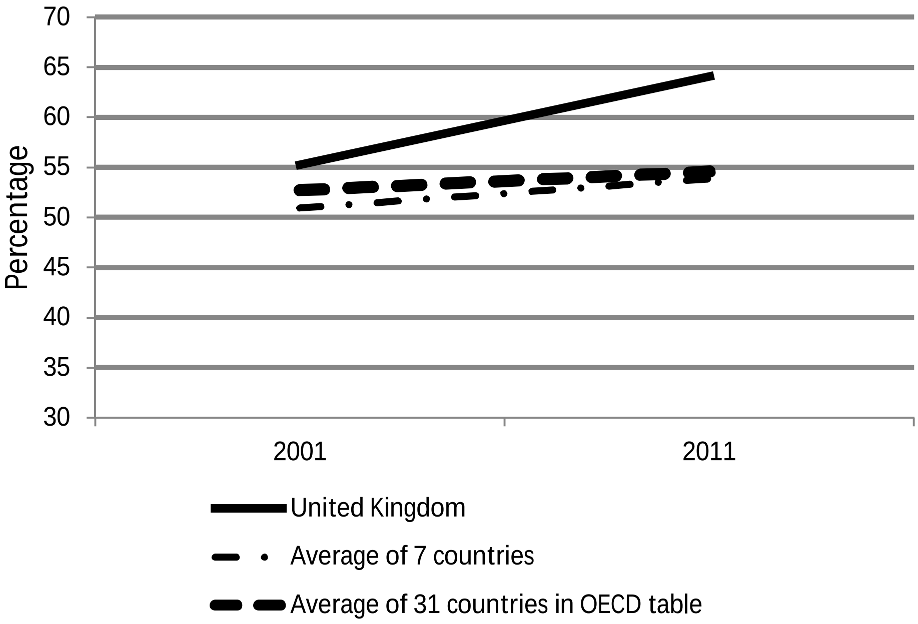

Figure 2: Changes in percentage of built component in GFCF 2001 and 2011

The differences between the UK and the other countries compared in Table 4 demonstrate that the UKBM model needs to be used with caution. Nevertheless, from the UKBM model covering the period from 1970 to 2012, two differences emerge compared to the official UN data sets. First, size of the construction sector in the UKBM model is much greater than the ISIC figures for the same years published by the UN. Secondly, the UKBM shows a higher growth rate than the International Standard Industrial Classification (ISIC) data of the construction industry. Examples of these results can be viewed in Figures 3 to 5 for the US, the UK and Japan. These results raise several issues and questions. Is the difference in size significant? Are the differences in growth rates significant? Which set of data supports which theories? Did global construction see an expansion since 1970? Or has the construction industry as a whole stagnated over the last 40 years?

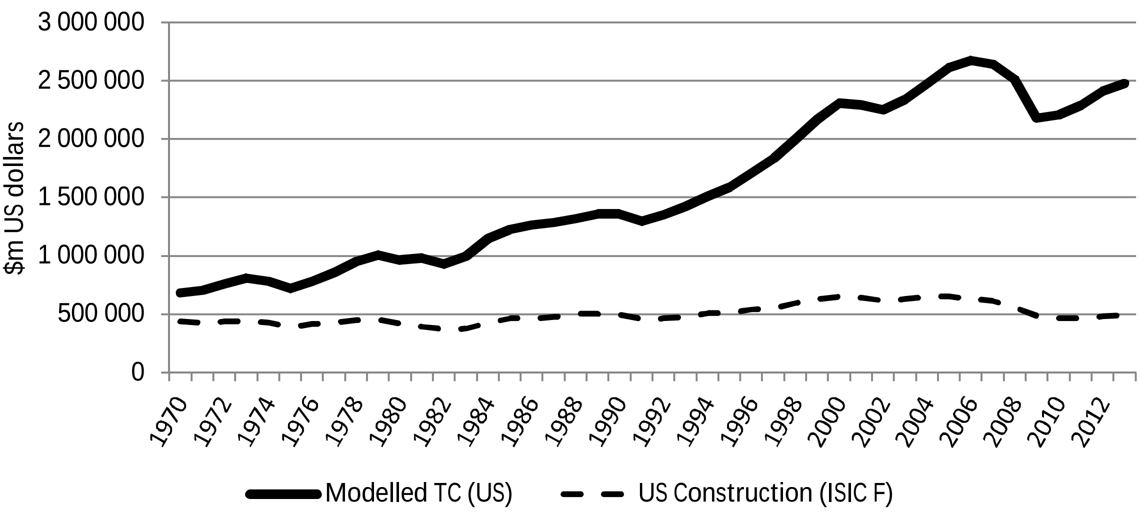

Figure 3: United States ISIC F Construction and the UKBM for construction output 1970 to 2013

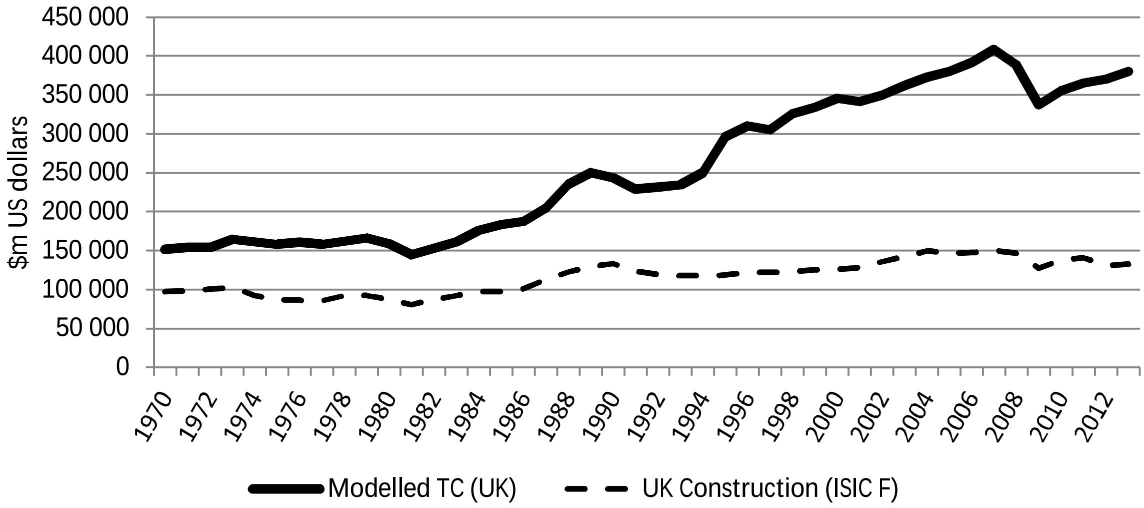

Figure 4: United Kingdom ISIC F Construction and the UKBM for construction output 1970 to 2013

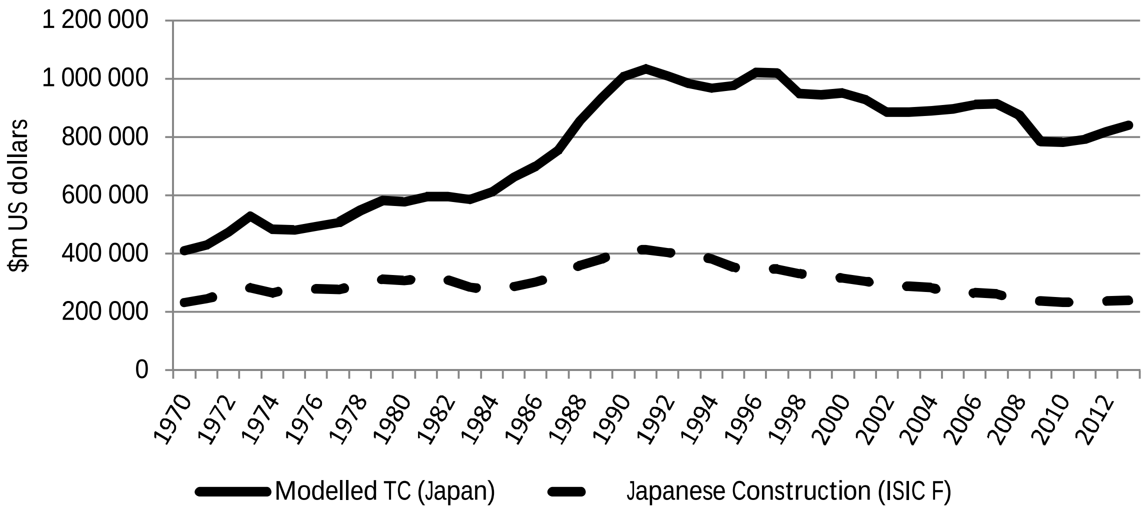

Figure 5: Japan ISIC F Construction and the UKBM for construction output 1970 to 2013

5. Concluding remarks

The UKBM is a first iteration of a model to find a consistent approach to measuring construction industries internationally. One feature of the UKBM model is that it treats all countries in the same way, making it possible to compare results as the methodology is consistent. However, this method has shown that using one country as a benchmark to base the coefficients of the model is too simple and too dependent on one country and the performance of its construction industry.

The limitations discussed above point to the need to either establish a basket of countries to form an average benchmark or to develop different benchmarks for different regions of the world or different economies at different stages of development.

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Factors influencing the renegotiation of public-private partnership road projects

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Abstract

A critical evaluation of recent literature reveals that there is evidence of a high incidence of renegotiation in public-private partnership (PPP) infrastructure projects, particularly in the road sector. This high incidence of renegotiation in road projects can be attributed to a number of factors, which influence the decision of the primary stakeholders to renegotiate the contract. Based on this prevailing situation in PPP road projects, this paper evaluates and assesses the factors influencing the renegotiation of PPP road projects. An exploratory research method involving a comprehensive literature review of PPP road projects was adopted. The findings of the study indicate that the factors influencing PPP road projects fall under design, economic, technical, institutional, regulatory, contractual, administrative and managerial, political, social and environmental categories. The paper concludes by identifying the factors, which have profound influence on the renegotiation of PPP road projects. These can be classed as design, regulatory, administrative, and technical factors in their respective order of literature prominence. The development of modalities to assess and ensure the credibility of PPP regulation and the proper estimation or evaluation of PPP road projects at the design, technical and administrative/managerial levels are recommended.

Keywords: Critical factors, renegotiation, public- private partnership, road projects and transport sector**.**

1. Introduction

Previous theoretical and empirical studies investigate contract renegotiation of PPP projects by investigating the incidences and influencing factors among others. Furthermore, notable studies across countries provide a summary of PPP infrastructure projects renegotiation, particularly in transport projects. Evidence from numerous renegotiation studies in Latin American countries as well as Portugal and Spain, reveals the characteristics of the respective cases of renegotiation. An examination of these cases reveals that the stakeholders involved in PPP infrastructure projects usually have reasons for the renegotiation of projects at strategic implementation points.

Given that the renegotiation of road projects is usually premised on the reasons identified by the public agency and private concessionaire, which may also be regarded as the motive of the parties to the contract. Hence, there are numerous reasons why stakeholders may want to renegotiate a contract in a PPP environment which may sometimes be distinct from the drivers of the renegotiation. However, what influences the decision of the stakeholders to renegotiate the contract is the subject of this discussion. These influence factors require in-depth and critical evaluation in order to arrive at appropriate answers with regards to the factors influencing PPP road project renegotiation. The clear reason for carrying out a critical study on this subject is the dearth of comprehensive literature in this area. Thus, this paper evaluates and assesses the factors which can positively or negatively influence the outcome of PPP road project renegotiations.

2. Overview of the Renegotiation of Transport Sector Projects

Road projects constitute significant means of transportation in developed and developing countries (Gor and Gitau 2010). Indeed, it has been procured on the basis of PPP across and has demonstrated a high percentage of renegotiations in many countries, e.g. Latin America and the Caribbean (Bitran et al., 2013), US (Gifford et al., 2014), Portugal (Sarmento, 2014), Spain (Baeza and Vassallo, 2010) and Greece (Nikolaidis and Roumboutsos, 2013). Examination of 254 renegotiations in Portuguese infrastructure projects reveals that the road sector accounted for 233 cases which ended with compensation to the private company (Sarmento, 2014). In Latin America, experience reveals that 54.7% of transport concession contracts awarded were renegotiated and mostly benefited the concessionaires (Guasch, 2004). Furthermore, Engel et al. (2009) note that the Chilean experience reveals that firms lowball their offers, expecting to break even through renegotiation. Governments also use renegotiations to increase spending and shift the burden of payment to future administrations. Thus, renegotiation of these concessions thus results in increases in the future costs of service for users.

Moreover, Reside and Mendoza (2010) appraise the Asian experience and reveal that about 70% of PPPs are renegotiated, which in most instances results in increased subsidies and financial compensation for the concessionaire companies. Renegotiation of PPP projects also tends to be unfavourable to the public sector in the United States of America (Gifford et al., 2014). Summarily, the study of Fatokun et al., (2015: 1254) review renegotiation issues and outcomes and agrees with the findings of these literature that *"most PPP projects, and particularly road projects are highly renegotiated and analysis of the renegotiation of PPP road projects across* *notable countries revealed that value for money (VfM) is not achieved for the public sector in most cases".*

Therefore, the high incidence of renegotiation in PPP road projects needs to be reviewed and investigated in order to identify the factors which influence contract renegotiation. Hence, the aim of this paper is to as far as possible elaborate on the findings of the previous paper i.e. (Fatokun et al., 2015) in order to fill the vacuum in knowledge through a thorough evaluation and explanation of renegotiation influence factors in PPP road projects. What is striking is the way the respective sub-factors are categorised under the main category, which relates to the respective phases of implementation. Obviously, the renegotiation of PPP road projects has been found to be influenced by several factors.

3. Research Methodology

This paper is based on a review of recent literature, most of it published within the last ten years and whose content were analysed systematically in line with the recommendation of Guasch (2005) for an extensive study to further the understanding of the various renegotiation issues in PPP projects (including roads). These issues are related to pre-concession, concession design and award, regulatory, institutional, economic/technical and administrative procedures. The review was done through an evaluation of twenty-three academic papers of which most were journals. It was observed that the factors which influence PPP road projects renegotiation fall under these issues. In addition, the review lead to the identification of fifty-two factors categorised into ten groups, all of which have influences on the renegotiation of PPP road projects. These categories elaborately delineate the underlying factors which encompass and extends beyond the related issues identified by previous studies as having influence on PPP road projects renegotiation.

4. Factors Influencing Renegotiation of PPP Road Projects

Many reasons and advantages have been adduced for the adoption of PPP. However, in spite of the reasons and advantages claimed for the adoption of PPP in infrastructure project delivery (including transport projects), this procurement method has over the years witnessed setbacks due to factors constraining its successful implementation. These factors include issues relating to incomplete contracting, project abandonment, cost and time overruns, and renegotiation among others (Guasch et al., 2014; Domingues and Zlatkovic, 2014; Nikolaidis, and Roumboutsos, 2013). However, one of the major factors is the renegotiation of PPP contracts (Cruz and Marques, 2013; Estache et al., 2009). The factors influencing the renegotiation of PPP projects can, therefore, be classified as design, contractual, technical, institutional, regulatory or legal, environmental, economic and social, etc. Table 1 shows in detail the respective sub-factors under each of these headings, giving the respective sources of the papers in which they are discussed.

Table 1: Factors Influencing the Renegotiation of PPP Road Projects

Influencing factors / Publication/Source	Cruz et al. (2015)	Guasch et al. (2014)	Domingues & Zlatkovic (2014)	Bitran et al.. (2013)	Cruz & Marques (2013)	Menezes and Ryan (2015)	Bi and Wang. (2011)	Montecino & Saavedra(2011)	Baeza & Vassallo (2010)	De Brux (2010)	Reside & Mendoza (2010)	Chan et al. (2010)	Saussier et al. (2009)	Athias & Nunez (2008)	Estache et al. (2009)	Guasch et al. (2007)	Engel et al. (2009)	Guasch & Straub (2009)	Guasch (2005:2004)	Estache et al. (2003)	Guasch et al. (2004)	Sarmento (2014)	Number of Citations
Design factors																							
Change in concession design scope					√																	√	2
Inaccurate estimation of traffic level	√	√	√					√	√														5
Misallocation of traffic risk		√	√					√	√												√		5
Inaccurate estimation of capital cost									√														1
Poorly written contract (ambiguity)		√	√							√									√				4
Technical factors																							
Unilateral changes of design concept during project execution	√				√																		2
Variations or additional works																						√	1
Specification changes during technical development of projects		√		√	√																	√	4
Efficiency or standard of technical skills and expertise											√												1
Delays during project execution																						√	1
Economic factors																							
Changes in economic policy		√						√						√					√				4
Changes in general price level		√			√																		2
Change in demand		√				√																	2
External or macro-economic shock				√			√				√				√						√		5
Weak economic environment											√											√	2
Contractual factors																							
Defective contract award criteria/ incorrect contractual assumptions											√								√	√		√	4
Contract characteristics															√								1
Inadequate contract mgt. expertise or knowledge															√								1
Use of multidimensional auctions													√										1
Effectiveness and efficiency of contract enforcement										√				√					√	√		√	5
Delays in expropriations	√				√																	√	3

Incomplete contract		√	√																				2
Administrative & managerial																							
Bidding error during procurement		√																					1
Anticipation of renegotiation at the contract formative stage				√						√				√			√						4
Opportunistic bidding		√					√			√													3
Evaluation of aggressive bid(Error)		√				√	√					√		√								√	6
Corruption at the contractor level		√																					1
Non-commitment to contract clause		√																					1
Administrative delays																						√	1
Transparency in the discharge of managerial responsibilities		√																					1
Institutional factors																							
Misaligned/weak institutions & jurisdiction of the decisions		√	√																				2
Regulatory & legal factors																							
Availability of regulatory institutes																	√	√					2
Changes to PPP legal framework or general procurement framework					√																		1
Poor or inadequate of regulatory account		√	√				√	√										√		√		√	7
Type of tariff regulation								√		√	√							√		√	√		6
Governance and regulatory effectiveness											√				√			√	√			√	5
Specific legal changes																						√	1
Weak legal environment																						√	1
High or incremental changes to corporate tax and levies																						√	1
Political factors																							
Political instability (e.g. change in govt. or change in govt. priorities)		√		√							√								√		√	√	6
Political opportunism		√															√		√				3
Corruption at governance level (e.g. misappropriation of funds)		√															√	√					3
Awarding concessions shortly before or after elections (Electoral cycles)		√								√												√	3
Inordinate ambition to meet or surpass electoral agenda									√														1
Nationality/ affiliation of the concessionaire (in terms of favouritism & patriotism)																			√	√			2
Environmental factors																							

Changes in design due to environmental problems,	✓					✓																	2
Environmental impact assessment			✓		✓																		2
Unforeseen events & challenges						✓																	1
Archaeological findings																						✓	1
Social factors																							
Social acceptability of projects characteristics			✓																				1
Social acceptability of user charges																✓							1
Cultural dimensions & acceptability																✓							1

Design Factors: Poor or inaccurate estimation of expected traffic during the viability studies can influence the renegotiation of PPP road projects. This error during the design stage is usually apparent in the underestimation or overestimation of expected traffic/demand levels. These have been identified as the main factors influencing PPP renegotiations in the road sectors of Spain and Latin America countries. (Guasch et al., 2014; Baeza and Vassallo, 2010). Nikolaidis and Roumboutsos (2013) corroborate these findings by identifying the inaccurate estimation of traffic volume as a major reason for PPP contract renegotiations in Greece. Thus, faulty contract design in terms of wrong specifications, an incorrect design matrix and dimensions, inflexibility of the design concept and inadequate strategic network planning are the bane of PPP contract renegotiations in the road sector.

The capital cost of the project may also be under- or overestimated by the cost evaluation expert at the design stage, which may necessitate the renegotiation of the project (Baeza and Vassallo, 2010; Athias and Nunez, 2008). Errors or mistakes at the design stage could impact PPP road projects, in addition to poor preliminary studies (Guasch et al., 2014). Such design errors could include incorrect assessment of the impact of loads on the road, revisions, modifications and improvements to the design, lack of as-built drawings during the conceptual stage and full preparation of drawings among others.

Technical Factors: Factors associated with the technical development or construction stage of PPP procurement could also influence renegotiation of PPP road projects. For instance, poor management of the construction process could result in the renegotiation of PPP projects at the construction stage. These can be attributed to the inadequate expertise and knowledge levels of the personnel involved in PPP road project implementation. Furthermore, unilateral changes to the project specifications and the inclusion of additional works or variation orders have been identified as factors which influence renegotiation during the technical development stage. There could be several reasons or motives for such changes, including the changing taste of the government or client or changes in the cost of materials.

The level of efficiency of the technical personnel has also been seen as contributing to the renegotiation of PPP road projects. Inefficiency manifests itself in delays in project implementation and high transaction costs during the technical development of the project. The results of these factors are time and cost overruns, which may necessitate the renegotiation of the contract duration and the contract sum respectively (Guasch et al., 2014; Sarmento, 2014). Thus, technical factors such as errors or omissions during construction could impact project objectives and ultimately lead to a revision of the agreed contract sum and an extension of the concession.

Economic Factors: Significant changes in economic circumstances, e.g. changes in economic regulation by the government with respect to exchange rates, currency valuation (i.e. devaluation and appreciation or) other financial policies etc., can drive renegotiation of PPP road projects (Montecino and Saavedra, 2011; Athias and Nunez, 2008). These changes have the tendency of positively or negatively influencing the renegotiation of PPP road projects during the implementation process prior to the completion and transfer of the facilities to the government. Therefore, unexpected changes in the economy could influence contract renegotiation.

A renegotiation could also occur as a result of the abuse of the financial equilibrium principle stated in the contract. For instance, the non-adherence to the defined financial budget and contract sum in accordance with the provision of the contract could necessitate renegotiation of PPP road projects. Furthermore, changes in the price of commodities, e.g. materials, labour and equipment, could result in the renegotiation of the contract. A change in demand for PPP products could also influence renegotiation of PPP projects (Guasch et al., 2014). Therefore, there could be a renegotiation of PPP road projects in a situation where there is a shortage of funds or the bankruptcy of the private concessionaire during the PPP road project implementation.

Contractual Factors: Incorrect assumptions in contract agreements may lead to the renegotiation of PPP road projects (Reside and Mendoza, 2010). These assumptions could relate to an incorrect risk sharing ratio or matrix, the improper allocation of responsibilities to the contractual parties, and erroneous specifications and clauses, etc. Errors in any of these areas could influence the renegotiation of the PPP contract at any stage of project implementation. The characteristics of the contract may also influence renegotiation (Estache et al., 2009). These may have to do with how realistic and accurate the contractual agreement is with respect to the concession period, contract specifications and the main and subsidiary objectives of the parties.

Moreover, the effectiveness of the way the contract is enforced influences PPP renegotiations (De Brux, 2010; Athias and Nunes, 2008; Guasch, 2005). The need for effective and efficient contract enforcement by the respective government agencies and designated consultants in the management of the contract cannot be over-emphasised. Delays in expropriations are one of the types of delay which may cause the renegotiation of PPP road projects (Cruz et al., 2015). The intensity of the delays experienced in terms of its length or duration has resulted in serious renegotiation problems due to the impact on cost and time variables.

Administrative and Managerial Factors: It is a key administrative and managerial responsibility to assess bids at the tender evaluation stage of a PPP road project in order to identify opportunistic and aggressive submissions, and failure to do this may lead to the renegotiation of the contract. The usual result of the poor evaluation and assessment of aggressive or opportunistic bids is that the initial contract sum submitted is inadequate, which means that the need usually arises for the renegotiation (usually upward review) of the PPP contract sum during project implementation in order to successfully complete the PPP road project (Fatokun et al., 2015).

Corrupt practices in the management of PPP road projects also play a significant role in the renegotiation of the contract. Country-level and firm corruption has been identified as a significant determinant of renegotiations. A more corrupt environment clearly leads to more firm-led renegotiations and significantly reduces the incidence of government-led ones (Guasch et al., 2014, Guasch and Straub, 2009). In contrast, less renegotiation occurs in an environment where corruption is less prevalent. Corruption manifests itself in several ways during renegotiation. First, renegotiation can be used as a good opportunity for governments to bypass the due process required for securing additional financing or authorization of increased investment (Guasch et al., 2014, Engel et al., 2009). Also, there may be collusion among the tenderers to increase the contract sum. Finally, administrative delays, which may be due to bureaucracy and human-related problems, are all examples of corruption, which may result in renegotiation.

<u>Institutional Factors:</u> There has been evidence of renegotiation of PPP projects as a result of misaligned institutions and the corporate decisions taken during the implementation of PPP projects (Guasch et al., 2014). These decisions may influence the renegotiation of PPP road projects. Nevertheless, corporate and regulatory institutions are vital to the sustenance of PPP. However, research has found that the inadequacy or lack of regulatory institution is one of the factors influencing the renegotiation of PPP road projects (Bitran et al., 2013). Thus the unavailability of institutions which can provide adequate corporate governance and administration of PPP projects has been identified as one of the factors influencing the renegotiation of PPP projects.

<u>Regulatory and legal Factors:</u> Specific changes to the legal framework, poor regulation and the lack or inadequacy of regulatory accounting could influence PPP renegotiations (Sarmento, 2014; Montecino and Saavedra, 2011). Also, non-transparent regulatory frameworks and processes for the renegotiation of PPP infrastructure projects can be attributed to the series of renegotiation experienced. These legal dimensions could necessitate specific changes to the terms and conditions of the PPP agreement or lead to the introduction of additional clauses to modify the scope of the original PPP road concessions contract. Hence there should be an understandable, well-defined and strong regulatory and legal framework, which spells out the modalities for contract renegotiation in order to reduce the negative influence of PPP renegotiation, as a weak regulatory and legal environment may easily lead to legal and regulatory changes, which ultimately encourages contract renegotiation.

<u>Political Factors:</u> The political situations such as a change in government or changes in the priorities of the government could influence the renegotiation of PPP road projects. A change in government may result in changes in policies and priorities which could manifest themselves in new areas of concern or investment in PPP infrastructure projects. Thus a need to renegotiate existing or ongoing PPP road projects may emerge as a result of the change in the political situation. Electoral cycles and the awarding of concession contracts shortly before or shortly after an election could also influence the renegotiation of PPP road projects. Different governments have different agendas during their term of office, with different cardinal objectives, which in turn guide their procurement decisions. Thus, the terms of ongoing PPP projects awarded by a previous government may not be aligned with the objectives of a new government and may therefore be discarded and replaced with new objectives.

Any motive to achieve new political objectives usually influences renegotiation of previously agreed PPP road contracts.

Environmental Factors: Some environmental factors drive renegotiation of PPP road projects. These factors have a bearing on the outcome of the projects and include all external conditions or influences on development projects. It has been observed that construction project development may be impaired by a lack of good knowledge and successful management of the impact of the environmental factors, which may influence the performance of such projects (Akanni et al., 2015). Thus, the impact of the environment on the successful implementation of PPP road projects cannot be over-emphasised. Environmental factors in this regard encompass but are not limited to all physical influences in the environment within which a construction project is sited. The geographical location of a project, ground conditions and weather patterns, etc. are environmental factors.

Notable PPP studies have identified changes in design as a result of environmental requirements as one of the factors influencing the renegotiation of PPP road projects (Cruz et al., 2015; Sarmento, 2014). These changes may be expedient in a situation where it becomes practically impossible to continue the construction of PPP road projects as a result of environmental problems and challenges impacting on them (Cruz et al., 2015; Menezes and Ryan, 2015). Furthermore, the impact of weather conditions (e.g. rain and sunlight), as well as archaeological finds, could cause obstacles to the continued construction of a road project (Menezes and Ryan, 2015). Such circumstances may, therefore lead to the renegotiation of PPP road projects.

Social Factors: The social acceptability of PPP road projects characteristics as well as the acceptability of the accruable cost or the degree or readiness of potential users to pay for the services provided has been examined by several scholars (Domingues and Zlatkovic, 2014; Guasch et al., 2014; Sarmento, 2014; Baeza and Vassallo, 2010). This situation has raised concerns about the ability of PPP to deliver the objectives of users and taxpayers in terms of value for money (VfM).

Adair et al. (2011:9) comment on these social concerns: “the rollout of the public-private partnership models has not met with universal approval; indeed in some countries there has been strong resistance to public-private partnerships with misgivings centred on the level of private sector profiteering as well as long-term obligations placed on the taxpayer”. This confirms that the poor level of users’ satisfaction is responsible for non-acceptance of PPP for infrastructure project delivery and provision of social services across countries. Indeed, the acceptability of PPP in the provision of social services has been strongly resisted in some countries through various means including industrial action. This resistance has led the governments of countries to provide subsidies to reduce charges and taxes imposed on road users.

5. Conclusions

The literature reviewed here has succeeded in categorising the various factors which could influence the renegotiation of PPP road projects, and identify the respective influences. The results of the review indicates that the design, regulatory, administrative, political, contractual, and economic factors have various sub-factors in their respective categories. Many authors agree that the following design-related factors influence the renegotiation of PPP road projects: misallocation of traffic risk, over/underestimation of traffic levels, defective contract award criteria or incorrect contractual assumptions/design, poorly written contracts (concession). Furthermore, regulatory and administrative factors follow design factors in the extent of the influence they exert. However, the sub-factor which exerts the most influence of all is inadequate or non-existent regulatory account (arising from the non-existence or weakness of a regulator), which is a regulatory factor. Other regulatory sub-factors, which can also be considered critical are the type of tariff regulation, including governance and regulatory effectiveness among others.

In conclusion, the renegotiation of road projects in a PPP environment is mostly attributable to design and regulatory factors. Although, there is a need for further qualitative or quantitative studies which should be methodologically analysed to establish and ascertain the criticality of these factors. In addition, there is a need for a proactive strategy to be developed in order to tackle the influence of the factors in each of the categories identified so as to promote profitable and positive renegotiation results. This strategy may necessitate the development of modalities to assess and ensure the credibility of PPP regulation, which will guide PPP renegotiation in the road sector. Also, proper design of concessions to ensure the elimination or reduction of the level of incorrectness and inaccuracies in the process will go a long way to reducing the negative influence of the factors identified. Finally, there is a need for greater transparency and due diligence in PPP, particularly at the pre-concession or bidding stage, in order to reduce the level of corruption and opportunistic behaviour on the part of the contracting parties.

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Identification of vacant space; a prerequisite for industrial and societal development

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Abstract

In the real state community, vacant space is mostly regarded as a cost and a negative factor. However from a societal perspective, vacant space might function as a necessity for growth and creativity. Vacant space is not merely relevant for companies and organisations, but also for residential areas. In order to satisfy space flexibility, companies and organisations must have access to additional space during periods of expansion as well as additional residential areas and other facilities for e.g. employees. Conversely, vacant space must be managed during times of recession. In current practices, space flexibility can be enhanced through efficiencies, ownership, relocation, leasing, and in a larger scale, through governmental and public initiatives. This paper presents new methodologies derived from strategies from manufacturing industry; which are here applied to identify vacant space and potential market. It has been discussed a certain amount of concepts for an efficient allocation of resources by relating to Facilities Management, Total Quality Management and ICT as a significant approach for rendering efficiencies in land use, particularly in countries characterised by scarcity of green areas and abundant “brownfields” are rather a topic for development. In a conclusive discussion, this paper argues that the identification of vacant space, in multiple perspectives, is crucial for the future for urban and regional planning.

Keywords: vacant space, development area, manufacturing methodology, Kano model

1. Introduction

How can various kinds of vacant space best match the various needs of users and stakeholders? Vacant space is generally regarded as a negative factor among investors in particular. However vacant space could as well be regarded as a resource. At the Facilities Management Master Course 2000 to 2003 at Chalmers University of Technology and at the Real estate management Master course at Politecnico of Milan the value of spatial vacancy was widely discussed and emphasized among the participating professional facilities managers; indeed vacancy during the discussions was not merely regarded as a negative factor for owners in particular, but also a necessity. Refurbishment at a hospitality plant, for example, must use vacant space by enabling continuous move of various sections of the hospital. Furthermore, in the ideas of dynamics of space use, growth firms for example have an advantage if they can expand to adjacent vacant spaces with permanent or temporarily leasehold contracts and maintaining a core of space for long term core activities. Studies in the industrial suburbs of Northern Italy, specifically in the Lombardy Region, render similar conclusions; the networks of entrepreneurial and manufacturing firms are dependent to access vacant space due to market fluctuations and demand for manufactured products. Having a close relation to business cycles, firms must as a consequence have a dynamic relation to space use and its facilities management. The management of space use can to a certain extent, become rendered more efficient and thus postpone decisions on expansion or full or partial relocation (Ciaramella and Dettwiler, 2012). Several consultancy firms measure frequently vacancy rates for benchmarking, forecasting and analysis of business cycle trends and real estate markets (often office space and retail space).

As a contribution on research and discussion on spatial occupancy, this paper aims to explore the nature of vacant space and the value of identifying various spatial categories that would more efficiently match the complexity of needs through means of ideas and methods from manufacturing industry.

2. Vacant space a significant parameter of our society

Who owns the vacant space? Suburban and urban space was a political issue after the Second World War when some philosophers and sociologists regarded new construction spaces as a common good and having primary purpose to satisfy human interaction (Lefebvre, 1968 and Bourdieu, 1984). Promotion of interaction in public areas gave 20th century influences on architecture and urban design (Gehl, 1987 and Hillier and Hanson, 1984 and other) which gave a balance of the physical artefacts (buildings and infrastructures) to the actual activities within urban spaces consisting of interaction and various services.

In recent years, conjoint with the debate on sustainability, houses and areas with development areas often become focus for new lifestyles, energy saving and even local food production. Still vacant areas needs financial means for development where public finance only covers the new constructions and refurbishment partially. Conjoint with the real estate crises in the beginning of 1990th, with a multitude of bankruptcies where the ownership was transferred to public entities, the idea of Private Public Partnership (PPP) become a solution; in order to develop abandoned buildings and areas; private interests were interweaved with public interests. Often a balance must be sought between private and public interest for development of vacant space. Vacant space has both negative and positive features; is a resource for governments to create so-called clusters and industrial development.

The occupancy oscillations due to business cycles with its dynamic forces between boom and recession are mirrored as well in the real estate market. Jong Lang Lasalle (http://www.jll.com/) illustrates the phenomenon as an “office property clock” by placing different cities around the world on upturn and downturn trends on office property market. Still, occupancy in these measurements are regarded ubiquitously a something positive, whereas the counterpart, vacant space is generalised as a negative factor.

The notion of natural vacancy has a significant role in Real Estate Economics as an intermediary factor between supply and demand. In fact, lag effects can be observed between cycles; demand and supply of office space (Pyhrr *et al.* (1999), Gabriel and Nothaft (1988), Whaeton (1990) and Sanderson *et al.* (2006)). Vacancy of office space is not only associated to acquisition or leasing but also to the problematics of location and service like facilities management. Additionally to the mentioned lag effects in real estate occupancy can also be observed in a facilities management perspective, where the use of office space and connected services does not follow simultaneously the fluctuation of GDP (Growth Domestic Product/Capita) probably because firms are contractually bound to previous periods (Dettwiler, 2008).

Reasons for vacant space have multiple reasons. In Europe vacant spaces is related to industrial areas for primary and secondary industries that have ceased or relocated their activities, so-called “brownfield” (CABERNET, 2015) that additionally often have contaminated soil, which implies considerable decontamination costs for successive constructions (Ferber *et al.* 2006).

In global perspective, the reasons for spatial vacancy have numerous exogenous factors e.g.:

- Obsolescence: Building themselves might not meet the needs or the, abundant areas activities have become obsolescent; e.g. manufacturing plants, military buildings and hospitals
- Competition: Location in general might have lost the attractiveness. Other areas are more attractive in terms of price, image, infrastructure, nearness etc.
- Destruction: The remains of old construction and contamination of soil makes it difficult (often due to protection of cultural heritage) and expensive to incorporate new structure
- Force majeure: Political and global market forces e.g. former communist states, Detroit automotive industry etc.

The interrelationship between relationships of factors might favourably be illustrated in a figure than simple enumeration of separated factors (Figure 1). The production of idle or abandoned industrial areas can be regarded as a mix of exogenous factors such as the global crisis and the deindustrialization and architectonic factors; and additionally such as the obsolescence of industrial spaces in urban areas.

Two interdependent parallel processes influence the extent and use of idle or abandoned industrial areas namely; (1) addition or “production” of new space and (2) re-use of vacant space. The challenge is to manage the themes of performance, obsolescence, life cycle of industrial spaces and infrastructures thorough analysis of needs of the modern industry. Considering which type of manufacturing that can be hosted by modern cities, and in the same time to meet modern requirements, would be to establish a sustainable renewal process of idle and abandoned industrial areas for manufacturing and production (Figure 1). For planners and architects, the ultimate challenge is to provide appropriate spaces to modern industries with an understanding of the complex circumstance of present and future production.

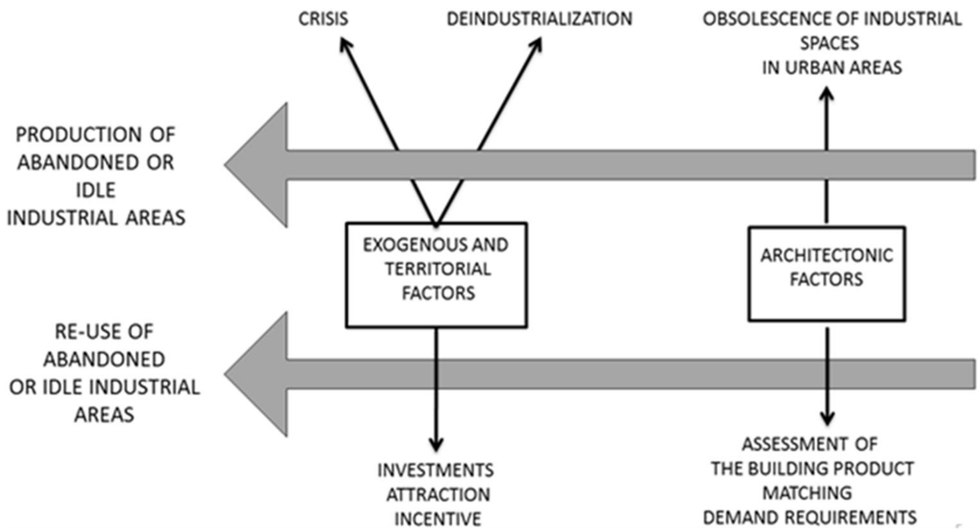

Figure 1: ***Key Factors and production of idle/abandoned industrial areas (Celani 2015, European Architects Network annual seminar, Milan, October, 17th 2015)***

Furthermore, the challenge is to assess physical nearness standards to building categories of residential and tertiary sector areas. Most countries have zoning policies that prohibits residential planning in manufacturing zones. However with the emergence of manufacturing industry with "clean" production, many modern industries of today can be regarded as a part of tertiary sector. In urban planning the urge for attaining higher congestion, mixture of dwellings and workplace in the same area tend to be accepted. Interestingly, such mixture would be a comeback to the old European urban structure.

3. Inspiration from industry; methodologies

Considering that vacant spaces could be regarded as an opportunity for the development of a region is connected with the characteristics of a real estate product and with potential market analysis. A demand and supply analysis is defined through the supply of spaces in terms of viability. The definition of a Brownfield site is related to the notions of market failures and market constraints (Ferber *et al*, 2006) and (Groenendijk, 2006).

The lack of information about areas to be redeveloped is related to "layers of risk" to the structural specification of Brownfield and would be the main constraint is how it can be financially sustainable of redevelopment. At this point it must be specifically considered the category of benefit that splits in its turn the social and economic benefits (De Sousa, 2000) from the direct financial benefits for specific actors: in the first case the intangible factors affect the evaluation of viability of a site and in the second case the requirements of business plans are strictly connected to the time to come to fruition of the renewed asset.

Another layer of risk is featured by restrictions at the urban planning level, resulting in a set of constraints and limitation for the end use of the redeveloped area. The end usage of the area can be influenced by the typical features of the area of the building objects into the area, and of the characteristics of the neighborhood (Ferber *et al*, 2006). Accessibility, location, and physical condition are fundamental categories of the Brownfield areas to be redeveloped, additionally the different level of possible contamination that renders it impossible to attain a standardization of reclamation and development costs for sites. Necessary information retrieval and data mining are to be considered as a cost burden due to activities connected to the project management of the renewal of the site. Preliminary studies incorporate costs, which in fact tend to increase in case of deficient information concerning the history of the site or connected deficient poor due diligence of the site. Here, ICT and Urban and Regional Public Databases would facilitate data processing and knowledge management.

3.1 Role of ICT and database information for reducing investment risk

Territorial data in Regione Lombardia are controlled and managed thru a GIS-based data-base. Analysis of the databases of Regione Lombardia reveals differences of needs and interests respectively among different categories of stakeholder (Celani, Ciaramella 2014); which is relevant to understand the interest function of different player into renewal of brownfield areas or regional planning. Table 1 represents stakeholders involved in the process of management of idle or abandoned areas.

Since the 1980s the “Kano Model” has been used in the manufacturing industry in order to enhance product development and customer satisfaction (Kano *et al.*, 1984). The Kano Model is further developed to three levels of requirements, which influence customer satisfaction; (1) “Must-be requirements”, (2) “One-dimensional requirements”, and (3) “Attractive requirements” (Suerwein *et al.* (1996). The categories of requirements can be considered as a scale from very basic level (1), just above dissatisfaction up to the highest degree of satisfaction, “the delight customers” (3).

Table 1. Basic Structure of Financial Interests and Needs among Stakeholders and Governments of Different Levels. (elaboration by authors)

	Private stakeholder	*National Government and national agencies*	*Regional Government*	*Local (municipality)*
Financial Interest	*Assessment and valorization of the areas (cash-flow)*	*Attraction of Investments*	*Management and control Polluted areas*	*Taxation of the underutilized areas*
Information needs	*Urbanistic development index, distance from infrastructures (transport, energy, IT), availability of resources*	*Societal development: Demography Industry, Political Targets, Infrastructure (connection larger networks)*	*Start-up investment, Growth firms and networks of growth firms,*	*Square meters of an area, ownership, energy, water supply*
Database Information needs	*Capability to support new actors on market, Creation of supply and demand*	*Regional databases are not interconnected under a National one*	*Regional database georeferenced (available)*	*Non-fully integrated databases, different for any municipality*

Using the Kano model for assessing the needs of the potential customer of a product and a service has widely been considered to be an attractive solution to identify attributes as key drivers to success for customers' satisfaction (Mikulic, 2007). In Mikulic's review it cannot be found any application in the field of Urban Renewal and attractiveness of the vacancies in terms of quality elements. However identification of quality elements for the potential investor would probably reduce the risk of vacancy, reducing the market failures risk. Considering Territorial marketing as a branch of marketing discipline (Bagautdinova *et al.* 2012) with specific features due to various location externalities, conclude us to regard the potential customer of a regional areas as a potential customer of a common good. Bagautdinova *et al.* (2012) regard the localization decisions of firms relates to the effect of globalization, which in its turn is related to (1) market challenges of international sales, (2) the changed space-time relationship in modern economy and (3) the distribution of migrants flows.

The specific needs of Companies; Regional and Urban strategies can be identified and ultimately coordinated when equilibrium between demand and supply is met; e.g. issues of the demand of spaces (not only physical) and offer of spaces (areas in the urban and regional areas), the general interest etc.

In order to create high quality urban structures that would match complexity of needs, of the "delight customers", tools from Total Quality Management (TQM) such as the House of Quality (Hauser and Clausing, 1988) would be worth applying in urban planning because such tools are developed to optimise multiple variables.

By aspiring to satisfy the customers' needs, an effect would be more competitive regional and urban areas as well as more competitive company that is located with business in the area. A potential use of the Kano Model for territorial and urban development and more in detail, in order to mitigate market failures in idle and abandoned areas re-use and allocation is connected with the idea of functionalization. Kano model represents a sophisticated tool to assess customer's needs, to draw functional requirements, to develop new concepts as a part of forecasting procedures and continuous strategy work. Total Quality Management tools in general have its origin and used in manufacturing sector, which is historically more dynamic and positive to undertake change and innovation than the construction industry. The Kano model is a primarily customer-oriented tool where market failures in the brownfield areas are often connected with a lack of development of a strategy to assess the needs of the market. The needs of innovative industries are often hidden or difficult to be standardized because of their complexity. The identification of customer requirements is a part of the theory development and it is proposed a construction guide for a Kano-based questionnaire in order to develop a tool useful to meet Kano's theory of classification of needs with survey techniques. The use of the method Suerwein *et al.* (1996), according to Kano's theory, and the following implementation for mitigating market failures in abandoned and idle industrial areas re-use is the possible way to understand and assess potential market needs and requirements for vacant space.

4. Vacant space; conceptualisation

The walls of buildings and physical boundaries are rarely coherent with the organisational activities and the multitude of current spatial needs of urban features like living and working. For example, the needs the organisational dynamics of activities growth firms could ideally expand its activities if vacant space is adjacent to the core activities (Ciaramella and Dettwiler, 2011). Areas with vacant space offer thereby a support to the dynamics of firms that have to expand their surfaces.

Vacant space of buildings has their roots in new constructions due to speculation and forecasted occupancy, as well as vacant space of older building that of various reasons have been abandoned. Some urban and suburban areas are (1) entirely vacant whereas (2) other areas are characterised by scattered occupancy (Table 2). The former situation (1) gives higher freedom for developers and stakeholders to refurbish and plan new areas; existing building of e.g. historical value can be refurbished and other building are demolished to give place for new infrastructure and construction.

The latter situation (2) seems however to be more complicated: the users of scattered occupancy can consist of dwelling as well of private or public activity; such complexity can be described in multiple interrelated dimensions: economics, sociology, governance and more. Users and inhabitants within scattered areas often have lower occupancy costs compared to dense urban areas. Process and discussion for revitalisation, refurbishment and changes implies an increase of costs, which implies among others a threat of being able to stay due to economic reasons. Social structures are as well subject to change and risk to disappear due to new changes. Experiments with methodologies of local democracy and collective design with work groups as an influencing factor in the planning process has been made since four decades however standardised to a minor extent.

Table 2. Differences between high spatial vacancy and partially vacant areas. (elaboration by authors)

Characteristics	*Area/District Low Spatial Vacancy, partially vacant areas*	*Area/District High Spatial Vacancy, entirely vacant areas*
New concepts/design	*Low freedom*	*High freedom, e.g. new sustainable design*
Image	*Influence both positive and negative from existing building stock*	*Freedom to create wanted image*
Function	*Existing infrastructure and service; applicability and adaption issues*	*Freedom to create new concepts of infrastructure and services*
Public investment on infrastructure	*Dependence on current status; re-investment*	*Entire new infrastructure, Governmental involvement*
Social structure	*Mixture of current and new users*	*New users*
Buildings	*Existing: refurbishment, friction to refurbish, new construction (e.g. in-fill projects). Mixed use of buildings*	*Demolition, New construction* *Refurbishment, Cultural Heritage (Degree of permission to refurbish)*
Services (FM)	*Divided with current occupiers, Economies of scope*	*Larger contracts, Economics of scale*
TQM	*Economies of scope*	*Economics of scale*
ICT	*Economies of scope*	*Economics of scale*

The strategic methodologies within manufacturing industry seem to be more advanced than within construction sector; the recent decades most products of manufacturing industries (e.g. textile, furniture, IT-hardware) has succeeded to lower the price for their products due to outsourcing, economies of scale, free competitive market etc..., the construction sector production has contrarily increased. Reducing building cost has become a governmental topic for promotion where construction industry is encouraged to learn from manufacturing industry in order to attain efficiencies. In the research of Facilities and corporate real estate management, a main issue is in fact the identification of needs among end-users and stakeholders. Therefore it would be appropriate to connect specific needs to specific space and land (Figure 2).

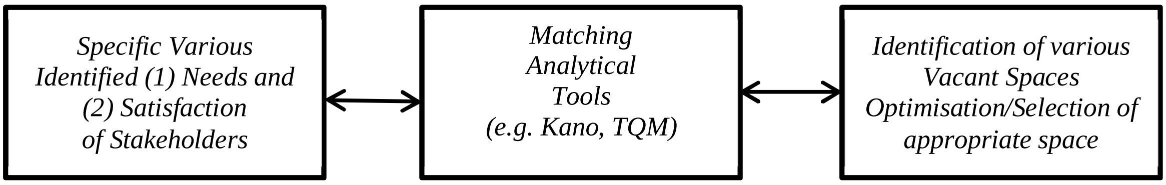

Figure 2: Matching of tools as means that connect identified spaces with identified needs.

Areas with vacant space that have nearness to city cores can be regarded as a reserve for expansion and urban development with first class image and profitability. Example of this are abandoned Wharfs plants or airports of large cities where substantial areas have been successfully transformed into residential areas and activity for the tertiary sector. The European Union conjoint with CABERNET (www.cabernet.org.uk) has categorized idle land into three categories (CABERNET 'ABC Model' of Brownfield Land Commercial Viability). A first approach to classify vacant space is would be the application of these categories and the concepts of Table 2 incorporates the idea of degree of vacancy. Table 3 renders a structure of basic nine categories based on the Kano Model and the ABC-Model subdivided into three main building categories.

Once identified areas enable preparation of strategic facilities management, e.g. bundling of service contracts. Circumstances of entirely vacant areas or scattered occupancy as we have seen in Table 2 give certainly implications on the notion of Table 3, like the extent of service deliveries, economics of scale etc.

Table 3. Basic structure that combines Building categories with ABC Model and areas requirements reading through Kano Model.

Building category /Vacant space category	*Manufacturing*	*Tertiary sector*	*Residential*
A. Commercially viable Sites (Self developing sites) "Attractive requirements"	*1.Minor surfaces/workshops in dense urban areas. Efficient and sophisticated services and infrastructure*	*2. Price Competitiveness, Affordable areas, High price office, established firms. New concepts of FM*	*3. Competitive flats, sustainable solutions, nearness to work and lifestyle facilities like shops, services, gym etc.*
B. Marginal Viable sites (Potential development sites) "One-dimensional requirements",	*4. Affordable areas. Basic needs met and contractual guaranteed. Efficient and safe service delivery*	*5. Start-up areas. Consultancy, offices, incubators, new high tech firms NTBFs (New technology based firms)*	*6. New lifestyle image, lower price. Young generation with new lifestyle, connection to entrepreneurship*

C. Non Viable Sites (Reserve sites) *"Must-be requirements",*	*7. Expansion areas, connected to 4.* *Basic service*	*8. Expansion area. Low tech service firms (cleaning, repair shops etc.)*	*9. Separated from 7. But not 8. Basic cheap living for e.g. temporary staff*

The identification of specific vacant space that would match specific needs is primarily dependent on current methodologies like ICT, BIM (Building Information Modelling), POE (Post Occupancy Evaluation), Forecasting methodology (e.g. scenario planning) and DSS (Decision Support System). The proposed inclusion of manufacturing strategic tools, like Kano model, should be regarded a contribution to the present complexity of planning tools. We mean that it would be worth to evaluate and further undertake research how manufacturing tools that can be implemented in existing system like BIM.

The logic and mathematical understanding of the problem can be expressed as follows:

$$S_{TOT}=S_{OCC}+\sum S_{VAC}=F(N_{FIN},N_{ECO},N_{SOC},N_{RES}) \quad (1)$$

- S_{TOT}=Total space of limited area (Buildings, Lands, Infrastructure) of e.g. an industrial plant.
- S_{OCC}=Present occupied space of an area, to be remained or relocated, or incorporated in future changes. S_{OCC}=0 in total abandoned areas as often is the case with brownfield areas for example.
- N_{FIN}, N_{ECO}, N_{SOC}, N_{RES} are the various identified needs among users and stakeholders in basic parameters that also defines the notion of sustainability of today, namely a balance of financial, ecological and social perspectives. N_{RES} represents factors that cannot directly be categorised in the three mentioned perspectives.

Continuing the reasoning of Table 3 above, the factor $\sum S_{VAC}$ of formula (1) would thus be a composition of the various identified vacant spaces consisting of land, infrastructure and buildings. The Kano model expects to connect the vacant spaces to various levels of services and facilities management concepts. The space dynamics between the different categories incorporates as well service activities, which would have a significant role unifying the entire area in order to attain efficiencies and goals. By that reason the mentioned spaces in formula (1) could as well be replaced by a composition of services, which we here name D, thus

$$D_{TOT}=D_{OCC}+\sum D_{VAC}=F(N_{FIN},N_{ECO},N_{SOC},N_{RES}) \quad (2)$$

The idea of formula (2) is as well similar to the thinking within facilities management to regard spaces also as a service *per se*, thus

$$D_{TOT}= S_{TOT} \quad (3)$$

Formula (3) has no operative value but should rather be considered as the idea of supporting space dynamics and incorporate flexibility to future change within the planned area.

5. Discussion

There are multiple ways to generate space, underutilized or abandoned; in the industrial and manufacturing sector respectively, the disappearance or relocation of heavy industry; aggressive policies attracts investments from countries, where the cost of labour and where the energy consumption is very low and which in its turn allows companies to increase their competitiveness. Functional obsolescence of some buildings, which take advantage of phenomena of re-location; but also in the service sector, according to the phenomenon that sociology calls "despatialization of labour" (Beck, 2000). In essence, for different reasons, the use of the space occupied by production activities and tertiary sectors gradually decreases; this implies the need to understand if and how this space can be used for a new lifecycle or whether it is necessary to think about a radical change of the original use. To understand the possible application of space, an appropriate interpretation of data like the qualitative characteristics and data mining of spaces or areas is necessary for further processing to the mentioned Kano model and DSS (Decision Support Systems).

The intrinsic problematics in Facilities Management methodology is the measurement of satisfaction (in order to identify needs) which one can suspect has various ground for biases. For example when users are regularly involved in surveys, workshops, interviews, post-occupancy evaluation (POEs) etc. an habitude to express and define needs, satisfaction and desires has uneven weight and proportions among different categories of users and stakeholders. This is not only a managerial problem but also a democratic and sociological problem. The boundary between “need” and “desire” is furthermore a not explored area and of considerable significance in the briefing process. A layering and categorisation of service concepts based to the Kano Model would favourably contribute to an appropriate identification of needs.

Vacant space might represent a problem but, in some cases, also be regarded as an opportunity: at the urban scale, at the scale of single plot and in the case of individual buildings. At urban scale, vacant space would encourage expansions and developments, giving rise to new functions; at the scale of a single plot, unused space can be a solution for congested areas: the most frequent concerns central or semi-central areas, where productive activities have been developed and after years they see turn their original vocation, the surrounding areas are transformed in residential areas and because of that any expansion of business set up is allowed (in Italy, the city of Milan has many cases of this type). The presence of areas throughout the city, with different sizes, becomes a problem that cannot be managed in an urban perspective, but requires as well the ability to analyse regularly local needs; which enable a retardation of the process of regeneration. At the scale of individual buildings, the free space may constitute a reserve to support any need to grow their business for end users or the possibility of entering new strategic functions.

Another significant theme is the importance to avoid the distortion of the vocation of the territories and to leave traces that make up a real cultural heritage. The physical nature of the land to its original state, but especially the artificial environment transformed and conditioned as it appears, where virtually nothing is excluded and potentially unrelated to technological environment, have become the object of study and conservation projects, transformation, but also of real 'restoration' of objects and places. Objects and places where for decades has operated a transformation of productive type, which has involved technological and human resources, where the traces of the past chase and overlap, creating synergies and contiguity that form the backdrop of our lives must be organized and this should engage the stakeholders in an integrated and comprehensive approach towards the future use of the land. Slow or sudden changes of entire territories, birth and death of small and large urban concentrations, productive areas, factories, industries, deserve systematic analysis to properly address any future project.

The fundamental problem of planning areas vacant space is the multitude of data, different interests and number of persons involved in the process. The ICT technology of today enables data processing and extracting appropriate information for planning, briefing and decision. The challenge to interweave complex factors is a part of managing processes and changes in manufacturing industry. It is to assume that the skill is more advanced in manufacturing industry because it is applied in daily continuous and standardised process, whereas the development an area of vacant space or brownfield area is a unique project where specific solutions must be tailor-made for the particular area. Planning experience from a developed area can only partially be transferred to another area.

Finally, since we argue that vacant space should be regarded as a valuable expansion resource and as reserve space *per se*, it would be motivated that new planned and refurbished areas of e.g brownfield never should be to 100 % occupied; some parts vacant space should be maintained as support for core activities of present companies, dwellings and organisations. Unsolved is still the partition of financing the vacant space.

6. Conclusions

In this paper we have argued to incorporate methods, learnings and ideas from the manufacturing industry into the planning process of idle and vacant areas. By means of primarily the Kano Model a higher accurateness is expected in order to identify various categories of vacant space, that would match varies needs. We argue that a better matching of spaces to various needs must as well be related to future urban structures with new values and attitudes, not only regarding finance and entrepreneurship, but also concerning sustainability, sociology and culture. New constructed or refurbished areas are not only "bricks and mortars" but also a physical space for activities and performance of complex services like FM and social interaction. Such progress within planning process would in fact be harmonized with the ideas of United Nations, where the notion of sustainability is defined through multiple perspectives.

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Size and Nature of the Auckland Private Rented Sector – Implications for the Spread of Housing Options

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Abstract

Housing scarcity and unaffordability in recent years has been a major concern in New Zealand's major cities, especially in Auckland. The need to accommodate New Zealand's growing population is a concern that is central to government housing policy, with attention having recently been focused on the capacity of the private rental sector to meet a range of housing needs. The objective of this research was to investigate the size and nature of the private rental housing sector in the Auckland region and to examine how the sector contributes to the spread of housing options in the region. Through the analysis of the existing data from five consecutive censuses, the research findings present a detailed analysis of the Auckland private rented sector, with a particular emphasis on the types of household it accommodates, their location within the region and the main housing typologies. These findings will assist various organisations and public authorities to establish priorities in their housing strategies in a way that best meets the demands of the current market, and also to clarify issues around the efficacy of existing policies relating to private renting.

Keywords: Housing, Private Rented Sector, New Zealand, Auckland

1. Introduction

Private renting is gradually becoming a reality as home ownership is increasingly difficult to attain in several major cities in New Zealand. The decision to own or rent a home is undoubtedly crucial for every household around the world including New Zealand. In recent years, New Zealand has experienced a substantial increase in the number of migrants in Auckland, which has subsequently led to a housing shortage and drastic increase in house prices, causing further housing pressure for low to medium income households. Many people will have some experience of renting privately during the course of their lives. Private renting offers a multitude of roles in housing biographies across the whole social spectrum, serving as a first port of call for new households, a 'bolt-hole' when housing circumstances change, a stopping-off point as people change jobs and move house, and for many households a long-term home.

The need to accommodate New Zealand's growing population is a concern that is central to government housing policy, with attention having recently been focused on the capacity of the private rental sector to meet a range of housing needs. The Productivity Commission (2012) considers it desirable for the housing market to maximise the options available for quality housing for everyone, regardless of income or tenure choice. As in other countries, disparities exist in the housing market in New Zealand. Sixty-four percent of low and middle income households in New Zealand reside in private rental homes and are likely to suffer from the effects of poor quality housing and unprofessional landlords (New Zealand Institute of Economic Research (NZIER) 2014). Increasing population and projected growth in the private rental sector is a trend in a number of western countries and is a likely feature in New Zealand's property market. An understanding of the size and nature of the private rental sector is necessary in order to gain an understanding of housing typologies that need to be built, and the changes required to existing dwellings to accommodate these households. Moreover, it is important to understand the New Zealand private rental sector''s capacity in order to determine how the sector's growth could be tailored to accommodate the country's rapidly growing urban population, particularly low and middle income households and specifically in Auckland. The key objective of this research is to examine the size and nature of the private rental sector, and the contribution it makes to the spread of housing options. The findings from this research will provide a reflection of Auckland's private rented sector, which is necessary to assist various organisations and public authorities to devise housing strategies and to re-establish their priorities according to the increasing population and housing demand.

2. Literature Review

Housing affordability in New Zealand, particularly in Auckland, has been a topic of growing concern for policy-makers and researchers. There has been debate around: the causes of rapidly rising house prices; the increasing disconnect between income levels, rent increases and house prices; and the degree to which affordability is actually a significant problem. Bassett and Malpass (2013) attribute declining housing affordability to a range of factors, including changes in household size and composition, increased building costs, shifting government rules and local government regulations. The Productivity Commission (2012) in their *Housing Affordability Enquiry* noted a range of potential factors contributing to rising house prices 'such as land supply restrictions, the problems with achieving scale in new house construction and inefficiencies, costs, and delays in regulatory processes'. They also highlighted concern around affordability for renters, although rents have not increased at the same rate as house prices, and noted 'that the current approach to social housing in New Zealand will not provide sufficient support for those in need'. Auckland is not alone among large cities worldwide in experiencing affordability problems, as similar trends are available in the USA, where with high amenities, growing populations and physical constraints they have also experienced high rates of housing price growth (Cowan, Burrough et al. 2014). The private rental sector is growing in proportion to the decline of home ownership and the low base of state housing, so increasing numbers of people now rely on rental accommodation. Private rented accommodation as a tenure has long been associated with affordability, due to the sector's perception of alternative housing for people who cannot afford owner-occupied homes (Bramley 2012). According to Rugg and Rhodes (2008), policy interventions that will change the private rented sector's perception as a housing option that sits behind the preferred tenures of owner-occupation and social renting are important. The private rented sector has the capacity to deliver new and affordable property supply, if backed up with adequate planning and policy interventions (Rugg and Rhodes 2008).

3. The Private Rented Sector: A New Zealand Perspective

New Zealand's rental market is comprised of the private rented market, social housing and mixed rental housing. In the private market, the landlord is a private person and tenants pay market rent with no government assistance. Also the quality of homes may be actively managed (and achieve a very high standard, e.g. new apartments built to code) or not managed at all (with the resultant range of quality down to the very poorest accommodation options). In the social housing sector, the landlord is the local government and tenants are recognised as vulnerable and are supported by a range of government agencies – the house quality is managed by landlord asset management. In the mixed rental category, the landlord is a private person and the tenants pay market rent but receive government accommodation assistance or support to supplement rent. Rental housing markets vary across the country, with Auckland under considerable pressure. The percentage of households renting privately in Auckland has increased, while the percentage renting from social housing or a local authority has reduced significantly. 76.9% of households in Auckland rented privately and 19.0% rented from the local authority. Elsewhere in New Zealand the trend is the same, with those renting privately making up 84.9% of renting households in 2013, compared with 79.0% in 2001 (Statistics New Zealand 2013).

The rental housing market is impacted by challenges faced by the housing market: affordability and supply. Generally, New Zealand has seen a significant decline in housing affordability as real house prices are accelerating faster than income. This decline in affordability make it harder for the renters who were hoping to rent only for a short time while saving to buy a home (Cowan, Burrough et al. 2014). Some parts of New Zealand have a shortage of homes as new house construction is below demand from population growth, household size change and migration (Cowan, Burrough et al. 2014). Demand for new housing is estimated to rise by more than 20,000 households per year and most of that growth is predicted for the Auckland region. An NZIER (2014) public discussion paper notes New Zealand has restrictive rental conditions when compared internationally. Tenure arrangements such as typical lease term, notice period for landlord, reasons a lease can be terminated, pet ownership and minor alterations (putting up pictures, painting, laying carpet) are more restrictive than in other countries such as Germany, France, The Netherlands and the UK. Such restrictive rental conditions makes rental housing a poor substitute for home ownership (NZIER, 2014). The insecurity of tenure is a clear barrier for tenants who might want to improve the condition of their rental home; it undermines renters approaching landlords to ask for repairs and maintenance, let alone performance upgrades (e.g. extractor fans, insulation) (Cowan, Burrough et al. 2014).

The private rental market might need to make significant adjustments in order to contribute to the demand growth in the face of not only reduced home ownership propensities, but also reduced government involvement in the provision of social housing. Also, the emergence of ever-increasing housing prices focused on the major cities such as Auckland and Christchurch, while some research by the Centre for Housing Research and Statistics New Zealand provides a valuable overview of the rental housing sector, but none of them are designed to offer the freedom of accessing specific information tailored to the private rented sector. An understanding of the current status of the private rented sector in terms of its size and nature is important to reveal multiple ways to approach the housing issues from several directions and provide relief for the overheated market.

4. Research Method

A quantitative research method was adopted in this study. Pre-existing data from New Zealand's last five censuses conducted between the period of 1991 and 2013 sourced from Statistics New Zealand was used in this study. The data was analysed using a filtering and clustering analysis method. It involved filtering out irrelevant data and the division of the collected data into similar household groups. While there were other methods of analysis suited for investigating pre-gathered data, the chosen method was renowned for providing statistically valid results (Pearce 2013). To ensure result accuracy, only the total number of households who have stated their type of tenure was used as a basis of calculating the percentage of the group in each table. The households who have not stated their tenure have been excluded. The problem was that difficulty in data collection from apartment dwellers, which is known as 'no sign of life', negatively, affected the quality of the census data in 2006 and 2013.

5. Results: Size and Nature of Auckland Private Rented Sector

This paper reports a part of the findings of an on-going research study at Massey University undertaken to determine the composition of the private rented sector and its implications for the spread of housing options in Auckland. This section provides answers to the research question posed in this study, through the analysis of existing data obtained from New Zealand's last five censuses available via Statistics New Zealand. Tables and charts are created and simplified where necessary to make the data easy to understand.

5.1 Tenure trends in the private rented sector across New Zealand

The private rented sector is currently thriving in New Zealand. The research results showed that between 1991 and 2013 the total number of renting households across the country steadily increased at an average increase rate of 0.4% per annum to reach approximately one-third of the total number of households in New Zealand. The percentage of renting households across the country steadily increased over the 22-year period, with a tendency towards the continual growth of the private rented sector. The changing size of the private rented sector over the last two decades compared to households not renting (owner-occupied and social housing) is illustrated in

Figure 1. This continual increase in the growth of the private rented sector may be attributed to several factors that include shortage of housing supply and increasing unaffordability. Moreover, households may choose to rent because renting offers flexibility and it provides access to housing and locational services that would be costly. While for some renting is the tenure of choice, for many it may reflect an inability to access home ownership.

Figure 1. Percentage increase and proportion of total households who rent vs do not rent in New Zealand between 1991 and 2013

5.2 Regional distribution of renting households

There are considerable regional variations in both the size of the private rented sector and the extent of growth experienced across the regions in New Zealand. The renting population was the highest in Auckland out of all the regions of New Zealand (10.6%), followed by the Canterbury and Wellington regions (3.7%), and Waikato (3.1%), and the rest of the regions have an evenly distributed number of households (see Table 1 below). Auckland's significance at a national scale is illustrated by comparing its number of renting households with other major cities, indicating that approximately one-third of all renters in the country are located in this region.

Table 1. Distribution of renting households around New Zealand's major cities

Area	2013

	Distribution of renting households		
	% against total number of all households nationwide	% against total number of renting households nationwide	Numbers
Otago	1.4%	4.6%	20,877
Manawatu-Wanganui	1.7%	5.4%	24,624
Bay of Plenty	2.0%	6.5%	29,280
Waikato	3.1%	9.8%	44,589
Wellington	3.7%	11.9%	53,931
Canterbury	3.7%	11.9%	54,084
Auckland	**10.6%**	**34.1%**	**154,347**
Others	4.9%	15.8%	71,403
Total households renting	31.2%	100.0%	453,135
Source: Statistics New Zealand (2015)			

The regional differences in the private rented sector across New Zealand could be related to the strength of the economy and the wider housing market in Auckland (Scanlon and Kochan 2011). In areas of relatively high economic performance such as Auckland, Wellington and Waikato, growth in the sector has been driven by high house prices, migration, housing supply shortages and high demand, and a relatively high proportion of mobile workers and students. Canterbury economic growth, however, could be attributed to the extent of post-construction activities and job opportunities, as well as the resettling of affected communities after the earthquake swarms in the region since 2010. By contrast, in areas of lower economic performance, growth is more often driven by a lack of supply of (and therefore access to) social housing. Besides, the number of households who rent in Auckland rose from 32% to 35% between 2006 and 2013, with no rise between 2001 and 2006 (see Table 2). This explains the beginning of an era of skyrocketing housing prices and the imbalance of housing supply and demand in Auckland, coupled with migration.

Table 2. Number of households renting in Auckland vs total number of households in Auckland

Area	**Auckland region**		
Year	**2001**	**2006**	**2013**
Tenure of household			
Households who rent	116,694	130,230	154,347
Total households stated	367,395	403,455	437,649
% of households who rent	32%	32%	35%

5.3 Households who rent

All 21 local board areas (LBAs) within Auckland, other than Orakei, experienced an increase up to 8.0% in the proportion of renting households between 2001 and 2013. Waitemata and Mangere-Otahuhu LBAs had slightly more numbers of renting households than the households who owned their houses in 2013 and experienced the most rapid growth (6.3%) between 2006 and 2013, along with the Otara-Papatoetoe LBA (5.7%). As illustrated on the distribution map in Figure 2, most of the renting households were located close to housing, work and locational services. Furthermore, households who rented their home were most likely to be one-family households (63.3%) or one-person households (23.5%). These are households that contain a one family nucleus, which can be a couple, a couple with children, or one parent with children. Other people who do not form a family, and who can be related or unrelated to the family, may also be present in the household. One-person households were the second most common, making up 18.4% of renting households in Auckland, while other multi-person households (such as unrelated people flatting together) made up 9.3% of households who rented their home. Most households who rented were doing so from the private rented sector (83.7%), an increase from 81.8% in 2006 and 78.4% in 2001.

5.4 Predominant Rental House Typology

In general, rental housing tended to have fewer bedrooms than housing that was owner-occupied homes. Of households who rented, 29.0% were in a two-bedroom home, compared with 13.8% of households who owned their home or held it in a family trust. Households who rented their home were less likely to be in a four-bedroom home (at 13.4%) than households who owned their home (28%). As illustrated in Table 3, most renting households consist of three-bedroom and two-bedroom dwellings. This is not much different when compared with the national and total Auckland average. In contrast, relatively high numbers of one-bedroom dwellings (41.0%) are located in the Waitemata area where the Auckland’s CBD is located.

Figure 2. Percentage of renting households in each LBA in 2013

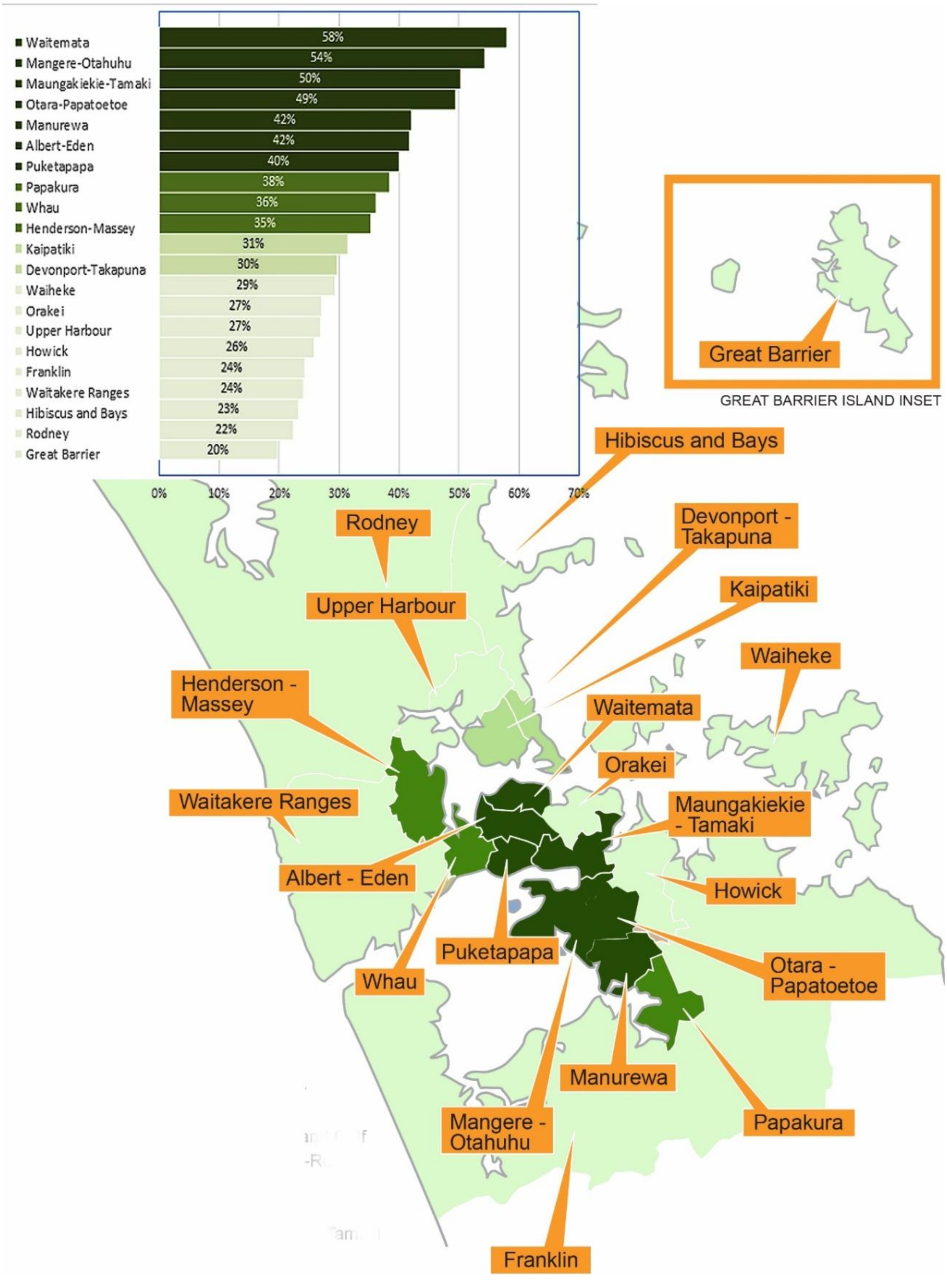

Table 3. Renting households by number of bedrooms in Auckland LBAs in 2013

Number of bedrooms	One bedroom		Two bedrooms		Three bedrooms		Four bedrooms		Five or more bedrooms		Total households stated
Area	No.	%	No.	%	No.	%	No.	%	No.	%	No.
Total New Zealand	54717	13	126171	29	176994	41	58452	13	17895	4	434229
Total Auckland	21168	14	45273	31	55029	37	19362	13	6537	4	147372
Rodney	477	12	1089	27	1548	38	684	17	258	6	4059
Hibiscus and Bays	729	10	1905	27	2859	40	1233	17	372	5	7092
Upper Harbour	453	11	996	23	1506	35	960	22	381	9	4296
Kaipatiki	840	10	2382	29	3603	44	984	12	357	4	8166
Devonport-Takapuna	726	13	2157	38	1899	34	657	12	189	3	5631
Henderson-Massey	708	7	2316	22	5607	53	1593	15	450	4	10671
Waitakere Ranges	492	14	849	24	1626	45	480	13	135	4	3579
Waiheke	189	20	348	36	330	34	81	8	21	2	963
Waitemata	6750	41	6306	38	2280	14	738	5	312	2	16386
Whau	1086	14	2154	28	3243	43	828	11	267	4	7575
Albert-Eden	2493	21	4938	41	2979	25	1182	10	504	4	12096
Puketapapa	690	12	1824	31	2268	39	792	14	279	5	5853
Orakei	1056	15	2688	37	2196	30	999	14	330	5	7269
Maungakiekie-Tamaki	1185	12	4317	42	3633	36	858	8	240	2	10230
Howick	711	7	2481	25	3972	40	2100	21	609	6	9873
Mangere-Otahuhu	687	9	2025	27	2985	40	1239	17	558	7	7494
Otara-Papatoetoe	708	9	2640	33	3519	44	840	10	357	4	8064
Manurewa	369	5	1554	20	4341	55	1230	15	450	6	7947
Papakura	312	6	1191	24	2382	48	858	17	219	4	4962
Franklin	489	10	1095	21	2238	44	1026	20	249	5	5094
Great Barrier	24	32	27	36	21	28	6	8	..		75

6. Discussion of Research Results

The private rented sector is currently increasing in absolute size and in terms of the proportion of households it accommodates. Attention has become focused on the capacity of the sector to meet a range of housing needs due to the unaffordability of owner-occupied homes and increasing demand for housing. The private rented sector currently accommodates approximately one-third of Auckland's households, with a projected increase to 42.3% by 2030. Moreover, the number of total rents based on private arrangements is expected to increase because of the government's recent attempt to reform the way state housing is managed, and it is highly likely that the volume of the private rented sector will remain strong for more years to come, if not increase. Most of the households who are renting outside of the Auckland suburbs tend to live in three-bedroom multi-storey dwellings, whereas households in the CBD were mostly living in one-bedroom unit dwellings. Household types and predominant housing typology location identified through the analysis provided a good indication of where the government and investors can prioritise in their development planning.

The need to accommodate an increasing population in New Zealand is a concern to the government, and attention has been focused on the growth of the private rented sector capacity to help this. However, a lack of framework for providing new housing to the private rented sector may serve as a deterrent to the growth of sector. There is a need for planning regulations with specific targets and objectives that would actively require a certain amount of properties to be let on the rental market in order to meet the predicted demand for housing. For instance, the emergence of younger mobile households and their inability to buy or own homes increases the demand for the spread of universal regulation in the private rented sector across the country. It is possible that where the private rented sector is generating new property, it tends to be in sub-markets where a high-density build is appropriate. The lack of government interference or regulation in housing rental contracts in the private sector is seen by many as challenge that limits the rental market's potential to provide renters with multi-year or even permanent tenancy. When compared to the tenancy contracts of other countries, such as Germany, France, the USA and The Netherlands, New Zealand is one of the most restrictive rental jurisdictions in terms of making minor home alterations, owning pets, termination of lease etc (Gibson 2014). Although the regional-specific correlation between sufficient housing supply and the change in the numbers for rental housing and house ownership is not known, it is certain that enough housing supply will positively contribute to overcoming the current inequality spread in the market. There is a need to identify and map the private rented sector niche markets in order to understand how the market can be defined in terms of demand and supply characteristics, distinctive rental practices, and in some cases specific types of policy interventions that shape the way the market operates.

7. Conclusion

The primary aim of this research was to investigate the structure and size of the Auckland private rented sector and its implications for the spread of housing options. The research results identified the different household types residing in Auckland’s private rented sector, their location and predominant building typologies. These results indicated that the growth in the proportion of renting households, coupled with the rapid increase in the cost of rent, signified that housing ownership in Auckland will become more challenging unless sufficient housing supply comes into action. Regardless of how significant the proportion of renting households becomes, it is crucial that more government intervention or regulatory requirements take place in order to provide sufficient housing options. An example can be creating mandatory minimum requirements for tenancy agreements in order to make renting a more ideal housing option for households.

It is important to note that while the chosen data collection method was best suited for the research topic, the range of data available from Statistics New Zealand and other organisations was not sufficient to carry out the in-depth research that was initially sought. Such a lack of information not only prevented identification of the target population’s behaviour over a longer period, but it also discovered what their actual needs might be in terms of getting desirable housing. The availability of detailed information on the target provide opportunity to clarify the issues around the efficacy of existing policy relating to private renting, and the need for further intervention.

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Payment discipline of public construction clients

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Abstract

Public sector´s payment discipline is said to have a significant impact on the private sector. German construction federations regularly run a comparison of payment practices between public construction clients and private clients amongst their members. The results of this investigation concerning the payment discipline of public construction clients often lead to criticism. Thus the present research project was started to examine independently and representatively the payment discipline of public construction clients. A survey provided the necessary empirical data. Using a standardized questionnaire based on both literature review and expert knowledge, more than 100 public construction clients were interviewed and their answers statistically evaluated. The project results can be summarized in the following categories: Description of payment transactions (partial and final invoices), causes of delayed payments (with different causes found on both sides) and first solution approaches. In conclusion, results show that payment discipline of public construction clients is better than it is said, but still has potential to be optimized.

Keywords: public sector, payment discipline, delay, survey, Germany

1. Introduction

The decline in construction volume in Germany since 1995 (minus 17%, minus € 45 billion) led to the consolidation of the construction industry; especially in the field of public procurement (minus 28%, minus € 10 billion) a continuously declining trend can be observed until today; all other areas (residential, commercial, etc.) show a constant level since the turn of the millennium (Statistisches Bundesamt 2012). In addition, reputation of the public construction clients has suffered on the timely payment of construction services provided (BWI-Bau 2008). In Germany, the payment periods for partial and final invoices are defined in the VOB Part B §16 (DIN 2010). Delays in the payment of already delivered goods and services usually cause additional costs in the form of interest, and these costs are to be reimbursed by those causing the delay. As a result, public sector´s payment discipline has a significant impact on the private sector, as Checherita-Westphal et al. (2016) and Flynn et al. (2014) point out.

Surveys carried out by a private construction federation amongst its members (BWI-Bau 2008) are inherently a subjective representation of the situation. In order to understand the real extent and the causes of delays in payment by public construction clients, an independent and representative survey was necessary.

The research project was to investigate the allegations on the part of private construction federations with respect to the payment behavior of public construction clients. This included the identification of payment transactions with non-adherence to the agreed deadlines, finding the cause of the delays in payment and – in the end – the development of solutions or "remedies".

2. Research method

A questionnaire was developed based on literature review and in cooperation with experts using guided workshops. In addition to the reasons for delays in payments, the questionnaire also asked for recommendations on how these delays can be reduced in the future.

Parallel to the preparation of questionnaires, contacts for the interviews were randomly selected out of the population, in our case the public construction clients in Germany. The conduction of the survey followed a uniform pattern: the interviewees received a web link for the online-questionnaire and were additionally introduced to the questionnaire by telephone.

The analysis of the survey results was carried out by electronic means. After the quantification of the payment delay, influence factors responsible for the delay were identified by comparing the average and median values (descriptive statistics). And in the end, first solutions to improve the current situation have been compiled.

3. Data

3.1 Population and selection of sample

The objective of the research project was to investigate the payment behavior of public construction clients on a representative basis and on all administrative levels. Consequently, the population of the survey were the public construction clients of Germany. The representativeness of the sample was ensured by a nonspecific and random selection of the sample.

Table 1: Comparison of population and sample: federal states

	Population		Sample		Deviation
	Quantity	Portion	Quantity	Portion	
01 Schleswig-Holstein	1,299	8%	36	8%	0%
02 Hamburg	4	0%	-	0%	0%
03 Lower Saxony	1,520	9%	42	9%	0%
04 Bremen	7	0%	-	0%	0%
05 Northrhine-Westphalia	850	5%	28	6%	1%
06 Hesse	890	5%	24	5%	0%
07 Rhineland Palatinate	2,556	16%	76	17%	1%
08 Baden-Württemberg	1.626	10%	55	12%	2%
09 Bavaria	3,629	22%	91	20%	-2%
10 Saarland	111	1%	-	0%	-1%
11 Berlin	4	0%	-	0%	0%
12 Brandenburg	638	4%	13	3%	-1%
13 Mecklenburg Western Pomerania	909	6%	25	6%	0%
14 Saxony	772	5%	26	6%	1%
15 Saxony-Anhalt	362	2%	8	2%	0%
16 Thuringia	1,132	7%	26	6%	-1%
TOTAL	16,309	100%	450	100%	0%

Table 2: Comparison of population and sample: administrative levels

	Population		Sample		Deviation
	Quantity	Portion	Quantity	Portion	
Federal state	16	0.1%	0	0.0%	-0.1%
Region	29	0.2%	0	0.0%	-0.2%
„Region“ (only in Baden-Württemberg)	12	0.1%	0	0.0%	-0.1%
District	402	2.5%	4	0.9%	-1.6%
Associated communities	4,581	28.1%	127	28.2%	0.1%
Community	11,269	69.1%	319	70.9%	1.8%
TOTAL	16,309	100%	450	100%	0.0%

3.2 Description of data base

3.2.1 Public construction clients

The data base was obtained by surveys. 450 people (the sample) were contacted by letter and by phone, which led to a return of N = 103 or a return rate of about 23%. The survey results show predominantly "communal projects (city, less than 100,000 people)" as public construction clients (see Figure 1); this reflects the population.

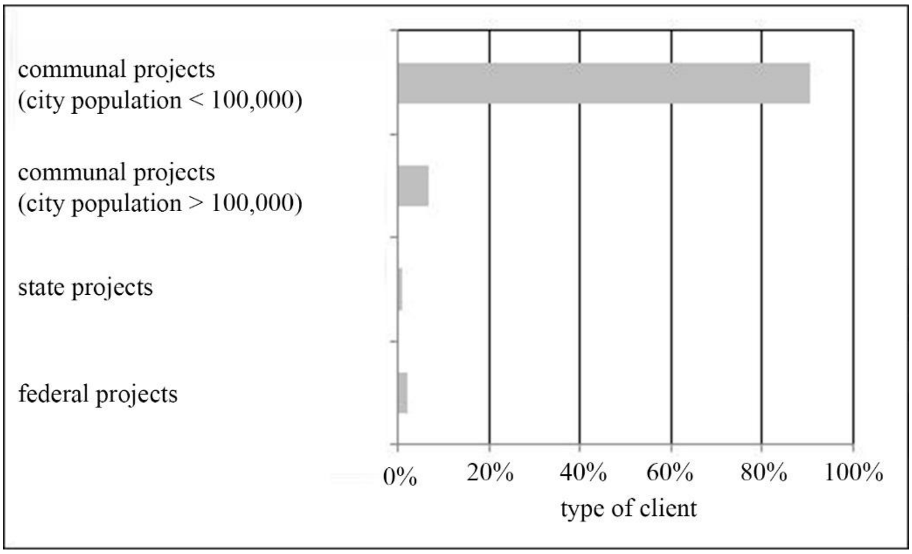

Figure 1: public construction clients per administrative level (N = 104, multiple answers possible)

Another characteristic of the sample was the question of the “specialized auditor". At only about 30% of the responding public construction clients, inspection took place by internal accounting.

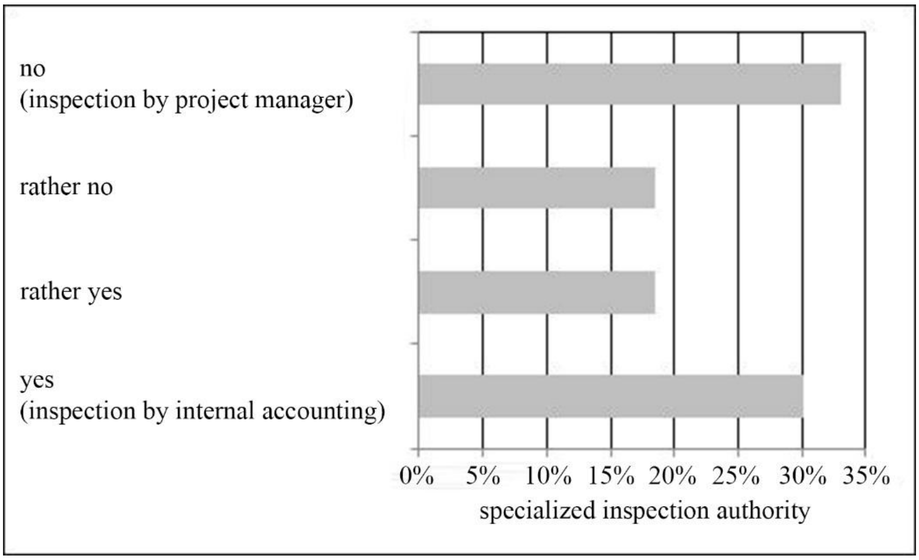

Figure 2: Specialized auditor (N = 103)

When looking at the distribution of project types, the sample shows a concentration of building and traffic construction projects. Moreover, it became clear that only two projects per year and per project type (building or traffic construction) were handled per public construction client (see Figure 3).

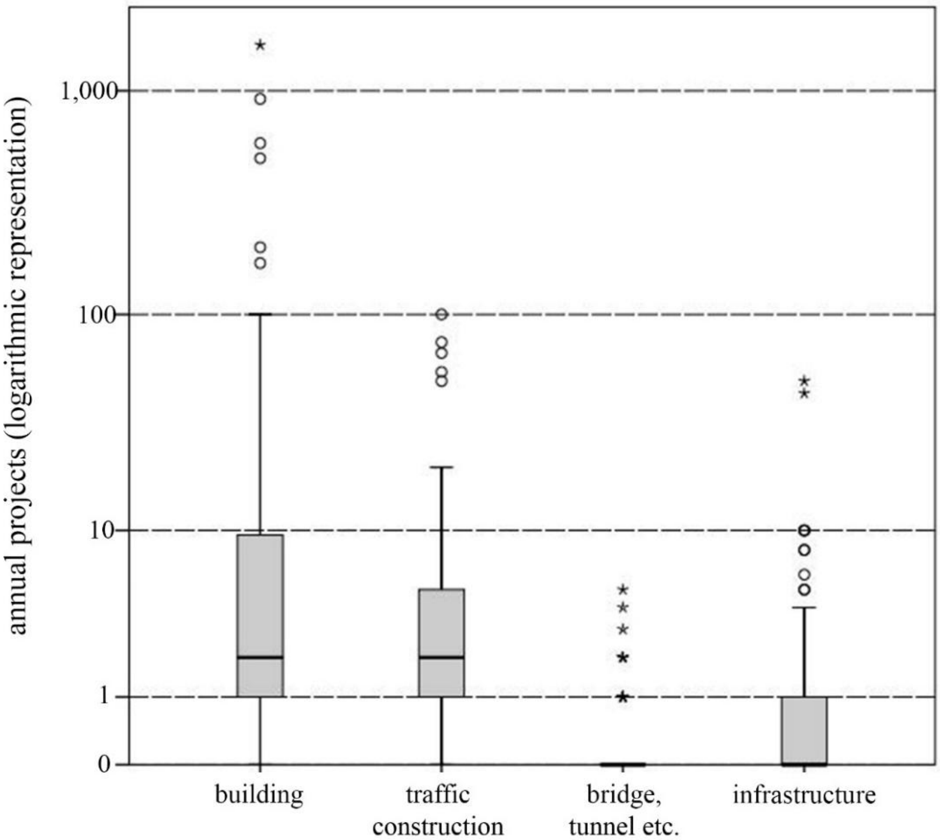

Figure 3: Number of annual projects per project type (logarithmic representation)

Another aspect of the sample is the ratio of 1 project with new building construction compared to 5 projects with or in existing building construction (extension, alteration, improvement, repair and maintenance). The size of the projects was approximately equally distributed on projects up to 10,000 € with a median of 20%, projects from 10,000 to 100,000 € with a median of 30% and projects from 100,000 to 2,000,000 € with a median of 20%. Projects amounting to more than € 2 million were barely represented in the sample, which is plausible for the observed population.

3.2.2 Invoices

The examined invoices can be differentiated between type of the order and type of invoice. Type of the order has been distinguished in the survey between the main order and supplementary orders, with 95% (median) on the main order. The invoices due to a supplementary order were generally of minor importance. The type of invoice was distinguished between partial and final invoices. The amount of partial invoices was approximately twice the amount of final invoices, the surveyed public construction clients indicated that they have worked on average on 60 partial and on 30 final invoices per year.

4. Results

4.1 Auditability of invoices

In Germany, there is a fundamental difference between partial and final invoices when it comes to their different payment periods allowed in accordance with VOB 2009 (Ingenstau 2010). In addition, it should be noted that this period only starts when the invoice is auditable; this date is not necessarily the date of the invoice or the date of delivery of the invoice. The survey results show that 5% (median) of the partial and final invoices were not auditable, while significant variations can be observed. The reasons for non-auditability of invoices based on the survey are displayed in Figure 4. It turns out that especially “error-containing documentation” repeatedly represents a reason for non-auditability.

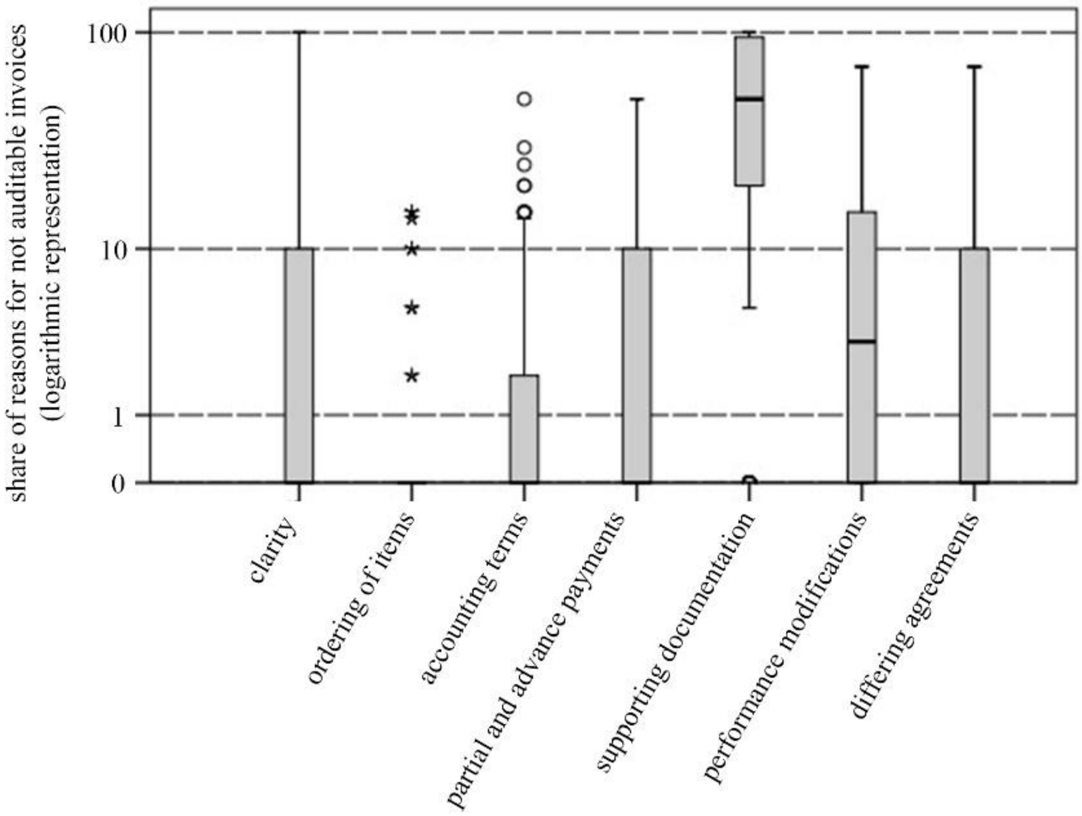

Figure 4: Percentage of reasons for not auditable invoices (logarithmic representation)

4.2 Payment behaviour in case of auditable partial invoices

With regard to the auditable partial invoices, the survey results show that according to the public construction clients, a median of 96% of the invoices were paid on time. The distribution is shown in Figure 5. In two cases, public construction clients stated that they paid the invoices on time in 50 % and 60% of cases.

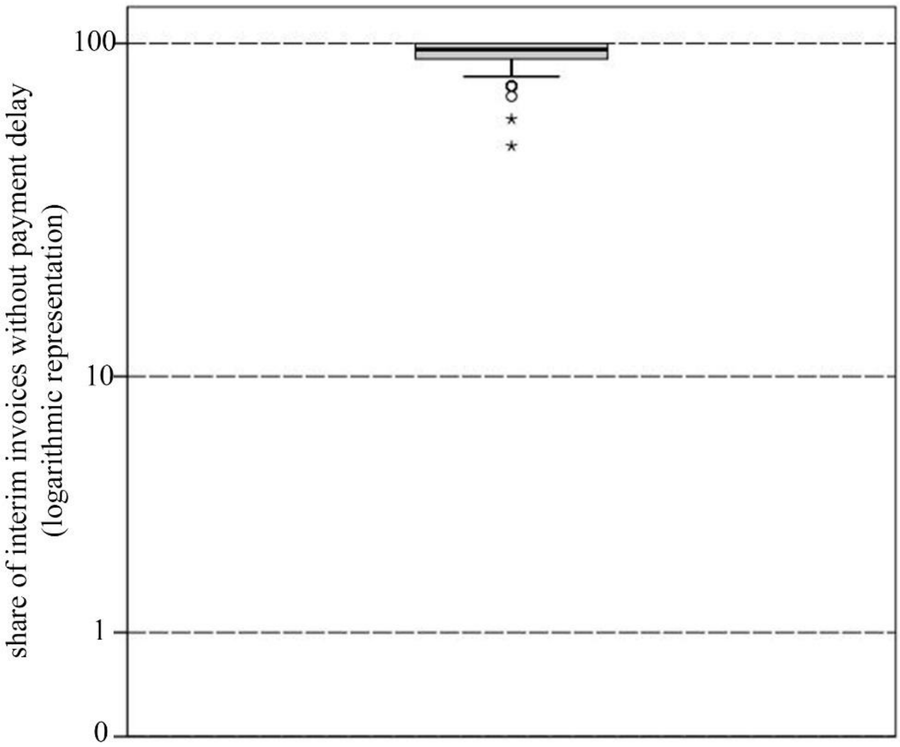

Figure 5: Percentage of partial invoices without payment delay (logarithmic representation)

This result is confirmed by the control question on the percentage of late payments with more than 18 days in accordance with VOB 2009; answers provide a median of 4%, which is the difference to the above 96%.

In addition to the proportion of the partial invoices paid within time or with late payments, the survey results also provide information on the extent of late payments. The survey distinguishes between the delay time and the average invoice amount. For the auditable partial invoices with late payments the following picture emerges: The delay time is 5 days (median) after the end of VOB period of 18 working days (lower and upper quartile at 5 and 10 days). The average invoice amount (median) is 10,000 € (lower and upper quartile at 5,000 € and 15,000 €). It should be noted that this is valid only for auditable partial invoices with payment delays. The partial invoices without payment delays are not included in the evaluation.

4.3 Payment behavior in case of auditable final invoices

Similar to the partial invoices, the auditable final invoices show that a large share of the invoices is handled without late payments. According to the public construction clients, they are paid on time with a median of 100% according to VOB (2009) with a given a period of 2 months. Only the lower quartile shows that 95% of the auditable final invoices are paid in due time (see Figure 6). In three cases, public construction clients stated that they paid the invoices on time only in 30, 40 or 50% of cases.

This result is confirmed by the control question on the percentage of late payments showing a median of 0% (lower quartile 5%), confirming the difference to the above 100% (lower quartile 95%).

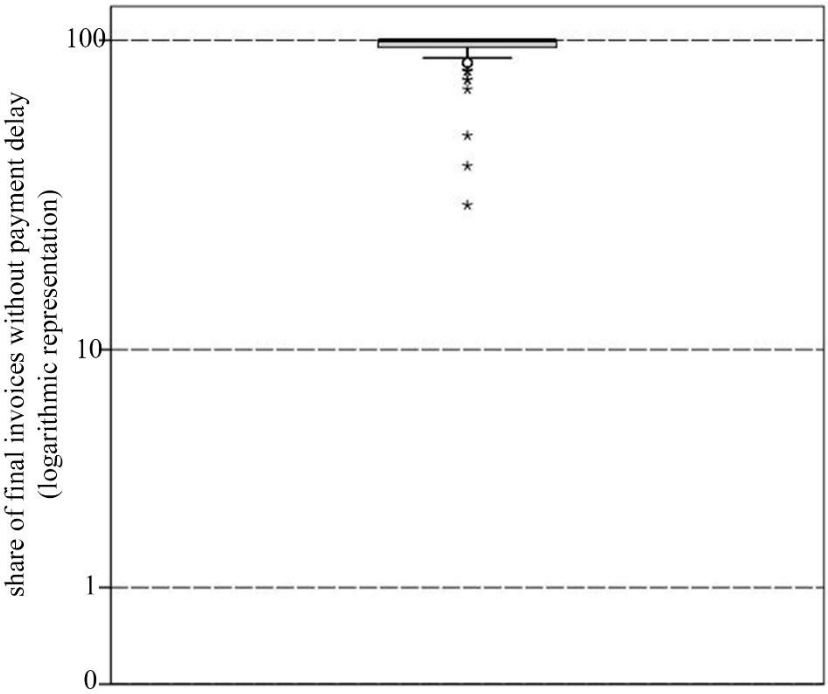

Figure 6: Percentage of final invoices without payment delay (logarithmic representation)

In addition to the proportion of the final invoices paid within time or with late payments, the survey results also provide information on the extent of late payments. Again, the survey differentiates between the delay time and the average invoice amount. For the auditable final invoices with late payments the following picture emerges: The delay time is 10 days (median) after the end of VOB period of 2 months (lower and upper quartile at 10 and 15 days). The average invoice amount (median) is 10,000 € (lower and upper quartile at 6,875 and 20,000 €). It should be noted that this is valid only for auditable final invoices with payment delays. The final invoices without payment delays are not included in the evaluation.

5. Discussion

5.1 Causes for payment delays

In addition to the detection and evaluation of payment transactions, there was another set of questions in the survey of this project, asking for responsible causes for delays in the payment of invoices. The public construction clients who indicated delays in paying the invoices, explained the backgrounds and named the causes, too. The interviewees could choose of a list of possible causes (as well as add their own) and rate each of these causes from their perspective (distribution of 100% on the respective causes). Within this context, the following causes can be described as relevant, with the specified sequence corresponding to the encountered ranking (see Figure 7): audit by external planning office too long (1st), increased work load on the part of auditors, vacation / illness of the auditor, incomplete, unsystematic quantity survey (all 2nd). It is thus clear that there are causes that can be found on the part of public construction clients, but also on the part of the other project participants. The public construction client has to deal especially with a limited staff capacity, as "increased workload of invoice auditor" and "vacation / illness of invoice auditor" show. With regard to the other project participants should be noted that some causes (e.g. "incomplete, unsystematic quantity survey") are attributable to the author of the invoice, as well as to other planning offices ("audit by external planning office too long"). The additional mentioned causes for late payments mainly points to the so called "Ortsbürgermeister", a non-professional mayor in villages or small towns, in many cases with lack of time, co-workers and/or experience in public construction projects.

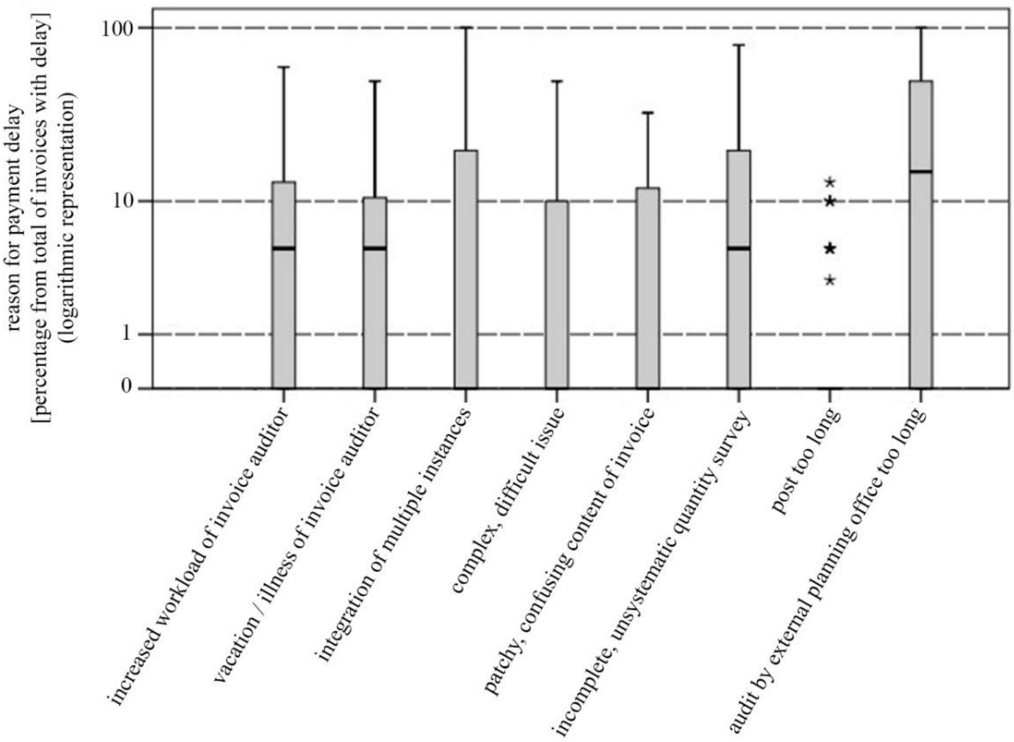

Figure 7: Reasons for late payments (logarithmic representation)

5.2 Possible approaches for solutions

Based on the above mentioned reasons for violation of payment deadlines, first guesses can be deduced to tell which solutions might be suitable. The survey also covers this issue, too. In terms of solutions or "remedies" to ensure compliance with the contractually agreed payment terms, the survey shows the following ranking (see Figure 8): early examination of quantity survey (1^{st}), increase of internal staffing (2^{nd}), clear rules on representation for holidays and disease; in addition, the contractor should be informed about the planned vacation (3^{rd}), raising awareness of the public construction client and the laboratory with regard to the problem of late payment eg. by means of events, brochures, etc. (4^{th}).

Besides the increase in personnel capacities on the part of public construction clients (2^{nd}), there are mainly organizational aspects that seem to offer a solution approach to the problem of late payments in accordance with the survey results (1^{st}), (3^{rd}) and (4^{th}). These organizational aspects are to be found on both sides of the client and the other project partners, and a special focus lies on the “early examination of quantity survey”.

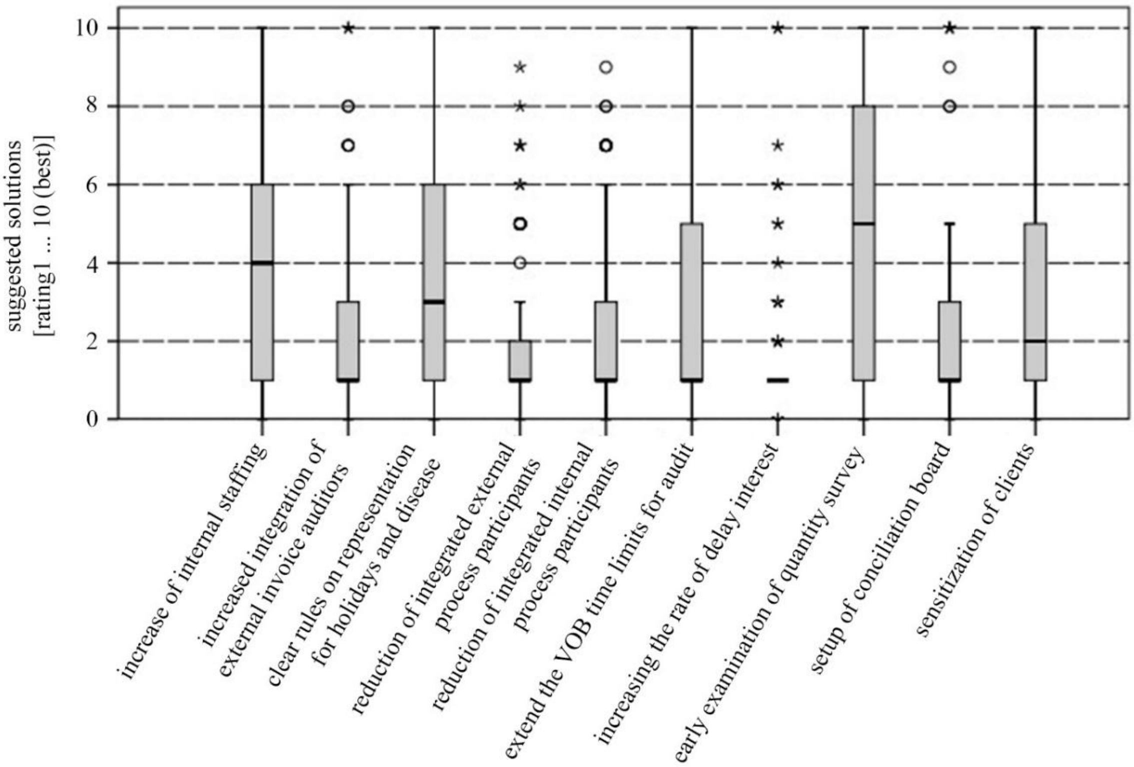

Figure 8: “Where do you see potential to ensure compliance with the payment deadlines?”

6. Conclusions

6.1 Overview

The results of the research can be summarized by the following points, which in turn represent responses to the initial research questions:

Acquisition and analysis of payment transactions, in particular the sizes and periods between receipt of the auditable invoice and the payment by the public construction client:

Auditable partial invoices show that a median of 96% was paid on time. If it comes to late payments, the delay time was 5 days (median) after the VOB period of 18 working days (lower and upper quartile of 5 and 10 days). The average invoice amount of late payment was 10,000 € (median) (lower and upper quartile of 5,000 € and 15,000 €). Auditable final invoices show that a median of 100% was paid on time. Only in the lower quartile a reduced figure of 95% of the auditable final invoices can be seen. If it comes to late payments, the delay time was 10 days (median) after VOB period of 2 months (lower and upper quartile of 10 and 15 days). The average invoice amount of late payment was 10,000 € (median) (lower and upper quartile of 6,875 € and 20,000 €).

Identification of the causes of delays in payment on the part of the public construction client and on the part of other project participants:

According to the findings of this research project, the causes for late payments lie on the part of the public construction client but also on the part of other project participants. The public construction client has to deal especially with a limited staff capacity, as mentioned by "increased workload on the part of auditors" and "vacation / illness of the auditor". With regard to the project participants, it should be noted that at least two causes are attributable to the author of the invoice ("incomplete, unsystematic quantity survey”) and the external planning offices involved in the audit (“control by external planning office too long”).

Development and presentation of possible solutions to ensure future compliance with the contractually agreed payment terms:

Besides the increase in personnel capacities on the part of the public construction client (2nd), there are mainly organizational aspects that can offer a solution to the problem of late payments in accordance with the survey results (1st, 3rd and 4th). These organizational aspects are to be found on both sides of the client and the other project partners, with a special focus on the early examination of quantity surveys.

Due to the methodological approach - in particular, the random selection of the sample and the unified survey – the present results can be qualified as representative and are transferable to the population (mainly to the administrative levels: “community” and “associated communities”).

6.2 Outlook

Public sector´s payment discipline has a significant impact on the private sector, as Checherita-Westphal et al. (2016) and Flynn et al. (2014) point out. Based on the present study results, the expected continued high relevance of the considered research questions and in addition to the implementation of the outlined "corrective measures" it is recommended to carry out at least one new survey in the medium term to better understand the long term development of the topic (including the initial effects of introduced “corrective actions”).

In a new survey, the concept of the actual survey does not necessarily have to be changed fundamentally since it has proved to be viable. However, if the questions should be extended to how the respective results depend on the “type of public construction client”, the “state”, the “type of invoice auditor” and so on, the sample of the currently about 100 responses would have to be largely extended, too. In any case, the selection of the sample (project construction clients to be interviewed) should be randomly again in order to get a representative picture of the population.

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Heightened Duties in Integrated Design and Delivery Contracts

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Abstract

In an archetypal contractual relationship each party is expected to look after its own best interests. Conversely, in a fiducial contractual relationship the fiduciary must act in the best interest of the other party. Integrated design and delivery contracts typically express a relationship of trust and confidence between contractor and owner. These expressions may obligate the contractor with if not strict fiducial duties at least heightened duties. These heightened duties have been characterized variously by U.S. Courts as something more than good faith and fair dealing; as a confidential relationship; or as a fiducial-like relationship.

Heightened duties may arise from a contractual expression of trust and confidence. U.S. Courts may also find that heightened duties are implied in the absence of any contractual expression thereof. Findings of heightened duties by U.S. Courts can be shown to depend more on the relative sophistication of the owner or the owner's agent in circumstances where the contractor can exercise a controlling influence over the owner's interests. And although express words of trust and confidence in a contract may not create heightened duties these expressions do have utility for helping U.S. Courts to find and enforce heightened duties under appropriate circumstances.

Herein proposed is a practical method of assessing the heightened duty expectations of the contractor by graphing a continuum of heightened duties against the level of sophistication of the owner and the ability of the contractor to exert influence.

Keywords: Fiduciary relationship, confidential relationship, good faith and fair dealing, integrated design and delivery.

1. Introduction

In an archetypal contractual relationship each party is expected to look after its own best interests. Conversely, in a fiducial contractual relationship the fiduciary must act in the best interest of the other party. A third type of contractual relationship creates confidential duties that lie somewhere in-between the extremes of the archetypal and the fiducial.

To know that a contractual relationship is archetypal, confidential or fiducial is to know what level of duty is expected and how to comport oneself so as not to breach that duty. Unfortunately, construction contracts rarely provide such specificity. Moreover, U.S. courts will find archetypal, confidential or fiducial relationships in the absence of any contractual expressions of those relationships. For now, we define heightened duties as an attention to the interests of the owner that exceeds that of an archetypal relationship without specificity as to whether that obligation rises to the level of confidential or fiducial or how those relationships are created.

The purpose of this paper is to assess the heightened duty expectations of designers and/or builders under integrated design and delivery contracts. It is an analytical paper adopting a classic legal research methodology focused upon primary and secondary legal research sources and designed to provide balanced findings in the form of a memorandum of law.

2. Integrated Design and Delivery

Design-Bid-Build [DBB] is the traditional project delivery methodology in the U.S. DBB has been widely vilified for precipitating highly adversarial project relationships. Such relationships are viewed as a root cause of cost overruns, late delivery, poor quality and owner dissatisfaction. Less in affirmation of this claim and more in a pragmatic acknowledgment that collaborative relationships, management strategies and organizational tactics have revolutionized other industries, the domestic construction industry has been adopting alternative project delivery methodologies. These alternative project delivery methodologies may be loosely categorized into three genres: design-build, construction management and integrated project delivery. Integrated design and delivery, as the phrase is used in this paper, refers to any of those genres or to any hybrid of those genres. The common theme of integrated design and delivery is involvement of a construction contractor early in the design process, typically requiring cost-plus type payment methods.

2.1 Design-Bid-Build

DBB is an established process in the U.S. It is sequential by definition: first the project's design must be completed, next there is a competitive bidding period, then an award, and finally the contractor builds, hence the moniker design-bid-build. Award is usually made to the lowest responsible and responsive bidder. A responsible bidder is one whom meets all business and financial qualifications specified in the bid solicitation (Federal Acquisition Regulation [FAR], § 9.104-2, 1984). A responsive bidder is one who complies with all material requirements of the bid solicitation (FAR, § 14.404-2(d), 1984).

DBB has its shortcomings. One shortcoming arises from the design process. State-of-the-art design solutions arise from two entrées: 1) access to the proprietary designs for equipment, materials and systems provided by manufacturers; and 2) the participation of the licensed specialty subcontractors who install and warrant those manufacturers' products. Designers engaged in the traditional DBB process lack access to both entrées. Thus, DBB tends to generate outmoded design solutions with lower levels of quality, ease of assembly and economy. Outmoded design becomes increasingly more problematic with complex projects.

Another shortcoming is time. Significant opportunity costs are lost while construction waits for the design process to go to 100% completion before the bid process starts and actual construction can begin. Worse, should all of the bids come in over budget, something that occurs all too often, the owner must go back to the designers to have their design revised and made less expensive, and then start all over again with bidding. DBB can be frustratingly time consuming.

Yet another shortcoming arises from the construction process itself. It can be adversarial to excess. This is particularly the case whenever the construction documents are inadequately developed or there is an abundance of performance specifications with indefinite performance criteria. Contractors, labouring under cutthroat, competitive pricing will seize every opportunity for relief through change orders, precipitating highly adversarial project relationships.

2.2 Design-Build

A design-build [DB] contractor, or design-builder, will take responsibility for both design and construction. DB contracts but can be configured with either firm-fixed-pricing or cost-plus pricing. But first, the owner must describe its intended scope of design and construction work and otherwise define its needs. This is accomplished with criteria documents. Typically, an owner, under separate contract with a design firm, develops criteria documents. Once that is accomplished, a two-part bid process begins.

During part one of the process, the owner solicits prequalification information from interested design builders. Responses are used to build a short-list of three to five of the most qualified firms. Typically, firms are not to respond with prices or technical solutions: the owner builds its short-list based solely upon the prequalification responses, such as evidence of prior experience performing the type of design and construction work that is being solicited. Ordinarily, the part one prequalification solicitation, commonly known as a request for qualifications [RFQ], will also define the scope of work of part two, identify both part one and part two evaluation factors, and assert the number of candidates that will be selected for the short-list.

During part two the short-listed candidates are invited to submit two separate competitive proposals in response to a request for proposals [RFP]. One of those proposals is a technical proposal, describing the design builder's technical response to the criteria documents. The other proposal is a cost or price proposal. The owner then picks the best proposal.

DB has its shortcoming. One arises from a hand-off of design control. The owner must rely on their criteria documents to describe their needs with sufficient clarity because apart from the criteria documents the owner will have little, if any, influence over the design. The design builder will design to the criteria documents and respond to the pricing method thereof, not necessarily to direction by the owner.

Another shortcoming arises from reactions to the first shortcoming. An owner wishing to retain more control over design may actually do some of the design and include that in its RFP. Such post-criteria design work is known as bridging. The designer who created the criteria documents is ordinarily retained for bridging. Bridging documents can include conceptual design documents, schematic design documents, design development documents and even some of the construction documents and specifications. Up to 70% of a design has been completed with bridging. But the more bridging, the more a DB project resembles DBB and all of the shortcomings that go with that.

Yet another shortcoming arises from organizational management. DB solicitations have a penchant for one-of-a-kind projects filled with special requirements. The firms that respond tend to be ad hoc teams, assembled from many different firms, each with different specializations, who may have or may not have ever worked together before. DB is a collaborative process between teams with very different interests. For collaboration to prevail over self-interest, working relationships must be founded on trust. Trust, however, is not a commodity; it is an interpersonal phenomenon (Child, Faulkner and Tallman, 2005).

2.3 Construction Management

The construction management [CM] methodology superimposes a CM layer over what would otherwise be a DBB project. Among other things, a construction manager provides preconstruction services. Preconstruction services are services related to design and planning activities such as: an evaluation of the project's program, schedule and budget; preliminary cost estimates; phasing plans; identification of long-lead items for procurement; preparation of bidder's lists; and bid evaluations.

The purpose of the CM project delivery methodology is to provide an owner with independent, third party consultation during design and construction. Early manifestations of the CM project delivery methodology had the construction manager providing preconstruction services during the design phase and administrative services, similar to what an architect or engineer would ordinarily provide in DBB, during the construction phase. This was known as CM-agency [CMa], alluding to a contractual agreement that installed the construction manager as an agent of the owner. The CMa does not guarantee budget or schedule. The owner retains the risk of cost and schedule.

In time, owners began to seek price and performance guarantees from CM firms. General contractors operating as construction managers proved willing, under certain circumstances, to provide these guarantees. A new project delivery methodology evolved, known as CM-at-risk

[CMAR]. This methodology distinctively differs from CMa in that cost and schedule risk is transferred from the owner to the construction manager.

For CMAR, an owner prequalifies construction managers whom have capability to provide both preconstruction services and actual construction. The selected construction manager then provides preconstruction services during the design process using cost-plus-fixed fee pricing. At a point in time when the construction documents are developed to the point of describing the project in sufficient detail, the construction manager provides a price for construction. The pricing method is usually cost-plus-fixed fee with a ceiling price, or cap that may not be exceeded. If this ceiling price, referred to as a guaranteed maximum price [GMP], exceeds the owner's budget, the owner can either order a redesign to budget, at the owner's expense, or stop the work and terminate all contracts. If the project does continue, a construction contract is executed with the construction manager, whose role comes to resemble the traditional role of a general contractor.

CMAR has its shortcomings. The CM layer adds additional costs. Proponents argue correctly that as a general contractor, the construction manager has access to manufacturers and licensed specialty subcontractors and that this results in higher quality, ease of assembly and lower costs. These benefits more than compensate for the additional cost of the CM layer, they argue. But it is often difficult to demonstrate these benefits because CMAR projects tend to be unique projects that do not possess a good baseline for comparison. It is instructive to note that some construction managers will charge little or nothing for preconstruction services, in effect giving them away in exchange for nothing more than the inside track to a construction contract award.

Another shortcoming arises if the construction manager's relationship with the owner during the design process dissolves into self-interest, as the construction manager becomes the general contractor and assumes cost and schedule risk. The owner may become burdened with additional oversight as it tries to administer the construction contract of its construction manager turned general contractor.

Yet another shortcoming relates to the same organizational management concerns that loom over DBB project delivery. At least in DB projects, some designers and builders have a healthy desire to work together. But CMAR is usually conceived as a shotgun marriage between architect/engineer and construction manager/general contractor where the construction manager is brought in, given a mandate over design but no contractual authority thereto. Whenever dysfunction sets in between the design firm or firms and the construction manager or its partners, inferior work products result.

2.4 Integrated Project Delivery

Integrated project delivery is a team-based, lean project delivery methodology (Matthews & Howell, 2005). Its contractual model is typically a multi-party agreement between owner, contractor and design professional. The American Institute of Architects defines this type of integrated project delivery as "…a method of project delivery distinguished by a contractual arrangement among a minimum of owner, constructor and design professional that aligns business interests of all parties" (AIA National | AIA California Council [AIACC], 2007). The However, the AIACC acknowledges that very few integrated project delivery projects involve such multi-party agreements. [1] (AIA and AIA Minnesota, 2012). Many integrated project delivery projects adapt the collaborative relationships, management strategies and organizational tactics while foregoing the multi-party agreement.

3. Heightened Duties

The archetypal construction contract is an agreement in which each party has equal bargaining power. In the past, a party to a contract was expected to look after itself owing no duty of care to the other party. In the twentieth century, jurisprudence in the U.S.A. began to hold contracting parties to the covenant of good faith and fair dealing (American Law Institute & National Conference of Commissioners on Uniform State Laws, 2009, §1-304; Sweet & Schneier, 2013, §17.02D). The United States Restatement (Second) of Contracts defines good faith, as "..faithfulness to an agreed common purpose and consistency with the justified expectations of the other party [and excluding] a variety of types of conduct characterised as involving 'bad faith' because they violate community standard of decency, fairness or reasonableness." (American Law Institute, 1987, §205). For the courts to find a breach of an implied duty of good faith in an archetypal construction contract the aggrieved party would have to show actual fraud.

A different type of relationship arises in a construction contract where there is a disparity of power and control between the parties. This type of relationship between contracting parties, known as a confidential relationship, was advanced by the Supreme Court of Georgia, as follows: "Any relations shall be deemed confidential…where one party is so situated as to exercise a controlling influence over the will, conduct, and interest of another; or where, from similar relation of mutual confidence, the law requires the utmost good faith; such as partners, principal and agent, etc." (*Davis v. Carpenter*, 1981).

A confidential relationship carries a higher level of duty than the archetypal relationship but that duty is breached by less egregious behaviour. For the courts to find a breach of duty on a contract expressing a confidential relationship, there need only be a showing that the stronger party exploited its relationship to take commercial advantage of the weaker party through intentional misrepresentation of material facts or a constructive fraud. It is not necessary to show actual fraud.

A fiduciary is one with superior knowledge and experience who is bound by a duty of trust and confidence to do what is in the best interest of another. The fiduciary first appeared in common law in the English case of *Keech v. Sandford (1726).* Exploring the contours of fiduciary duty to a minor child, that case established that a trustee owes a strict duty of loyalty. More recently in

[1] The AIA identifies nine pure integrated project delivery projects: Sutter Health's Cathedral Hill Hospital of San Francisco and Fairfield Medical Office Building of Fairfield, California; the MERCY Master Plan Facility Remodel of Lorain, Ohio; the Lawrence & Schiller office remodel of Sioux Falls, South Dakota; the SpawGlass Regional Office of Austin, Texas; the Autodesk, Inc. interior renovation in Waltham, Massachusetts; Cardinal Glennon Children's Hospital Expansion of St. Louis, Missouri; the St. Clare Health Center of Fenton, Missouri; and Encircle Health Ambulatory Care Center in Appleton, Wisconsin.

the U.S., Chief Judge Cardozo established a strict standard of fiduciary conduct, asserting "Many forms of conduct permissible in a workaday world for those acting at arm's length, are forbidden to those bound by fiduciary ties. A trustee is held to something stricter than the morals of the market place" (1928). The reasoning in *Meinhard* was very similar to the reasoning found in Keech: the fiduciary is bound by the rule of undivided loyalty that exists to reinforce the integrity of trusting relationships (*Meinhard v. Salmon, 1928).*

A fiducial relationship carries the highest level of duty but it can be breached by the slightest error of judgment. For the courts to find a breach of duty on a contract expressing a fiduciary relationship it is necessary only to show that the contractor did not act in the owner's best interest. It is not necessary to show fraud, constructive fraud or misrepresentation. It is only necessary to show that the contractor's act or failure to act, even when clearly communicated to the owner and competently performed, was not in the owner's best interest.

The fiduciary relationship, the confidential relationship, and good faith and fair dealing are similar in that they all require attention to the interest of another. They differ in the degree that one party must subordinate its own self-interests. The fiduciary must completely subordinate its own self-interest to the interest of another. Good faith and fair dealing does not require subordination of self-interest as long as the interest of another is not abused. The confidential relationship falls somewhere in-between.

To know that a contractual relationship is archetypal, confidential or fiducial is to know what level of duty is expected and how to comport oneself so as not to breach that duty. Unfortunately, construction contracts rarely provide such specificity. We can, however, identify express words in construction contracts that place heightened duties upon contractors. For now, we define heightened duties as an attention to the interests of the owner that exceeds that of an archetypal relationship without specificity as to whether that obligation rises to the level of confidential or fiducial.

4. Contractual Expressions of Heightened Duties

A typical expression of heightened duties is found in §1.2 of AIA Document A133™ – 2009 *Standard Form of Agreement Between Owner and Construction Manager as Constructor where the basis of payment is the Cost of the Work Plus a Fee with a Guaranteed Maximum Price,* which states in pertinent part:

> "§ 1.2 Relationship of the Parties - The Construction Manager accepts the relationship of trust and confidence established by this Agreement and covenants with the Owner to cooperate with the Architect and exercise the Construction Manager's skill and judgment in furthering the interests of the Owner…" (American Institute of Architects [AIA], 2009).

Table 1: Occurrence of "trust and confidence" language in AIA Standard Form Contracts

Document	Purpose	Clause
A101-2007	Cost + Fee with GMP	Art. 3
A103-2007	Cost + Fee without GMP	Art. 3
A133-2009	CMAR Cost + Fee with GMP	§ 1.3
A134-2009	CMAR Cost + Fee without GMP	§ 1.2
A141-2014	Exhibit A (Cost + Fee Design-Build)	§ A.5.6
A295-2008	IPD General Conditions	§ 9.1.3

The words "relationship of trust and confidence" are words in the art of law that infer heightened duties. Table 1 lists other occurrences of identical expressions of "trust and confidence" elsewhere in the AIA suite of contract documents. Heightened duties are inferred in DBB, DB, CMAR and IPD contracts. In each case these heightened duties are associated with the cost-plus pricing method.

5. Court Findings on Heightened Duties

At first glance, interpretations by U.S. courts of contractual language such as that found in AIA Document 131 §1.2 are mixed. In some cases a fiduciary relationship was found while in others it was not. However, there is a coherent pattern of decisions. The facts of each case at bar appear to have more influence on the court's decisions than the express contract language.

On several occasions U.S. Courts have found a heightened duty in construction contracts with language similar to AIA's A133 §1.2. In *Henson v. Barker* the Florida Court of Appeal found that AIA trust and confidence language in a cost-plus contract with a GMP for construction of an 8-unit condominium project placed a heightened duty on the contractor "to disclose any latent defects in construction that would materially impair the value of the structure" (1994). In *A.A. & E.B. Jones v. Boucher*, the owner, who was having a house built on a cost-plus basis, was confronted with a $593,878 bill against a GMP of $250,000; an architect that died during construction; a contractor that kept ramping up the change orders; and no way of knowing what was being billed for the lack of detail on the invoices (1974). In *Jones v. Hiser* the contractor, building a home on a cost-plus basis with an initial estimate and no GMP, did not bother to track costs or communicate cost changes to the owner until the end of the project (1984). In both *Boucher* and *Hiser* the courts found that the contractors acted in bad faith. While they did find that the express words of the contract created a fiduciary duty, that finding was only used to support their finding of bad faith. Typically, the breach of a fiduciary duty requires more than the absence of fraud or misrepresentation. Bad faith appears to have been that something extra.

Several U.S. Courts have found no heightened duties within agreements negotiated between contractors and sophisticated business owners. In a dispute over cost overruns, the Superior Court of New Jersey found no heightened duty on a cost-plus-fixed-fee contract for construction of a factory outlet store because the owner was a Real Estate Investment Trust [REIT] whom employed an experienced Vice-President of Construction (*Avon v. Martin*, 2000). Despite language similar to the AIA's trust and confidence language, the court held that the contractor did not have "superior power, knowledge or control over the terms" of the work (*Avon v. Martin*, 2000). In *Eastover Ridge v Metric* the Court of Appeals of North Carolina found no heightened duties, despite AIA contract language, on a negotiated cost-plus contract where the architect had agency authority and extensive duties on behalf of the owner for the construction of 216 apartment units, a clubhouse, a pool, tennis courts, a maintenance building and landscaping (2000). The *Eastover* court attributed sophistication to an owner who hired an architect as his agent (*Eastover Ridge v Metric*, 2000). In a dispute over a verbal cost-plus contract to build a dream home valued at over $4,000,000 the Wyoming Supreme Court did not find a confidential relationship because the owner was a successful and sophisticated businessman (*Garrison v. CC Builders*, 2008). The same outcome would likely have been found had there been a written contract with AIA trust and confidence language.

We can surmise from this that when the owner is a sophisticated builder or becomes so by virtue of hiring a professional architect and the contractor lacks power, knowledge or control over the terms of the work, the courts will find no heightened duties. Express words of trust and confidence in a construction contract will not alter that prescription.

On several occasions U.S. Courts have found a heightened duty in construction contracts that lacked express trust and confidence language. In *Hitt v. Smallwood* a contractor with a fixed price contract to build a garage for a homeowner entered into a contract to do additional work on a cost-plus basis. The court found that the contractor had a heightened duty to keep accurate records (1926). In *Romine v Rex Darnall* a fixed-price contract to construct a home was found to be a cost-plus contract with a fixed fee and the appellate court found that cost-plus contracts include an implicit condition that contractors will "make every reasonable effort to minimize costs" (1976). In *Shaw v. Bula* the Missouri Supreme Court found for the homeowner because records produced by the contractor were not sufficiently accurate (1949).

All three of these owners were homeowners. A homeowner will not be presumed sophisticated and a contractor will be presumed to have superior knowledge of construction and power over the terms. There was evidence of misrepresentation, through either commission or omission, by all three contractors. A showing that a stronger party exploited its relationship to take commercial advantage of a weaker party through intentional misrepresentation of material facts establishes a breach of a confidential duty. Although these courts found heightened duties they did not choose to characterize this duty as a confidential duty.

The facts of any particular case appear to influence the court's propensity to find that contractors have heightened duties. When the owner is a sophisticated builder or becomes so by virtue of hiring a professional architect and the contractor lacks power, knowledge or control over the terms of the work, the courts will find no heightened duties. Express words of trust and confidence in a construction contract will not alter that prescription. The courts may find the heightened duty of a confidential relationship or the strict duty of a fiduciary relationship with or without express contractual language to that effect. Figure 1 graphically illustrates the propensity to find archetypal, confidential or fiducial relationships along two axis: the CM's ability to influence the owner; and the level of the owner's sophistication.

The courts tend to define the duty that was breached by the egregiousness of the contractor's behaviour, not the other way around. Breach of a fiducial relationship is implicated when the only evidence is bad faith. Breach of a confidential relationship is implicated when the evidence shows misrepresentation or constructive fraud. Breach of an archetypal relationship is implicated by evidence of actual fraud.

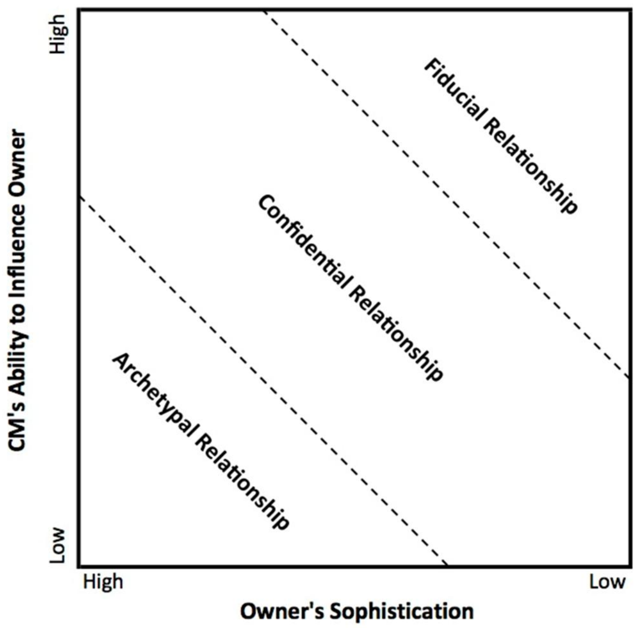

Figure 1: Heightened Duty Implications

6. Conclusions

In a construction contract expressing an archetypal relationship the contracting parties are held to an implied covenant of good faith and fair dealing. For the courts to find a breach of that implied duty the aggrieved party would have to show actual fraud. A construction contract expressing a confidential relationship carries a higher level of duty than the archetypal relationship but that duty is breached by less egregious behaviour. For the courts to find a breach of duty on a contract expressing a confidential relationship there need only be a showing that the stronger party exploited its relationship to take commercial advantage of the weaker party through intentional misrepresentation of material facts or a constructive fraud. It is not necessary to show actual fraud. A construction contract expressing a fiducial relationship carries the highest level of duty but can be breached by the slightest error of judgment. For the courts to find a breach of duty on a contract expressing a fiduciary relationship it is necessary only to show that the contractor did not act in the owner's best interest. It is not necessary to show fraud, constructive fraud or misrepresentation. It is only necessary to show that the contractor's act or failure to act, even when clearly communicated to the owner and competently performed, was not in the owner's best interest.

The facts of any particular case appear to influence the court's propensity to find that contractors have heightened duties. When the owner is a sophisticated builder or becomes so by virtue of hiring a professional architect and the contractor lacks power, knowledge or control over the terms of the work, the courts will find no heightened duties. When the owner is unsophisticated and the contractor has power, knowledge or control over the terms of the work the courts may find the heightened duty of a confidential relationship or the strict duty of a fiduciary relationship with or without express contractual language to that effect. Figure 1 graphically illustrates the propensity to find archetypal, confidential or fiducial relationships.

Finally, the courts tend to define the duty that was breached by the egregiousness of the contractor's behaviour, not the other way around. Breach of a fiducial relationship is implicated when the only evidence is bad faith. Breach of a confidential relationship is implicated when the evidence shows misrepresentation or constructive fraud. Breach of an archetypal relationship is implicated by evidence of actual fraud.

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Effective school networks

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Abstract

Schools are the most expensive public service after the social and health care in Finland. Education provided by the schools is essential to the renewal of the workforce and to the development of the national economy. Educational services are produced in a network of school facilities. The size of schools, the distance between them and the quality of the facilities are most important drivers of the quality and cost of the education. The article is based on empirical data from 19 primary and secondary school networks in Southern Finland. Networks studied have neither high quality nor reasonable cost. A simulation model was created to study the potential for enhancement of the networks. The model was created based on the fact that there is a connection between the size of the school and the average size of the classes. Savings were the differences between the given model and the present costs. Simulation models showed that there is a remarkable potential for savings by redesigning the networks. The savings of school networks varied between 775 € per pupil to 3120 € per pupil. The average saving was 134 € per capita**.** On a national level the savings would be approximately 0,7 billion € a year.

Keywords: school networks, school size, facility cost, educational economics

1. Introduction

Finnish schools are mainly owned and operated by municipalities. The State supports municipalities, but they are wholly responsible for arranging and offering education and other services. This article studies the cost and quality of Finnish primary and secondary school networks. There has been a lot of discussion about the quality and cost of individual units in Finland, but seldom about the whole network. However, it is the network, not the units which provide the service to the citizens. If equality between taxpayers and users are wanted a few well functioning units are not enough. The level and cost of service should be somewhat constant everywhere.

Finnish schools are small. The average size of all schools (primary and secondary) is 195 students in Finland (FNBE 2013) when in US, the average size is 550 (Keaton 2012). In EU countries median primary school size is approximately 350 students (Bolam 2000). US National Center for Educations Statistics considers 300 pupils the smallest category, 500 to 1200 is medium and over

1200 large category (Keaton 2012). There are no schools in Finland which are in Keaton's large size category.

Finland is sparsely populated country and there are many small schools in the rural areas. 41% of Finnish schools have less than 100 students when only 10% of the pupils study in them (FNBE 2013). Such a network of small schools is expensive, and there are serious doubts whether the small schools are able to provide high quality educational services. There is an ongoing debate about the benefits of the small schools to the pupils and to the community (Kalaoja & Pietarinen 2009). The amounts of small rural schools have dropped dramatically during the last decades (ibid.). The closures of small schools always raise fierce public debate, even though they impact only a minority of the pupils. The quality of larger schools or the network as a whole is seldom discussed.

What we are interested in is the quality and cost of the networks. This study is based on our work on 19 school networks in Southern Finland. We studied the cost of tuition, the cost and quality of the facilities and formed alternative or simulated models for networks. We were able to show remarkable savings as a difference between the existing networks and simulated ones.

1.1 Research questions

The research tries to find an answer to following research questions:

1. What is the overall quality and cost of school networks in the municipalities studied?

2. What would be the ideal school networks for the municipalities studied?

3. What would it cost to build and operate such networks compared to the cost of operating the existing networks?

The costs of transportation were not included, because they are minimal compared to other costs.

2. Methodology

Research is based on material gathered during the years 2011-2013 from 19 municipalities, population of which is a total of 450 000. The municipalities studied are small or medium size municipalities in Finland, population of which are between 2000 and 50 000 inhabitants. They form 8,34 % of Finnish population.

The empirical part is based on the simulation model. The simulation model was created to study the potential for enhancement of the networks. The simulation model was created based on the fact that there is a connection between the size of the school and the average size of the classes. The average class-size is one of the most important factor behind the total cost of a school, because teachers' salaries are the biggest single expense of a school and the amount of teachers in a school is dependent on the amount of classes. Using the simulation model, three different service networks per city or municipality were created based on the school size and average class size. The simulation model is presented more carefully in 4.3.

2.1 Structure of the work

This research consists of 8 sections. Firstly, chapter three concentrates on the theory and introduce previous researches related to the topic. Chapter four focuses on the empirical part of the study. The chapter describes in detail the data collection, research method and simulation model. In chapter five the results of the study are presented and in chapter six results are discusses more carefully. Finally, in chapter seven strings are pulled together in the form of a conclusion.

3. Theoretical background/Literature review

Theoretical background of this study is divided into two sections. In the first section different kinds of networks are presented. The section also introduces optimization methods for school network planning and typical characteristics of the school networks in Finland. The second section concentrates on size of the units i.e. how to school size and class size affect learning outcomes.

3.1 Networks

According to Merriam-Webster (2016) dictionary network is "an interconnected or interrelated chain, group, or system *<a network of hotels>*". A group of schools owned by a municipality form a network because:

- they are interrelated: there is a limited number of students and they all have to go to a school, if one school grows bigger, the others have to decrease in size
- they are interconnected: there is a limit to a distance between two schools
- they form a system: not one school but all the schools are needed to provide school services to a municipality

Network theory studies all kinds of networks: air traffic networks, computer networks, social networks, to mention just a few. Typical to all kind of networks are that they are formed by nodes and links connecting the nodes. The basic type of a network is a *random network* (fig 1), where nodes and links are evenly distributed. Highway network is a typical example of a random network. The problem with a random network is that one has to go through many links to get from one place to another. This is called *network distance*: the amount of links between two places. (Barabási 2002)

The degree of separation describes the overall quality of a network: how many links there are on average between two randomly chosen points. The degree of separation of the internet is nineteen: any two internet sites are nineteen links or "clicks" away from each other (on average). This is possible, because these networks are not random: there are short-cuts which make the world smaller.

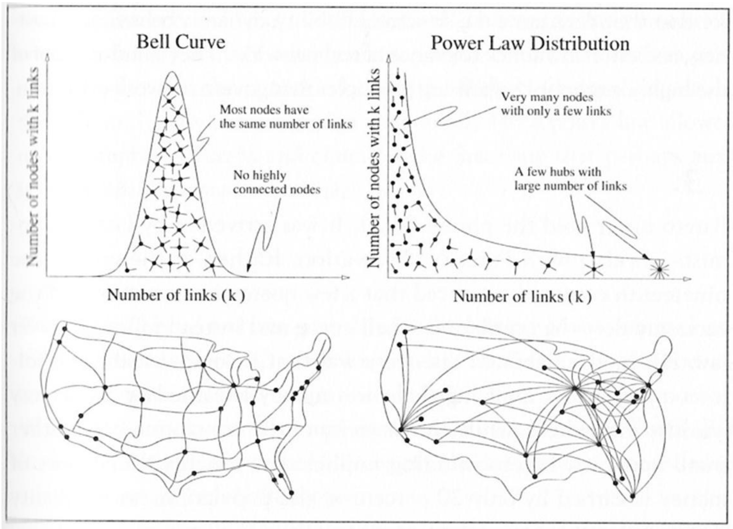

Figure 1. *The degree distribution of random network (top left) follows a bell curve. Most nodes have the same number of links, and nodes with a very large number of links do not exist. Scale-free network (top right) has a power law degree distribution of links. Most nodes have only a few links, held together by a few highly connected hubs (Barabási 2002: 71).*

The internet has a small degree of separation, because it has “hubs”: super-nodes to which there is a link from most of the other nodes. A network based on few hubs and plenty of nodes with only a few links are called *a scale-free network*. Air traffic network is a typical example of a scale-free network. There are hubs like Heathrow and Paris De Gaulle and lots of unimportant small airports. If you can get to Heathrow from one of the small airports, you can get to almost anywhere from there. The internet is another example of a scale-free network.

Are public schools random or scale-free networks? Statistics of schools in Finland would suggest that they resemble more random network than scale-free one. If each pupil and each school are considered nodes, the distribution of links is the same as the amount of pupils in one school. The distribution of links in Finnish school network is more bell curve than a power degree distribution (fig 2)

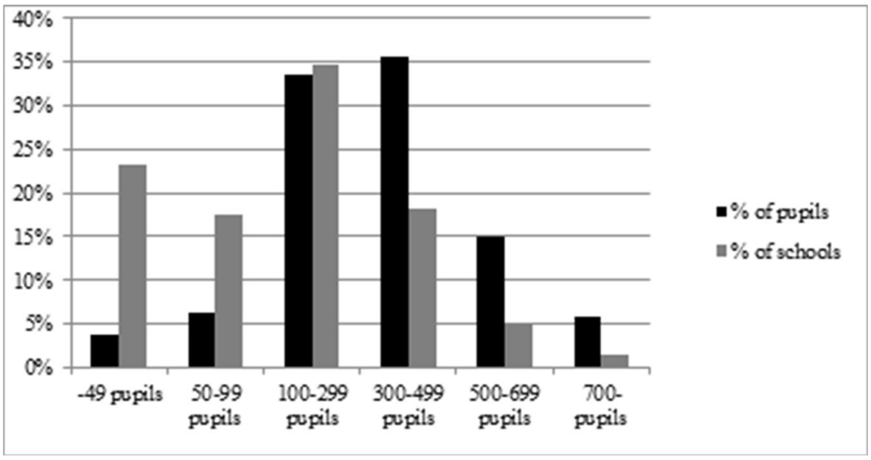

Figure 2. *The distribution of Finnish schools and pupils according to the schools size in 2013 (Finnish National Board of Education FNBE 2013).*

3.2 School networks

3.2.1 Optimization methods for school network planning

Schools can be seen as the physical infrastructures used to produce educational services. Together with teachers, whose responsibility is to supply labour for the process, schools constitute the determining production factors used in educational sector. (Antunes & Peeters, 2000) The main target of educational network planning is to satisfy demand as much as possible. When that target is reached, the objectives will generally involve maximizing socio-economic benefits which is basically the same as minimizing costs. There can also be other objectives such as maximizing accessibility, which has been the main idea behind the development of the Finnish compulsory school network (Kuikka, 1996; Antunes & Peeters, 2000)

From the society point of view, one of the key problems in the educational sector is how the educational network should be planned so that it could serve educational demand in a certain region in the short, medium and long term. However, during the last decades, planning processes of educational networks have become increasingly complex. The educational network planning problem consists of many questions which should be solved: where schools should be located, what their size should be, which schools should be kept open and which ones should be closed, whether it is necessary to build new schools, what class sizes should be and so on. (Antunes & Peeters, 2000; Teixeira & Antunes, 2008) The planning problem has been researched on general level by several authors (see e.g. Erlenkotter, 1967; Roodman & Schwartz, 1975; Roodman & Schwartz, 1977; Fong & Srinivasan, 1981; Van Roy & Erlenkotter, 1982; Jacobsen, 1990; Shulman, 1991; Marianov & Serra 2002). Two separate research fields have focused on studying school network problems: “multi-regional capacity expansion” and “dynamic facility location”. These approaches are based on different kinds of mathematic optimization models which try to determine optimal network structure. (Erlenkotter, 1967; Roodman & Schwartz, 1975; Roodman & Schwartz, 1977; Fong & Srinivasan, 1981; Van Roy & Erlenkotter, 1982; Jacobsen, 1990; Shulman, 1991; Marianov & Serra 2002). The literature review shows that there are also several articles which deal specifically with school networks. Henig & Gershak (1986), Greenleaf & Harrison (1987), Tewari & Jena (1987), Viegas (1987) Beguin et al. (1989), Pizzolato (1994), Antunes & Peeters (2000) and Teixeira & Antunes, (2008) present different kinds of optimization models for school network planning purposes, just to mention a few. However, the optimization models are typically very detailed and contain just a few variables, are designed for specific conditions, respond for specific needs, or contain other restrictions. They are often too complex for practical planning purposes.

3.2.2 School network in Finland

The main idea behind the development of the Finnish compulsory school network has been to have schools close to the pupils which mean that the distance from home to school should be less than 5 km. This has led to a situation where almost every village in rural area has its own school. However, reduced birth rates, migration, changes in the economic structure, and improvement of rural road conditions started the closure wave of small rural schools in the late 1960s. The founding of the current comprehensive school system which ensured equal educational opportunities for all citizens improved the position of small rural schools for a while, but deep recession at the end of 1980s and early 1990s put the future of the small rural schools under threat. (Kuikka, 1996; Laukkanen & Muhonen, 1981; Kalaoja & Pietarinen, 2009)

In the early decades of the 2000s the demographic structure has changed in Finland. The National Board of Education (2004) predicted that the number of children of compulsory school age will fall approximately 10 % in every ten years at the beginning of the 2000s. In addition the trend towards rural-urban migration intensifies and regional centralisation will continue. (National Board of Education, 2004). Also the economic difficulties of Finland due to the downturn of past years create pressure for savings in public expenditure. In addition, Finland is already sparsely populated country (340 000 km^2 with population of approx. 5 million) so it is evident that there will be the growing need to cut the costs of the school network in Finland. To make the cost savings possible the unit size of schools needs to be increased and more effective school network to be planned. (Kalaoja & Pietarinen, 2009)

3.3 Size of units and economies of scale

Size of units is closely related to the term *economies of scale*. The basic idea behind economies of scale is that enterprises can get the cost advantages due to size or scale of operation. Increasing the size of units typically leads to economies of scale because fixed costs are spread over more units of outputs. In the educational unit context, economies of scale means that fixed costs could be spread over a larger pupil base (Lee & Smith, 1997). In this chapter optimal sizes of educational units and impact of a class size on learning outcomes are presented.

3.3.1 The optimal size of a school

According to Leithwood's and Jantzi's (2009) review of 59 post-1990 studies related to school size, pupils in small schools perform better than pupils in large schools. There is a lot of evidence in favour of smaller schools in the studies. However, the term "small school" and "large school" vary between the studies so it would make more sense to ask what the optimal size of a school is and is there difference between the optimal size of an elementary school and a high school (Cotton, 1996; Lee & Smith, 1997; Leithwood & Jantzi, 2009)

The exact size of an optimal school is difficult to determine, because the optimal school size depends on many different variables such as diversity of pupil background and differences between elementary schools and secondary schools. In an elementary school, where lots of pupils have diverse disadvantaged backgrounds, the size shouldn't be more than 300 pupils. In an elementary school with heterogeneous or relatively advantaged pupils the size should be smaller than 500 pupils. The size of an elementary school, where pupils are of diverse or disadvantaged background, should not be more than 600 pupils and with heterogeneous or relatively advantaged pupils, the size should be smaller than 1000 pupils. (Cotton, 1996; Lee & Smith, 1997; Leithwood & Jantzi, 2009)

In the previous paragraph the recommended upper limits of school sizes were presented, but there are minimum limits as well. Where the bigger schools tend to be more formal and bureaucratic, reducing school size too much leads to constrain courses and to reduced ability to respond to the special needs of pupils (Lee & Smith, 1997). Many researchers have reached the conclusion that an appropriate and effective size for an elementary school is 300-400 pupils and for a secondary school 400-800 pupils. (Cotton, 1996; Lee & Smith, 1997; Lee & Loeb, 2000). According to these studies 76% of Finnish schools are undersized.

3.3.2 The impact of a class size on learning outcomes

It is very typical that parents and teachers assume that reducing class size leads automatically to better learning outcomes. It increases pressure on politicians to reduce class sizes or at least prevent them from increasing in many countries, also in Finland. (Pedder, 2006) Class sizes are one of the most discussed and most researched topics in pedagogical field of science. It is easy to find arguments for and against the claim that reducing class sizes would lead to better learning outcomes. Those who support class size reduction typically argue that reducing class size leads to higher quality instruction, student-centred teaching, more individualized instruction, fewer disruptions and so on. On the other hand, there is a huge amount of studies which claim that there is no evidence that reducing class size would lead to improved learning outcomes. (Hattie, 2005)

One of the most impressive and the most discussed study on class size was Project STAR (Student-Teacher Achievement Ratios) which began in Tennesee in 1985. Project STAR involved 6500 students in 329 classrooms in 79 schools. The students were divided into a regular class (22-26 students) or to a small class (13-17 students). The students were held in classes of same size for the next 3 years and teachers didn't get any special instructions for teaching different size of classes. The study showed that reducing class size had only a small effect on learning outcomes. The overall effects were 0,15-0,27 in favour of small classes on a scale of 0,0-1,0 according to a meta-analysis of Project STAR. The benefits of small classes were greater for students who had worse socio-economic background. (Finn & Achilles, 1990; Word et al., 1990; Finn et al., 1991; Achilles, 1999, 2002; Ritter & Boruch, 1999; Achilles & Finn, 2000; Achilles et al., 2002).

Also the other studies after Project STAR have lead to the same kind of results. Typically the overall effects of class size reduction has been something between 0,1 and 0,2. For example Goldstein et al. (2000), Dustmann et al. (2003), Johnson et al. (2004), Blatchford et al. (2005) and Urquiola (2006) have studied the impact of learning outcomes when reducing class size from 25 to 15 pupils and they have come to a 0,1-0,2 effect-size. The effect-size of class size reduction could be considered small or even tiny, when compared to many other possible enhancement solutions. Hattie (2005) has listed 46 influences on student achievement and the place of class size (place no. 40) is clearly among the smallest effect-sizes. Average effect-size of different influences on learning was 0,40 according to Hattie's meta-analyses. One of the most popular explanations of why effect-size of class size reduction is so small (0,1-0,2) is that actually teachers of smaller classes adopt the same teaching methods they use in larger classes and are not optimizing the opportunities of fewer students in classroom. (Hattie, 2005) It can be said that class size reduction is an expensive educational reform, its positive effects on the learning outcome are uncertain and there is no scientific evidence that smaller class sizes automatically lead to better learning outcomes.

4. Methods

4.1 What are the quality and cost of a network?

In this study the quality and cost of a network consists of:

<u>The quality and cost of the individual units and buildings</u>

- The technical quality of the buildings and other constructions
- The quality of the individual buildings measured by square meters per student
- The cost of the buildings measured by the cost per square meter or cost per pupil
- The cost of the individual operational units measured by the cost per pupil

<u>The quality of a each municipal school network of units and buildings</u>

- The variation of the quality of the whole network of buildings measured by square meters per pupil or child
- The variation of the cost of the individual building units measured by the cost per sq meter or cost per pupil
- The variation of the cost of the individual operational units measured by the cost per pupil

The cost or length of transportation to and between units is not part of this research. The costs of transportation are minimal compared to other operational costs.

4.2 Empirical data

Research is based on material gathered during years 2011-2013 from 19 Finnish municipalities population of which is 450 000 together. The municipalities studied are small or medium size municipalities, population of which are between 2000 and 50 000 inhabitants. They form 8,34 % of Finnish population.

4.3 Simulation model

Usually school networks are approached from the inductive point-of-view: the enhancement starts from the existing school networks. Existing schools are analyzed and the proposals for embetterment are about closing units or creating new ones. However, this approach has some weaknesses. The schools are built for multiple reasons throughout the one and a half century history of Finnish public education. Nobody would build the school network today the way it has been built. In philosopher David Hume's words, we cannot derive "ought" from "is".

We have chosen a more deductive kind of an approach. Instead of existing school facilities we take the existing population only as the starting point. We do not speculate with the future changes in population but try to answer the question: "What would the quality and expenses be if we had built a more effective network in the past?" This gives us a possibility to compare today's expenses with what they *ought to be*. This method we call "a simulation model". The savings of a model are the difference between the existing costs and the possible costs.

The models are created based on the fact that there is a connection between the size of the school and the average size of the classes. The average class-size is the one of the most important factor behind the total cost of a school. Teachers' salaries are the biggest single expense of a school and the amount of teachers in a school is dependent on the amount of classes.

The amount of class series in a school is an important variable. The bigger the school, the more classes it has on any given grade (i.e. 1A, 1B, 1C, 1D and so on). The more classes a school has in one grade, the higher the average size of a class can be without any one class being oversized.

Three different models per municipality were created based on the school size and average class size. The new schools were sized ideally only based on the population data in each area. There operational costs were calculated. All of the school buildings were sized according to the Finnish norms. The facility cost per m^2 was the same as the existing cost, so all of the savings resulted from the diminished area. Simulation models were validated by comparing the results with the school size and cost database of Finnish Ministry of Education.

The savings in central costs (administration, catering, ICT and so on) were included. The investments needed to build the new networks were calculated on following assumption:

- half of the buildings would be either new or extensions to existing facilities

- half of the buildings would be completely renovated old buildings and the rate of their repair would be 80%

5. Results

5.1 The age of the facilities

More than 50% of the facilities studied are more than 40 years old. Only one quarter of the facilities were build after the year 1990. Half of the schools were built after the year 1970 and half of the day-care centres were built after the year 1990 (appendix 1).

5.2 Indoor air quality

According to the user surveys more than 25 percent of the pupils are studying in facilities which have serious indoor-air problems. Only 33% were satisfied with the indoor air quality.

5.3 Amount of space

According to Finnish norms there should be between 7,5 - 10 m^2 of net floor area per pupil in schools. Finnish norms allow much more space per user than many other norms. According to British Metric Handbook (Littlefield 2005) there should be 3,8 gross m^2 per pupil plus additional 200 m^2.

In the data there are no networks even near the norm. The smallest average space in a school network is 14 square meters and the largest 20 square meters. The average is 14,37 m^2. There is plenty of space in Finnish schools. This could be seen as an asset, but the problem is the great variation. In the whole data the amount of space per pupil varies between 3 m^2 to 57 m^2.

Does more space per user always mean higher quality? The amount of space can be seen as a benefit only to a certain extent. After certain limit the interaction between individuals suffers due to long distances. According to the user survey there seems to be little correlation between the amount of space and user satisfaction. The huge variation inside networks cannot be seen as a positive factor. The space is one important resource which should be shared in equal amounts between users.

5.4 Cost of facilities

The average cost of facilities (capital costs not included) was 61,5 € per gross m^2 a year. The least expensive network cost 46,2 € per gross m^2 a year and the most expensive network cost 114,3 € per m^2 a year. The highest school building was 223 € and the lowest 27 € per year. Expenses were lower and the variation smaller in bigger units. Bigger units cause less travelling between the units for facility staff, less maintenance objects and so on than smaller units.

Cost per pupil is product cost per m^2 and amount of m^2 per pupil. Because of the excessive use of space, the cost of facilities per pupil was high in all networks. The average expense per pupil was 1,218 € per year. The lowest expense was 216 € and the highest 3,810 € per pupil.

The cost per m^2 is an indicator of the effectiveness of the maintenance organisation and the quality of the structures. However, the most important factor is the total cost per user in a year. The goal of a municipal organization is not to own property but to provide services of high quality on reasonable cost. Whatever measurement we use, the conclusion is that the facilities are too expensive and the variation of the cost is too big.

5.5 Cost of education

However, the cost of facilities is only 20%-25%[1] of the total cost according to our database of 19 municipalities. The biggest expense is the cost of education. This includes salaries, meals[2], transportation, administrations and so on, salaries being the biggest single cost. The cost of education varies between 4,500 € a year per pupil to 32 000 € a year depending mainly on the size of the school.

5.6 Savings

Simulation models were made for all 19 municipalities. The savings of school networks varied between 775 € per pupil to 3 120 € per pupil. The average saving was 134 € per capita, which would mean one percentage point lower taxes. This would mean more than 2,7 M€ yearly savings in a city of 20,000 inhabitants. The savings are big enough to allow complete replacement or renovation of the entire network of public building infrastructure.

On national level the savings would be 0,73 billion € a year. The investment needed would be 1868 € per capita. On national level it would mean 10,2 billion € investment. There would be 3,7 million gross square meters smaller area in buildings, which would have a great impact on carbon footprint.

6. Discussion

The variation and the level of the cost per pupil of either the facilities or the education are unacceptable. Citizens pay the same taxes and some of them get considerably more services per pupil than the others. The quality of services is often related to smaller and less effective units. Many factors of higher quality service environment are only present in reasonably sized units (better ICT, work teams, student support and so on). There is a serious doubt whether the quality

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[1] Including capital costs. The expenses are only 10%.

[2] There are free meals in all Finnish schools and day-care centers for everybody

of the services has any correlation with the money spent, which makes things even worse. The networks studied have neither high quality nor reasonable cost.

If the service networks had been designed only based on the demography and optimization of the size of the units they would consist of a few larger units in urban centres, accompanied by medium size units in rural areas. No school should be smaller than 300 pupils

This kind of network would resemble scale-free network (Barabási 2002) and would be less vulnerable to either decline or increase of demand. The present networks are random ones based on the optimization of the distance. Distances have lost their importance today, due to downfall of transportation cost and digital revolution.

7. Conclusions

The costs related to facilities are only 20-25% compared to the operative costs. The main conclusion of the study was that the service structure should be studied and planned first; the facilities have only a supportive function. This has not been the approach in municipalities so far. The focus has been on individual buildings and their construction, the operational school networks have been forced to fit into the existing building network.

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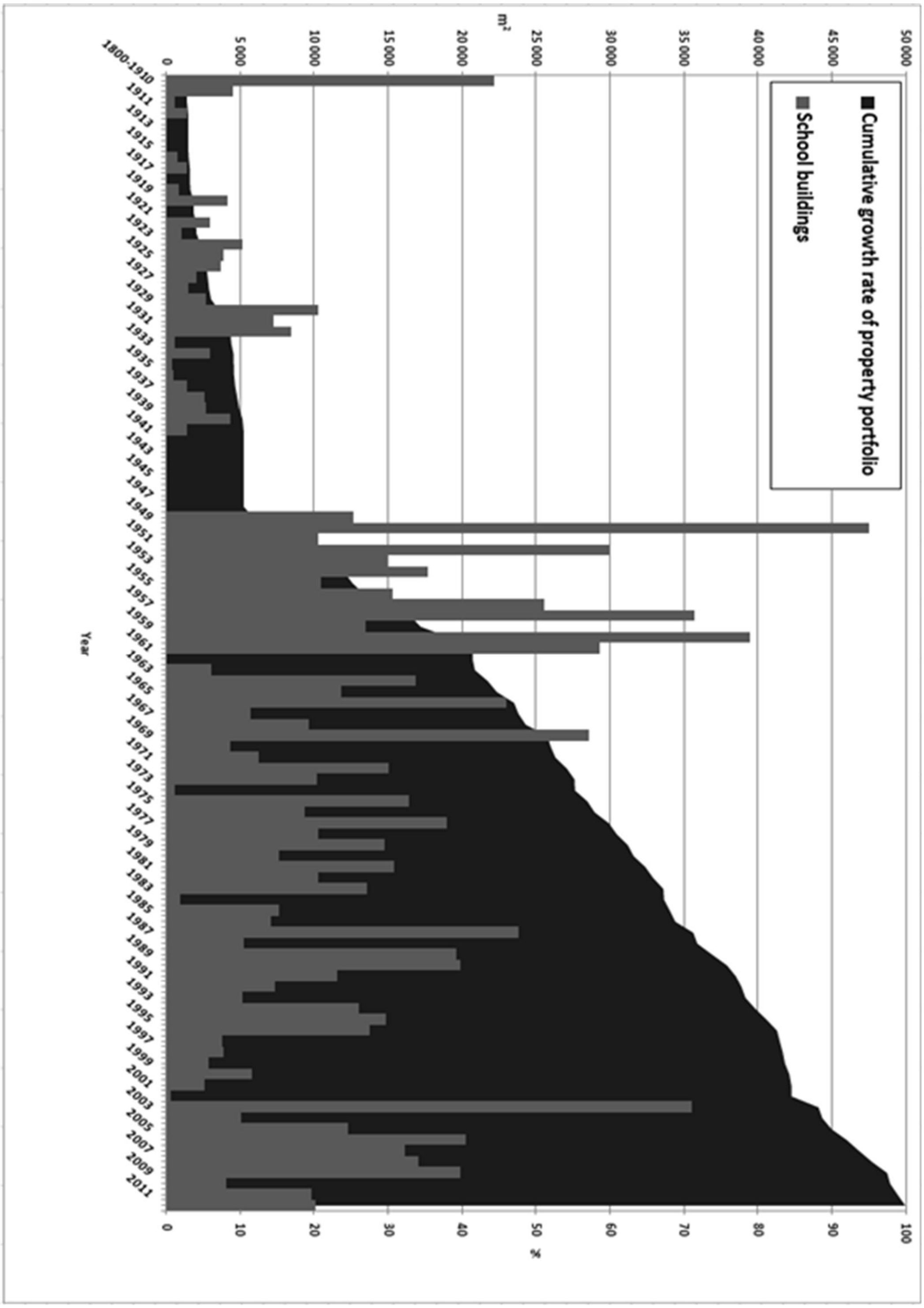
Appendix 1.

Age distribution of facilities per square meter and their cumulative age.



Factors Affecting the Development & Implementation of The Structural Aspects of the Nigeria Building Code Amongst the Stakeholder's within the House Building Construction sector in the Lokoja Municipality

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Abstract

The failure of the Nigeria Building Code (BC) development and implementation for the structural house building construction process in the Lokoja Municipality to protect the buildings, occupants and the environment as a result of vested stakeholder interests reverberates with significant impacts on house building failures leading to fatalities. There have been 742 recorded deaths, 96 injuries and 63 building failures: three cases from 1976–1978, 19 cases from 1982–1995, and 42 cases from 2000 to 16 September 2014 in Nigeria. These cause investors to lose confidence and allow the entry of non-professionals into the industry. This paper identifies and examines the key factors that affect the development and implementation of structural aspects of house BCs, drawing on contextual analysis and international experience. This paper represents part of a large Ph.D. research project, focusing on the key internal and external factors affecting the development and implementation of structural aspects of a BC. This paper has identified a multitude of inter-locking key factors that affect BC implementation in Lokoja including legislation, absence of approved standards, lack of good leadership, lack of political interest or will, inadequate implementation processes, lack of code awareness, high poverty level, high professional fees and insufficient public dialogue. There are also causal factors involved, which impact risks associated with the non-implementation of the code on consumers and the development of industry and professional practice. These include corruption, professional rivalry, professional vested interest, inadequate capacity building, absence of professional involvement in decision making, lack of respect for the poor and public opinion, abuse of human rights and unemployment

Keywords: Building Code, Development, Implementation, Structural Aspects, Stakeholder

1. Introduction

Building codes (BCs), which stipulate minimum standards for building health, safety and the wellbeing of the occupants and their environments, have been in existence from the time humans began manipulating their own environment. The first recorded case that set a minimum standard for building practises was the Code of Hammurabi in ca. 3000 BC (Trombly, 2006). The non-implementation of Nigeria BCs, which set minimum standards for building practises, has caused severe consequences regarding structural building collapse in the house building construction industry in Nigeria (Olusola et al, 2011). Codes are designed to protect buildings from structural failure, and the people and property inside them from death and extreme adverse effects on health and safety. BC development laid a solid foundation on which professionals boast of their work meeting minimum standards in a particular jurisdiction (Ghosh, 2002). All houses and their construction and management stages are regulated by BCs, which seek to harmonise best practises, materials, methods and processes to achieve a building that is habitable (Ayedun et al, 2012).

The building process, from planning and design to construction and management, is very complex; therefore, it requires a very strong regulatory regime and compliance mechanisms to sustain expected standards. The emphasis on building construction with very little attention to planning, implementation and enforcement among the stakeholders can be regarded as tantamount to impropriety (Davidson et al, 2003). The responsibility for building plan approval rests with the department of urban planning at the Federal, State and Municipal levels in Nigeria, while the execution, supervision and management of the operational process for implementation rests within
the development control department; who enforce the implementation and ensure that the professionals and owner comply with building code provisions (NBC, 2006). However, the enforcement; once it is adopted provides an opportunity for training regarding the required skills and new technology for enforcement, implementation and compliance encompassing all stakeholders in the house building construction process (Olusola et al, 2011).

This paper reports details from previous studies to identify and establish the key factors preventing the implementation of the Nigeria BC to structural aspects of house building construction in the Lokoja municipality, Nigeria. Various studies have outlined different factors affecting the implementation of structural aspects of Nigeria BCs such as lack of enactment (Obiegbu , 2008), poor leadership, lack of political will, poor implementation practices,(Fagbele, 2010), lack of code reference standard, lack of BC awareness (Dauda et al, 2012), insufficient implementation and approval of building development processes, insufficient public dialogue and lack of innovative technology (Olagunju *et al*, 2013; Olusola *et al*, 2011). These studies have concluded that in order to overcome the challenges affecting the implementation of BC, the casual factors must be identified and uprooted to reduce the risks associated with poor house building construction practices. The aim of this paper is to identify and examine key factors that affect the structural aspects of BCs with respect to the casual factors and the subsequent risks to the consumer, professional practice and the house building industry in support of prior research findings.

2. BC features and their regulatory problems

The BCs have different components that work together to ensure a building's safety, benefits, welfare convenience to all persons involved in building processes (CASA, 2012). Al-Fahad (2012) stated that the Productivity Commission (2004) presented the four aspects of BCs (see also NBC, 2006; Act, 2013: p.21; ICC, 2006; 2009): legislative (legal aspects of building rules and regulations), social (deals with the relationship of the people with respect to the code and the building environment), administrative (deals with BC administration and the discharge of its functions in any country) and technical (deals with technical requirements for pre-design, design, construction and post construction). With these features, clarifying any part of a problem that might arise can easily be achieved. These features are inter-connected; relating different features of the BC with associated problems that must be collectively resolved for improved implementation.

The Building Control requirements within Nigeria lie at the centre of an idea or discussion surrounded by a multitude of problems. The individual legal, administrative, technical and social problems affect the functionality of the BC. All problems are in a circle, indicating that all problems affect each other. To eradicate the BC problems, the legal, technical, social and administrative problems must be solved simultaneously, to not pollute the central idea of its basic objectives through their correspondences.

3. Structural Aspects of house Building Construction Process

In current building practises within Lokoja municipality, the structural aspects of house building construction involve the following stages: from building design for approval by urban planning department to building construction to the monitoring and inspection by the development control department. Table 1 presents typical development planning permit procedures for building structural aspects approval within Nigeria.

Table 1: A summary of the building approval process within Nigeria

S/no	Approval process	S/no	Approval process
1	Submission of building plans and supporting documents	6	Charting of development plans into relevant plots to check if within the layout plans of the government information data
2	Initial scrutiny of the basic design and documentation requirements	7	Township, processing and endorsement of the plans
3	Registration of the plans for approval and inspection with receipt attached	8	Collection by the person that submitted the plans
4	Inspection of the site by development control to write a report based on standard regulation	9	Monitoring post approval
5	Payment of approval processing fees to further enhance the treatment of plans	10	Penalty for the contravention of approval process

Source: Building development control offices, December (2014)

The supporting documents to be attached to the complete set of building plans include: Environmental Impact Assessment report (for factory or industrial buildings), Site Analysis Report for all building plans, and Letter of Attestation[1]. The letter must include the name; professional qualification (must be member of Council of Registered Builder of Nigeria (CORBON) or Council for the Regulation of Engineering in Nigeria (COREN), a photocopy of the certificates, residential address and functional telephone numbers of the builders.

3.1 Regulatory Enforcement Monitoring in the Current House Building Construction Process

[1] Implementation policy started in 2011 by the Development Control Abuja and Lagos State for builders and engineers involved in the erection of multi-storey buildings, as a result of incessant collapse of buildings

Olaitan and Yakubu (2013) reported a field survey for developing areas of Lokoja. They presented a damming report on the regulatory failure and non-compliance practises of the building code provision. The survey is summarised as in table 2 below.

Table 2: A summary of Building regulatory failure & non- compliance practices

Building type	No. of houses observed	No. of building approval obtained	No. of visits by Development Control during construction	No. of architects, builders and engineers involved	Drainage provision	Road setback allowed	Total
Storey buildings							
BOldPQrts	5	1	0	1	2	1	10
GDM	5	2	0	2	1	0	10
Z8	7	2	0	0	0	5	13
Felele	15	4	0	2	1	2	24
Bungalows							
BOldPQrts	30	5	0	2	1	3	41
GDM	25	3	0	0	1	4	33
Z8	20	4	0	0	0	9	33
Felele	60	7	0	3	0	2	72
Total	167	28	0	10	6	26	237

Source: Adapted and modified from Olaitan and Yakubu , (2013: p.145)

Where: BOldPQrts=Back of old poly quarters, GDM=Gadumo, Z8=Zone 8

The study presented in Table 2 observed 167 buildings, of which, 28 buildings obtained approval, representing 16%. Ten had at least one professional, amounting 0.59%, and 0.0% of site visits were recoded for enforcement indicating a total regulatory failure of enforcement

3.2 Recorded Cases of Structural Building Failure

The figure below illustrates an example of recorded cases of building failure across the country. Bayo (1995, cited by Tanko et al, 2013), Kingsley (2010), Abimbola and James (2012) and author recorded a total of 63 structural building collapse: three cases from 1976–1978, 19 cases from 1982–1995, and 42 cases from 2000 to 16 September 2014 in Nigeria. There have been 742 recorded deaths, 96 injuries and 63 building failures. Fagbenle and Oluwunmi (2010) argued that professionals and non-professionals undermined the regulation of BCs for structural buildings because of inadequate legislation and unaccountability in the industry. The study recommended the life imprisonment as the minimum punishment for those involved in any building collapse.

4. Key Factors Affecting the Implementation of BC Structural Element Provisions

The body of literature reviewed presented various factors that impede the implementation of the structural aspects of the building code provision. These factors include a lack of awareness of the NBC and a lack of legal framework. Dauda *et al* (2012) argued that the lack of awareness among the populace reduces the degree of compliance with the required regulations. The more people are aware of the existence of these regulations within their municipality the better; their awareness partly determines the extent to which people will comply with the regulations. Further, Dauda *et al* (2012) stressed that lack of legal framework makes legislative support difficult. Another key factor is uncontrolled urban growth. Abubakari and Romanus (2011) observed that urban growth was not adequately controlled due to the rapid, chaotic growth of cities during a rapid period of industrial development as witnessed in counties such as Nigeria. There was a massive exodus of migration to the cities in search of greener pastures, which created squatter settlements and informal sector activities that continued to grow because of implementation problems (Wafula, 2012). The increased urban pressure on buildings and facilities is due to a lack of government unplanned urbanisation in line with urban growth.

The majority of urban centres in developing countries are not planned, and where plans exist, enforcement is absent (Kimani & Musungu, 2010). An inadequate implementation process and manpower for enforcement is another key factor identified in reviews. Berrisford (2010) showed that unclear implementation procedures for structural aspects of buildings and inadequate technical manpower within the local authority to enforce implementation of building development were a serious challenge in African cities (Berrisford, 2010). The study observed that the local council had neither clear standards for implementing each of the structural aspects of the code provisions nor the technical expertise in the areas of building health inspectors. Absence of approved standards and laxity in the approval process also discourage developers to submit their drawings for approval and start development immediately without worrying about consequences of their actions. If the approval process can be hastened, barriers to the implementation of building regulations will be eliminated (Berrisford, 2010).

Lack of government directive and promotion is also identified as key factor hindering the development and implementation of the structural aspects of the BCs provisions in Lokoja Municipality. The development policies in developing countries have been characterised by failures as a result of bureaucratic decisions, delays, poor specialised bodies, ineffective local institutions and staff, lack of institutional framework for development planning and the lack of or inadequate participation by the beneficiary population, as cited in many African countries − Botswana, Kenya, Zambia, Zimbabwe, Tanzania and Nigeria Berrisford, 2010). The federal government's concentration of power has left local governments with no experts to drive policy formulation and implementation in an effective direction (Berrisford, 2010). Political Interference or lack of political will at all levels is also cited as another factor hindering the further development and implementation of building code provisions. Obiegbu confirmed that the government, both central and local council, lack commitment to building regulations, which has clearly been seen in the case of Nigeria's BCs, which have come before the national assembly for decades without legal backing. In the opinion of Nyangweso, (2007), a high professional fee is also identified as a constraint to implementation. On average, each professional charges 3–15% of the total cost of house construction as professional fees. Land within a developing area (like Lokoja) costs N800, 000 (£2,858.01) for 450.00 m^2 of land. Such high costs may discourage developers to involve professional in the development of house building construction, thereby increasing the risk of building collapse much further (Berrisford, 2010).

Other factors that impede the development and implementation of BCs in developing countries are as follows; absence of a national building safety strategy, out-dated and incomplete building legislation, lack of data regarding the country's building market and legislation requirements in both the public and private sectors, weak private-sector technological capability due to a shortage of adequately trained staff, out-dated bylaws, quality control and safety systems, inability to enforce building control and development Initiatives and underfunded regulatory agencies lacking skilled staff and other necessary resources, resulting in inadequate inspection, monitoring and certification capabilities (Fundi et al, 2011; Kimani & Musungu, 2010).

4.1 Causal Factors/Impact Risk of Non-Implementation of BC Provisions

A number of studies have identified casual factors associated with the poor implementation of building code provisions within Nigeria as a whole. For instance, Ayedun et al (2012) and Oyinola (2011) agreed that corruption at different levels of political leadership and amongst stakeholders impedes the implementation of standards in Nigeria. Corruption in Nigeria, as presented by the authors, comes in different dimensions: lack of quality education for children, election manipulation by money and bribery, and backdoor business decided in one man's sitting room to steal public resources (Transparency International, 2013). The Civil Society Organisations Report (2008), Transparency International (2013), Ayedun et al (2012), Oyinola (2011) and others attributed the following reasons to corruption in Nigeria:

- Weak government corruption fighting institutions.
- Lack of access to public information.
- Pre-bargaining and negotiation.
- A low record of punitive punishment for corrupt officials.
- Insincerity of government.
- Insecurity of informants.
- Systemic disorder.
- Poverty.
- Nepotism

Lack of professional involvement in house building construction is another causal factor that impedes implementation. Omeife and Windapo (2013) argued that a lack of professional participation in house building construction affects the implementation of standards, thereby causing building collapse. Hence, Agapiou *et al* (1998), therefore, called for greater efforts to enhance the collaboration and coordination of all stakeholders working towards better housing for all. Professional rivalry and mutual suspicious are also causal factors. Agapiou *et al* (1998) upheld that stakeholders should develop cordial relationships for the interest of clients and projects, and denounce the current practises of opponent attacks, which exist in the construction industry. The study suggested that there should be an interest in making the relationships work to achieve the desired goals among stakeholders, recognizing that cordial working relationships may not be free from constraints, but closer ties among stakeholders in closing the existing gaps and wastages will go a long way in overcoming the obstacles to create trust and to reduce the cost of construction. The study highlighted some key factors for 'effective partnership relationships', such as "Compatibility among stakeholder, each stakeholder norms of practices, High degree of internal trust, Robust team building, Genuine openness towards those outside the partnership" Agapiou *et al* (1998: p.359). Another causal factor that impedes the implementation of structural aspects of house building is inadequate capacity building. Dixit (2008) stated that implementing BCs could be easy through capacity building by training all management, professionals, and artisans/tradesmen (etc.) to develop control. The risks associated with non-implementation of the BCs due to causal factors were incessant collapse of structural aspects of buildings, loss of investors in the sector, unplanned cities, and non-professionals in the industry, substandard building materials, and congestion of houses, blockages of drainages and roads, and environmental pollution.

4.2 Strategies to Improve the Implementation of BC Provisions within Nigeria

Many authors have supported different models that could ease the implementation process among various stakeholders, including Pinder *et al* (2013) who stated that, if more adaptable buildings were constructed in terms of standard regulations, cost considerations and cultural considerations, the change in the mind set of stakeholders would help resolve a key issue through his model, the Virtuous Circle to Curb the Circle of Blame (Pinder *et al*, 2013). The model posits that government policies and regulations have a greater influence on the mind-sets of the people concerning choices of buildings. However, few studies have modelled how the regulatory enforcement design can be complied with effectively to balance the interests of all stakeholders. Compliance to Building Code requirements is fraught with difficulties if construction firms, Central and Local Government lack effective expertise to comply with regulatory requirements. The lack of expertise necessitates the need for a top-down approach to raise awareness amongst the multitude of professionals involved in the house building process, as well as artisans/tradesmen, house owners and the general public (Surya 2008), coupled with strengthening of the role & capacity of local government officials, academic institutions and NGOs in the implementation process. Agapiou (1998) highlighted the significance of capacity building through training and development of personnel, which would invariably enhance the implementation process of the structural aspects of BCs in the house building construction industry (see also Dixit, 2008). Agapiou (1998) stated that more emphasis should be on performance criteria for training instead of merely showing the syllabus to be covered and assessing the trainer. The trainer must design qualifications in line with the statement of competence via valid assessment of work performance. They must also monitor the inspectors, evaluate and verify the system for a successful implementation of the training programme that has recently began in the house building construction industry in Nigeria.

5. Conclusions

What this paper aimed to achieve was to identify and examine key factors that constrain the development and implementation of BCs. It was observed that the structural aspects of the BC were not being implemented as a result of policy (administrative) and legislative failures from government agencies at all levels. These failures adversely affected the implementation of the technical features by the various professionals involved in the building construction process and, therefore, created lapses in the publicity of the BC. These were blamed on causal factors that significantly increased building risks over time. It can be stated that the administrative features of BC policies are critically important to the development and implementation of BCs, and impact significantly government enforcement agencies (town planning boards, development control, etc.), professionals implementing technical features into their practices and others complying with the standards. If the key factors that affect the development and implementation of BCs must be eliminated, an effective policy design framework must be put into place to uproot and break the causal factor's shark-like teeth that grip the key factors. This paper suggested strongly that, taking into account the identified key and causal factors, an effective policy development and detailed implementation framework design showing what to do, who will do it, when it has to be done, how it should be done and time taken amongst the stakeholders would drastically reduce the impact risks on the industry and help solve the problem of non-implementation of the BC and incessant collapse of buildings. This paper has clearly presented a solution involving stakeholders' mind set change, partnership and collaborative working relationships, and mutual trust building to ease the implementation process and capacity building of stakeholders. The findings of this paper has identified that; systemic disorder including; high level of national corruption, professional rivalry/vested interest, inadequate capacity building amongst the stakeholder's through bureaucratic process impede the development and implementation of structural aspects of BC within the house construction sector in Lokoja Municipality, Nigeria.

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Improving Early Stakeholder engagement process for Infrastructure projects

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Abstract

Infrastructure construction projects engaged multiple stakeholders directly and indirectly during the pre-construction stages until completion. In large projects, stakeholders have varying needs, interests, rights and demands. Projects that actively engaged with their stakeholders are more likely to succeed. The main purpose of engaging the stakeholder is to ensure their needs and preferences are reflected in the outcome. Early stakeholder engagement creates the ability to gain first-hand information to improve project and community outcomes. Engagement can address challenges and better manage. This paper investigates improvements that can be made through the engagement process to improve project and community outcomes. This paper applies a qualitative research methodology based on interviews and observation from two case studies, comparing stakeholder arrangements in New Zealand and Malaysia. The comparative findings show the values of stakeholder engagement obtained during the pre-construction process. From the case studies, this paper highlights three main implications of early engagement showing that close engagement with the public; transparent information and better understanding of the design concept could improve project outcomes.

Keywords: early stakeholder engagement, stakeholders, engagement process, infrastructure projects, Malaysia, New Zealand

1. Introduction

Large infrastructure projects are characterised by uncertainty, risks and complexity. Infrastructure projects can be politically sensitive and highly demanding (Cornick and Mather, 1999; Clegg et al., 2002; Cicmil and Marshall, 2005). Large infrastructure projects have a large number of stakeholders, complex procurement arrangements and tend to engaged multiple stakeholder with various interest, objectives, power and background (Cornick and Mather, 1999; Clegg et al., 2002; Cicmil and Marshall, 2005; Aaltonen, 2010). Involvement of internal stakeholders in an infrastructure project may range from simple consultation on design briefs to responsibility for the design of components, systems, processes, or services (Aapaoja, 2014). External stakeholders, who are those affected by the project being delivered, also need to be consulted. In comparison with the healthcare and education sectors, the development of public participation and stakeholder engagement in construction industry is still very rudimentary (Rowe and Frewer, 2005). However, a good process of engagement helps the project organisation develop good relationships with stakeholder. Marthur et al., (2008) stated that the construction industry should engage with stakeholders to determine what they need. The roles, needs and responsibilities of stakeholders impact on the time, cost and quality of a project. The more complex the developed project is, the earlier the stakeholder should be involved. Engaging the stakeholder, especially the community and public, as early as possible improve the chances of a good outcome. Literature has recognised the importance of involving stakeholders during the early stages of a project, although few techniques for assessing their needs have been developed and tested (Smith and Love, 2004).

This paper investigates improvements that can be made through the engagement process to improve project and community outcomes. The aim of this paper is to focus on identifying possible improvements in the process of stakeholder engagement in the planning stage of infrastructure projects. This study examines the early stakeholder engagement process that has been used in case studies in New Zealand and Malaysia which were analysed to find out best practice and compare practice.

2. The stakeholder engagement process

2.1 Parties involved

Winch (2007) classified stakeholders into three: project stakeholders, internal stakeholders and external stakeholders. Project stakeholders are those from the client organisation. Internal stakeholders are stakeholders in legal contract with the client. External stakeholders have a direct interest in the project includes public and private actors. Project and external stakeholders have the most influence on a project (Dix, 2010). Ward and Chapman (2008) pointed out that stakeholders are a main source of uncertainty in large construction projects where stakeholder entities, their claims and interrelationships at every project phases create project uncertainties. For instance, local and regional stakeholders are concerned with the influence of construction activities on their daily routine activities and life style and can use political relationships to affect outcomes (Ernzen et al., 2001; El-Gohary, 2006). The quality of a construction is also largely dependent on the appropriate performance management of diverse stakeholders, especially contractors and consultants (Sui Pheng and Ke-Wei, 1996). This means that, if major parties of a contract are not committed to properly carrying out their responsibilities, it is likely to adversely affect the final project quality level (Heravitorbati et al., 2011).

2.2 Practices in the engagement process

The methods of engagement with stakeholders depend on a range of factors, including stakeholder willingness to participate. Basic engagement methods for infrastructure projects include one-to-one individual meetings or group meetings. Karlsen (2002) discussed the engagement process in six steps: initial planning, identification of the stakeholder, analysis of the stakeholder involved, frequent communication, action taken and following-up. Young (2006) proposed with three stages involving identifying stakeholder, gathering information and analysing influences of stakeholders. Walker (2008) discusses the process of identifying stakeholders to prioritising stakeholders, visualising and mapping stakeholders, engaging them and lastly monitoring effectiveness of communications. While Jeffery (2009) suggested the process should extend from internal preparation and alignment, building trust, consulting, responding and implementing, monitoring, planning and understanding the stakeholders in the later stages of the project.

The process of engagement requires mechanisms and opportunities for stakeholders to provide a substantive input (Foo et al., 2011). Foo et al., (2011), reported that stakeholder engagement process may be one-way or two-way, depending on the flow of information where one way is information given to stakeholder through, for example, project exhibitions and presentations. Two ways includes seeking information and opinion from the stakeholder, such as dialogue sessions and customer satisfaction surveys. Previous research has supported the practice of engaging multidisciplinary stakeholders in two ways public engagement, especially in construction development projects (Hooton et al., 2011).

Engagement is part of the decision-making process. A systemic engagement process will improve stakeholder’s understanding and improve decisions. As such, adverse reactions from stakeholders can be reduced. Public engagement is one of the most direct approaches to manifesting and resolving potential conflict and improving stakeholder’s satisfaction (Rowe and Frewer, 2005). Leung et al., 2013 believed that different stakeholders have different types of power and interests on public engagement projects. Power inequalities and imbalanced interests, which create the potential to escalate conflict, often represent as critical barriers to meaningful engagement and engagement success (Prell et al., 2007).

Ng et al., (2012) stated that in developing countries, the engagement process is still regarded by some governments as a non-value adding task when it comes to infrastructure project. The study showed failure of some public participation exercises due to a lack of a systematic framework in the engagement process. Controversy and conflict may arise over the location, size and design of project if potential impact of a proposed project is not adequately communicated (Olander and Landin, 2005). Common issues arising among project managers in communicating with external stakeholders of projects is how and when to be engaged. An Early stakeholder identification program should be an initial stage in stakeholder engagement practice. Yang et al., (2011) claimed that challenges of the project manager are in the process of stakeholder identification and their needs, and formulating proper engagement strategies. Some stakeholders can be sensitive and sceptical. Some stakeholders believe that decisions have been made before they are involved, giving a negative effect on the level of participation in the programme; including individuals participating in an antagonistic way or refraining from participation altogether (El-Gohary et al, 2006). Dix (2012) stated it is very important to acknowledge the potential conflict between the known roles as stakeholders and their legal and moral responsibility for their interests. This can be achieved through open communication and appropriate reporting system. From the management, it is a necessary to recognise issue of the stakeholders' who affected with the project. Identifying issues earlier could change the way of external stakeholders' action towards the project.

3. METHODOLOGY

This paper carried out case studies from two large infrastructure projects, one in New Zealand and one in Malaysia. The projects were a well-known expressway project in northland of New Zealand and a mega project of public transit railway in Malaysia. Semi-structured interviews took place with key, internal and external stakeholders of the projects. The external stakeholders including a non-government transportation agency, historic and cultural agency, community groups, councils and environmental groups, public community was undertaken. The focus of these interviews was to elicit feedback from the stakeholders on their understanding on the engagement process undertaken. It is also aimed to seek out their perception/satisfaction/view throughout the process, as well as improvements that could be made by the project client to improve the practice of stakeholder engagement. A profile of the interviewees can be found in Table 1. Initial discussions prior to the formal interview ensured that those selected were appropriate to represent the views of their respective groups, agencies or the community. The interviewees included a balance of those who supported, opposed and neutral towards the infrastructure scheme. The study was limited to the early stages/planning stage of the project, because this is where external stakeholders and community exerts the strongest influence on the project.

Table 1 Profile of interviewees

Case studies	***Stakeholder Code***	***Affiliation***	***Concern***	***Interest***
Expressway project, New Zealand	*SN_A*	*Project Manager*	*Alliance*	*Project*
	SN_B	*Stakeholder Manager*	*Alliance*	*Project*
	SN_C	*Advisor of national historic agency*	*Oppose in part*	*Historical heritage, culture*
	SN_D	*District community board*	*Oppose in part*	*Interchange and local connectivity*
	SN_E	*Community group member 1*	*Oppose in full*	*Own land, social effects*
	SN_F	*Community group member 2*	*Support in full*	*Expressway, interchange, local people*

	SN_G	*Manager of regional council*	*Support in part*	*Local river, flood, land management*
	SN_H	*Affected School representative*	*Opposed in full*	*Sustainability and fairness*
	SN_I	*Representative of business organisation*	*Support in full*	*Good access, environmental mitigation*
Mass rapid transit railway, Malaysia	*SM_J*	*Stakeholder Director*	*Project owner*	*Railway*
	SM_K	*Project Manager*	*Project owner*	*Railway*
	SM_L	*Business owner*	*Support in part*	*Regular customer, new trading area*
	SM_M	*Community representative of High end residential*	*Support in full*	*Railway track, access to resident*
	SM_N	*Land owner representative of old trading area*	*Opposed in part*	*Relocation, acquisition*
	SM_O	*Shop owner representative of old historical building*	*Opposed in full*	*Demolition of historical building*
	SM_P	*Community representative of affected housing area*	*Support in part*	*Land acquisition, new houses*
	SM_Q	*Public transport user*	*Support in full*	*Railways*

A prepared list of questions was used as a tool for face-to-face discussion. Interviews were recorded and transcribed typically lasted 30 minutes to 1 hour. The data analysis procedure involved converting raw narrative data (interview notes, audiotapes) into partially processed data (transcripts), which were then coded (with the aid of NVIVO software). Key steps in the stakeholder engagement process were then developed from the coding process. The process followed standard university ethics protocols for research.

4. Findings and discussion

4.1 Two cases: similar issues - the New Zealand Expressway project and the Malaysian Mass rapid transit system

This project is a key component of a number of national, regional and local transport strategies, policies and plans. This project includes the upgrading of State Highway 1 (SH1) between the Wellington Airport and Levin having been identified as a RoNS (Road of National Significance). It is stated in the

Government Policy Statement on Land Transport Funding as identified by the Government in May 2009. The expressway project in New Zealand portrays the extensive engagement process from 2010 until 2012. One of the objectives of Road of National Significance (RoNS) the 16 kilometres project aims to improve the connection of roadways in the Wellington and was procured by Alliance procurement method. A refine scheme design addressed urban form issues, following an extensive engagement process with the community and council.

The second case study of a mega infrastructure project is within the vicinity of Klang Valley, Malaysia. Klang Valley is the centred area of Kuala Lumpur, the capital of Malaysia, adjoining cities and suburbs in the state of Selangor. The Klang Valley mass rapid transit system is part of Greater Kuala Lumpur (KL) project, which will be part of the public transport system that aims to support the achievement of a vibrant Greater KL metropolis. This project is of 51 kilometres of railway including an integrated urban mass rapid transit system for greater connectivity for KL. The project is first phase of three phase project, total in overall distance of 150 kilometres long and is one of Malaysia's largest infrastructure project. Upon completion, the project could cover a radius of 20km from the city centre and when fully operational would serve up to two million passenger per day. This project was procured by the design and build delivery system.

4.2 The Process of engagement – initial/planning stage

4.2.1 Initial stage in New Zealand Expressway project

Involvement of stakeholders started early with a series of meetings with the stakeholders including the community and included writing to the affected stakeholders and announcements about the project in the national media such as national television and newspapers. At this stage, the project owner was offering the stakeholder information to assist them in understanding the project and telling the community and public about the project and affected area. Because of the early start, significant levels of interaction with stakeholders achieved.

During the first phase of the engagement process in 2009, scoping and corridor assessment, time was taken to inform and gain an understanding of the views of the affected community, key stakeholders, iwi (indigenous) group and other public members. The client delivered the method of community, stakeholder and general public engagement on the preferred route for a four-lane expressway. During inception stage the project consultation included responses to community concerns around the construction project. During this period, the agency worked with targeted group of stakeholders to clarify the project scope and process. The Early Start Team was established as a specialist team selected for their expertise along the affected area of the expressway project, and their ability to engage with the local community. Project constraints were identified from stakeholders such as impact on the town centre and Business Park, ground conditions, environmental impacts, local traffic impacts including pedestrian and cycleway. A Community Reference Group (CRG) was established with Terms of Reference including:, the invited member must be engaged with open-minded and informed dialogue, focus on real issues, focus on opportunities and benefits, different communities must be recognised, continuity through project phases with the community and disseminating project information to wider community. The CRG held workshops during which different options could be shared. Project expos were also held throughout the expressway project. Engagement included a series of expos and exhibitions held several. Mock up models of the expressway was used to aid the understanding of the community and to picture the bigger idea of the expressway. The expos were a platform for discussion with the wider stakeholders. The client also established a local presence at the area and transformed a "shop front" into a Visitor Centre by the time construction started. The "shop front" was regularly staff by members of project. Other engagement methods used were web-based online discussion forums.

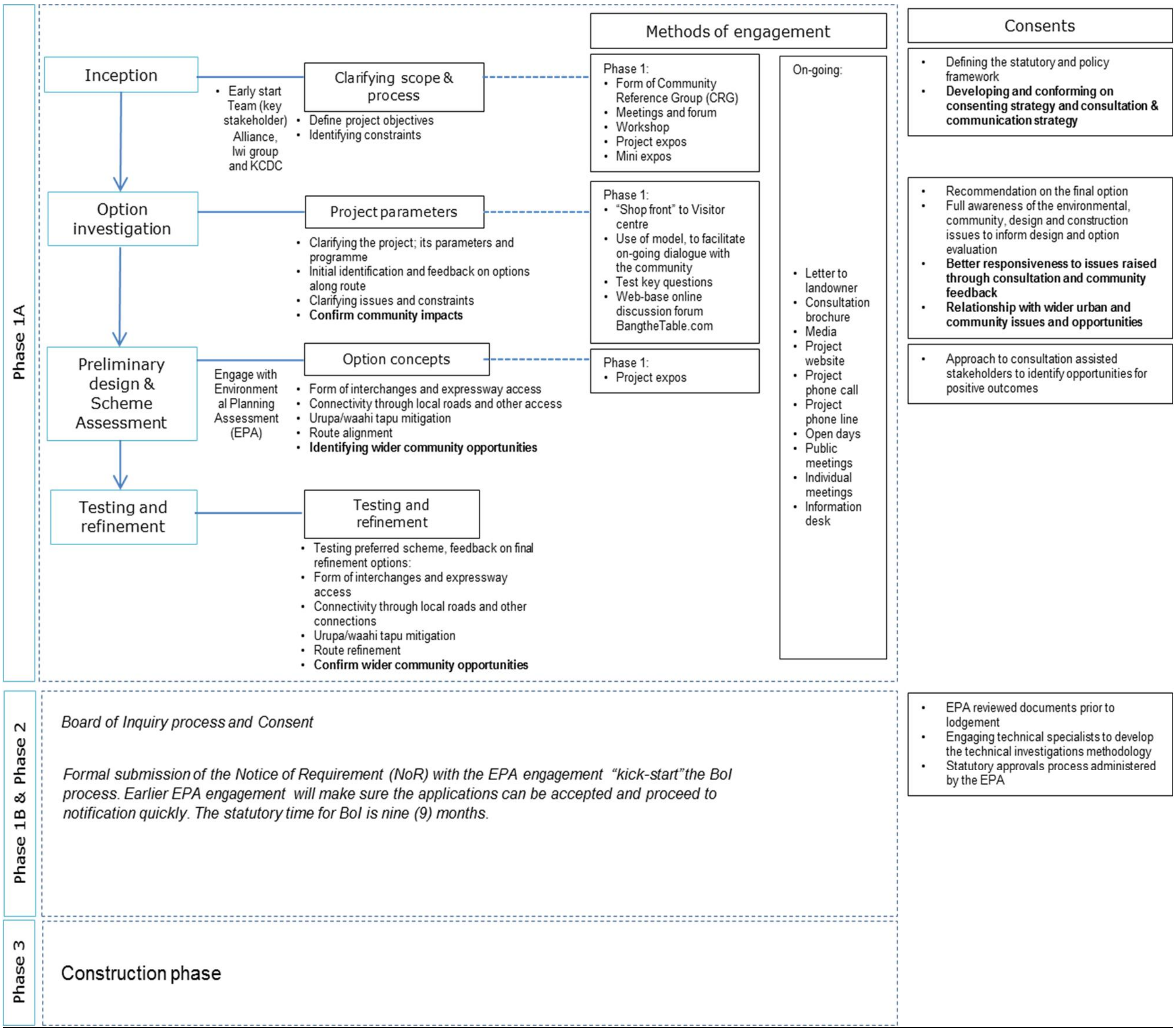

Figure 1 shows the progressive process of the engagement of the New Zealand expressway project.

In the process of Preliminary design and Scheme assessment, concentrated periods of consultation occurred. At this stage, wider community opportunities were identified. Throughout the process on-going opportunities of the community input or queries were recorded. At this stage, project expos acted as a platform to present the concept of the expressway and to obtain feedback and identify further issues. The final option for the expressway and refined detail were communicated to stakeholders. Issues such as cycleway and pedestrian linkages, local road, old state highway were issues requiring input from the community.

The earlier engagement period ran for 10 weeks. Letters to stakeholders were sent to potentially affected property owners, followed by a consultation brochure with a feedback form to ask the effected stakeholders preferred route options. Information of the expressway could be viewed through a project website, open days, information desks and also through a project phone line. Public meetings and meetings with individuals within the community were held. More than 200 engagement sessions were conducted between 2010 until 2012 on the first phase of engagement session.

4.2.2 Initial stage in Malaysia mass rapid transit system

The first stage of the engagement programme for the Malaysian MRT system was to educate the community and other external stakeholders. The agency developed connections with the community through a programme that they formed at the beginning. This included with campaigns and events. This promoted awareness about the MRT project and educated the public about the need for mass rapid transit system. One of the campaign that was conducted was the project's logo competition and "I Love MRT" best slogan. The agency also provided updates on the progress of the construction of this first phase line through social media. The project owner approached public schools within the Klang Valley vicinity, which helped to develop awareness among school students on the importance of the project.

The project adopted a standard practice that any community living or operating a business adjacent to the railway alignment and potentially impacted by the construction of the railway project must be kept informed of construction activities. Such engagement ranged from town-hall gathering to one-on-one meetings. Communities could also raise issues and give feedback. During the period under review, more than 60 engagement sessions were organised with residents, resident associations, business people, traders and other group. The most common types of feedback include concern over noise generated from construction work, traffic congestion and concern over living close to the railway alignment. Many stakeholders also expressed the hope that the railway project was completed as soon possible so that inconvenience can be minimised. A stakeholder could lodge a report regarding their properties through free phone line or visit a project information centre located at the corporation headquarters, or visit two information kiosks within the project area.

Engagement sessions were conducted throughout the early project stages and, from the interviews with the management team and the stakeholders, which led to seventy per cent of the affected residents and business owners supporting the project. An extensive and continuous effort was conducted to promote the project to the public during the early start of the project. Campaigns and programmes taking place at the early phase of the planning project advocated reasons on the needs of urban rail system in the city. Public attention was focussed on finding solutions for land issues including novel ideas of allowing privately owned land to coexist with the project by way of a Mutual Agreement between the landowner and the corporation. Almost all owners of shops and houses along Jalan Sultan retained ownership of their properties while allowing the project tunnel to be built underneath. In an effort to keep stakeholders updated with latest project work plans and works to be carried out, regular engagement sessions were initiated to ensure timely and effective dissemination of project and construction-related information to the residents living within the construction worksites vicinity. The process of the engagement followed is shown in Figure 2.

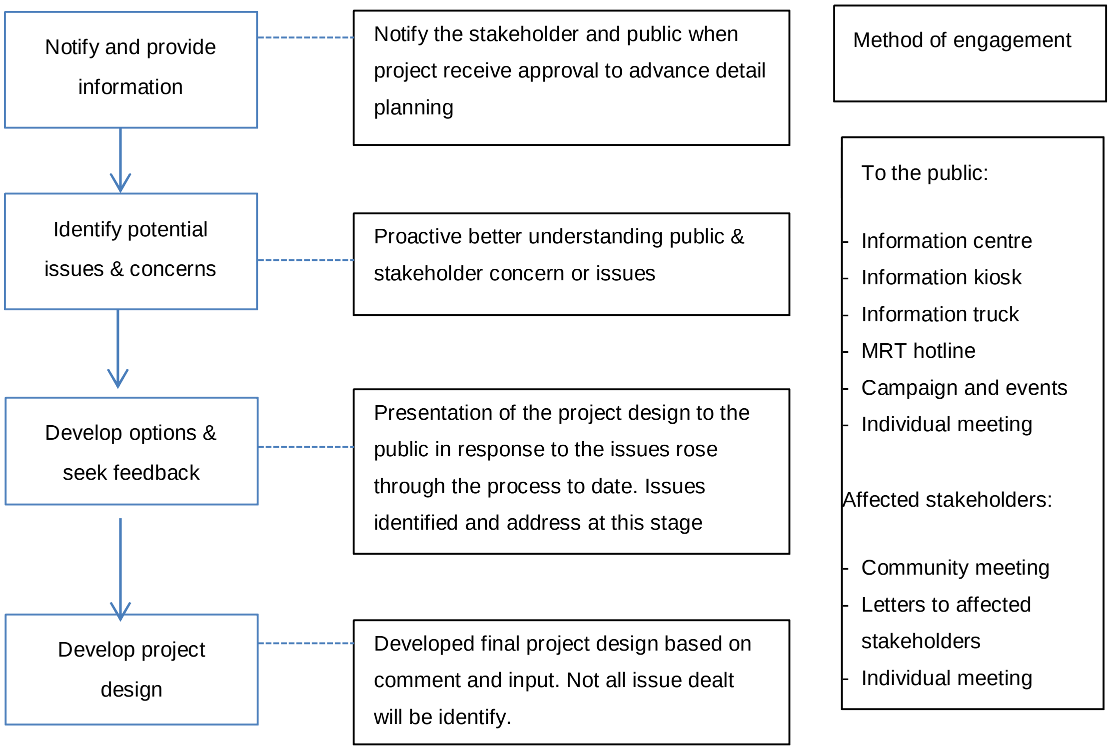

Figure 2: Process of initial preparation and alignment of Klang Valley MRT project

4.3 Three focus areas for engagement success

Closely engaging the public

The need for closely engaging with the public is so that the public develops an awareness of the project and the client obtains feedback and opinions from the public about the project. Stakeholders want to be part of the project. It is essential that their opinions are sought and they are listened to and their ideas are collated and integrated into the project process. In both cases stakeholders were encouraged to provide their opinions. Without adequate consultation, even if stakeholders are not against the project, they can become unhappy with the way the project is being implemented without due consideration for the well-being of people directly affected by the project.

Transparency of information

In term of transparency of the information, both cases provided information. The New Zealand expressway case study showed more transparency of information then Klang Valley mass rapid transit case study. For example, expressway has a central website accessible to the public consisting of a large amount of information regarding the project and the stakeholders. Important information was able to retrieved from the website such as stakeholders entities (agency, organisation, individual landowners, traders etc.) and who was affected (directly or indirectly) with the project. In the mass rapid transit project information were not easily accessible. Information had to be retrieved from informal channels such blogs and online forums, where official verification of the information is more difficult. Both expressway and mass rapid transit have information on the community perspective but only on the expressway were the community comments analyse through a comprehensive community report which was accessible through the website for expressway. This report showed the analyses of feedback such as what was the interest, their insights and opinion on the project and stakeholder list. In Malaysia, although the public community were able to provide comment and feedback, the report analysis was too generic. For example, detail information such as compilation of what are their interests, feedback and stakeholder list were not accessible. Information from the expressway case study was more transparent and accessible to the public than mass rapid transit case study.

Improving stakeholder understanding of the design concept

Socialising design concepts with stakeholders through engagement processes improves mutual understanding of needs. In the mass rapid transit case study, the engagement stage could be improved during the design concept stage of the project. The project authority should offer details of the plans, especially where land acquisitions are likely. The expressway three design options were all presented to the stakeholders. The stakeholder could help make a decision on which path the expressway should follow based on the consultation process and feedback.

5. Conclusions

Engaging stakeholders in large-scale projects can be a complicated and lengthy process. Infrastructure projects, which involve many stakeholders, must have a developed engagement process. The engagement process should start at the early preparation stage. Ineffective stakeholder engagement will cause problems for the project. The benefit of understanding the stakeholders leads to better outcomes as their needs and interest can be used to develop solutions to project challenges. This paper has focused on how to improve an engagement process in a large infrastructure project through considering three simple factors in the engagement process – engage closely; improve transparency and improve stakeholder understanding of the design concepts. By developing mechanisms for improving these three features, early stakeholder engagement will lead to better long-term project outcomes.

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Development of a Collaborative Briefing Approach to Support Stakeholder Engagement in Construction Briefing

Abstract

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Construction briefing is the process that a project client either formally or informally informs the designer of his or her requirements of a project at the pre-design stage. Literature shows that construction briefing is recognised as one of the most important processes in project management and therefore, it is crucial to get the brief right at the beginning so as to ensure effective delivery of the project in time and within budget. A previous study introduced the concept framework named "Collaborative Briefing Approach" (CBA) which was designed to empower the traditionally mobilised briefing team to work collaboratively with a large group of multi-disciplinary stakeholders as an integrated briefing team in the form of a virtual organisation through a shared digital workspace created on a computer network. This paper presents the findings of the said study and describes an on-going study designed to investigate the extent to which the use of CBA approach can improve the effectiveness and efficiency as well as the quality of outputs of the briefing process. This study adopts two research methods including controlled experimental study and action research and their details are presented in the paper. These two studies are the pioneer research studies that introduce a shared digital workspace to enable all members to work together remotely and asynchronously in the briefing process. They will demonstrate a new knowledge on how to apply collaboration technology to improve the process and output quality of construction briefing in a practical manner.

Keywords: Construction Briefing, Stakeholders, Collaboration, Collaborative Briefing Approach

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Development of a Collaborative Briefing Approach to Support Stakeholder Engagement in Construction Briefing

1 Introduction

Briefing is the first step in design process that a client either formally or informally informs others of his or her needs, aspirations and desires of a project (O'Reilly, 1987; CIB, 1997; Hershberger, 1999). Briefing can be considered to be synonymous with 'Architectural Programming' used in North America (Kelly and Duerk, 2002) and 'Scope Management' used in Australia (Peakman, 2008). These terms essentially describe the same activity and they are interchangeable. It is also described as a process of identifying and analysing the needs, aims and constraints of the client and the relevant parties, in formulating the design problem (ISO, 1994, BSI, 1995).

Briefing is recognised as one of the most important processes in project management. At the pre-design stage, briefing investigates the nature of design problem by helping clients to define, translate, communicate and present their needs and wants into a set of written project requirements in form of specific technical characteristics, functional performance criteria and quality standards. These requirements, which are the root of briefing, act as a basis for approaching designers (O'Reilly, 1987, Barrett and Hudson, 1996, Barrett et al., 1999; Bowen et al., 1999). At the design stage, these requirements provide guidelines on examining the developed design options so as to determine the optimal one, according to the defined design problem. At the post-design stage, these requirements help clients to review the selected design options during the construction and operation phases (Kelly and Duerk, 2002). As explained above, significant resources are committed in briefing and therefore, it is crucial to get the brief right at the beginning so as to ensure the effective delivery of the project in time and within budget (MacPherson et al., 1992; Latham, 1994; Newman, 1996). As a result, clients are strongly recommended to define and examine their needs in terms of project requirements, before and during briefing (HMSO, 1964; HMSO, 1994 and CIB, 1997).

This paper aims to introduce the Collaborative Briefing Approach and discuss its potential of improving the value of project briefing by capturing the inputs from stakeholders through collaboration technology. It begins to discuss the importance of stakeholder engagement in construction briefing and then introduces the concept of Collaborative Briefing Approach. It follows by a discussion about the associated research studies on this topic

2 Stakeholder engagement in construction briefing

2.1 Stakeholder theory and stakeholders

Stakeholder theory was originated from stakeholder concept, which divided major stakeholders into four groups including shareholders, employees, customers, and the general public in General Electric Company in 1929 (Mishra, 2013). This stakeholder concept was fully articulated by Freeman, who drew on various literatures including corporate planning, systems theory, and corporate social responsibility to develop the concept into a theory (Freeman, 1984). The theory identifies and models the groups which are stakeholders of a corporation, and both describes and recommends methods by which management can give due regard to the interests of those groups (Donaldson and Preston, 1995). It suggests that a modern organisation has relationships with many constituent groups but traditional management theories cannot address the “shifts” in business environment induced by the impacts from internal stakeholders and external stakeholders. Consequently, the theory argues that organisations should take into account all of those groups and individuals that can affect, or are affected by, the accomplishment of the business enterprise instead of limited to shareholders only (Freeman, 1984). Based on the said theory, a UK example of the key stakeholders in a redevelopment project is presented in Figure 1.

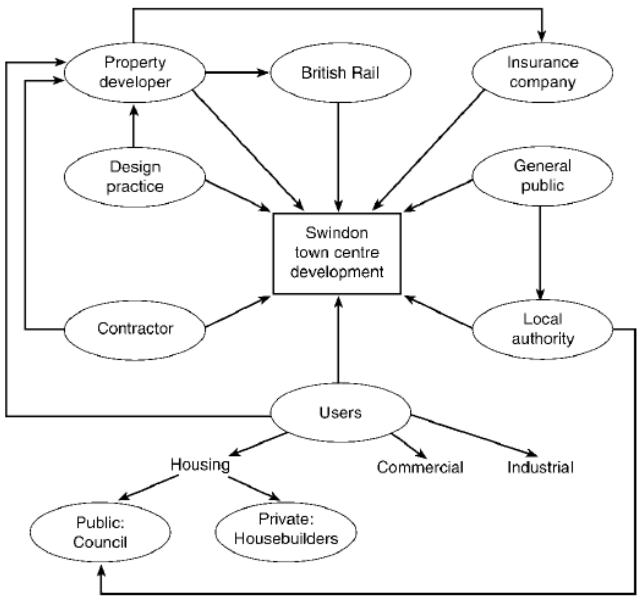

Figure 1 : *Key stakeholders in the Swindon redevelopment project (Newcombe, 2003)*

The above sample indicates the relationships between various groups and individuals in a single analytical framework. Each oval representing a group of stakeholders. The central square, which represents the project, is surrounded by a number of other ovals with directional arrows toward the square as well as ovals (Freeman, 1984).

2.2 Stakeholder theory and construction briefing

As described by MacPherson et al. (1992), briefing develops an interface between the project design process and the social-political environment in construction. With reference to the stakeholder theory, briefing should involve a large number of stakeholders other than the project design team members and they include builders, suppliers, operators, end-users, government bodies, professional representatives and residents as shown in Figure 2, which is in line with the concepts applied in the IFSIUER model and its variance proposed by Kua (2007, 2016).

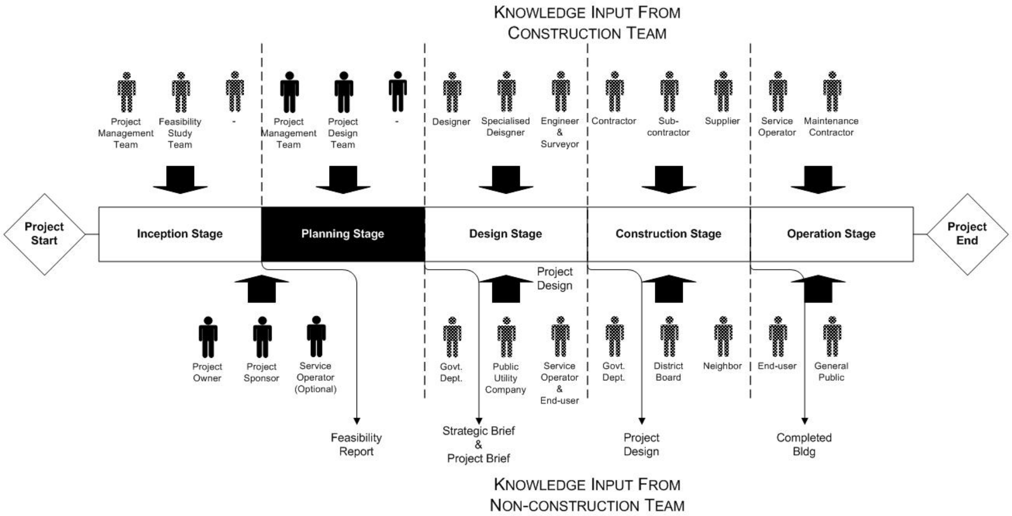

Figure 2 : *Stakeholder knowledge input to briefing*

Moreover, briefing requires a full spectrum of knowledge and skills involved in various construction stages to make the best decisions in the briefing process (MacPherson et al., 1992; Kelly and Duerk, 2002). However, stakeholders own a substantial amount of important information and tacit knowledge, which are kept hidden, without sharing across projects due to the 'wall syndrome' (Kamara et al., 2002). As shown in Figure 2, they add value to briefing and their early participation makes the following general contribution to the briefing process (Kelly and Duerk, 2002).

- provide technical knowledge that helps to increase the amount of available project information
- provide professional advice to identify the potential problems
- provide the latest technology to promote creativity and innovative solutions

2.3 The research opportunity

In recent years, the role and importance of these stakeholders have been recognised in the modern management concepts such as partnering, supply chain management and lean construction etc. For example, the early involvement of operators in private participated public projects helps enables designers to have more information about the operation requirements to anticipate potential problem areas and make better design. In construction, clients should involve stakeholder inputs so as to add value to briefing (HMSO, 1994) but literature shows that their participation is very limited in construction briefing. For example, construction briefing is usually limited to a small group of key stakeholders including project owners, sponsors and designers. It is because some project owners may fear that more stakeholder involvement could lead to a flood of “wish lists” which is challenging to accommodate. Moreover, it would be expensive and time consuming to organise large stakeholder meetings and to resolve all stakeholder conflicts, in turn delaying the design progress. As a result, the value of briefing products would be sub-optimal because the valuable inputs from these stakeholders have been locked (Shen and Chung, 2006).

It is assumed that the overall values of briefs can be significantly improved if we can unlock, capture and manage the stakeholder inputs in a more efficient and effective way. Since collaboration technology which enables people in working together in ‘virtual space’ is an effective tool in improving team communication and collaboration, authors suggest that there is plenty of room for using collaboration technology to conduct construction briefing in a virtual environment in pursuit of greater involvement of stakeholders.

3 Collaborative Briefing Approach

'Collaborative Briefing Approach' (CBA) is designed to empower the traditionally mobilised briefing team to work collaboratively with a large group of multi-disciplinary stakeholders as an integrated briefing team in the form of a virtual organisation through a shared digital workspace created on a computer network (Chung et al., 2009 and Chung, 2010). The CBA approach introduces a shared digital workspace that serves as a collaborative platform and enables all members to work together remotely and asynchronously so as to achieve greater stakeholder participation in briefing. Since stakeholders contribute in bringing professional knowledge, experience and creativity to briefing, greater stakeholder participation will increase their inputs and result in more fruitful briefing outputs.

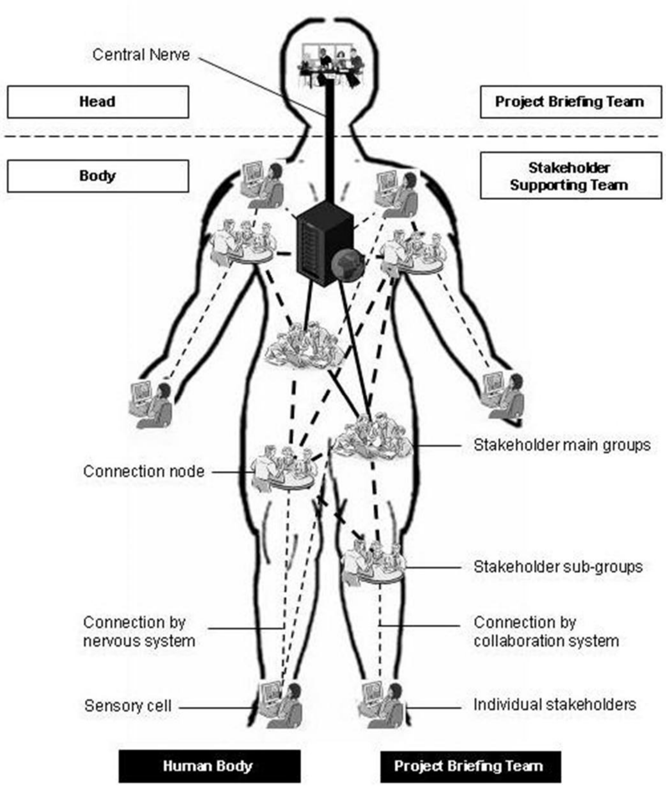

Figure 3 : *A virtual organisation in briefing (Chung et al., 2009)*

As shown in Figure 3 there are significant similarities in the organisation structure and the communication hierarchy between them. For example, team members (cells) are working closely with in-house colleagues to form a sub-group (tissue) in representing their organisations (e.g. contractors). Various sub-groups are working together to form a main group (organ) in representing their professionals (e.g. engineering consultant group). Several main groups combine to form a functional unit (system) in representing their roles (e.g. construction team). Lastly, various functional units are working together as a virtual organisation (human body) in representing a whole team in briefing (e.g. briefing team). Drawing parallels with the concept of a biological neural network that connects cells, tissues, organs and systems tougher with brains in humans; a computer-based collaborating system is proposed to manage the discussion among team members within this virtual organisation in briefing. The above analogy is only for indication of the holistic interactions rather than for over-simplification of briefing needs (Chung et al., 2009).

4 An on-going study

4.1 Phase 1 study

A research study titled “Improving megaproject briefing through enhanced collaboration with ICT” was conducted in 2010 to explore the feasibility of applying collaboration technology to improve the briefing output by capturing stakeholder values through the enhanced collaboration between clients and stakeholders in the briefing process (Chung et al., 2008, Chung et al., 2009, Chung, 2010, and Chung, 2015). Under this study, a comprehensive survey investigating and comparing the strengths and weaknesses of common briefing practice in the Hong Kong construction industry was completed and based on which, a theoretical foundation for the research was established. In addition, a new briefing approach named 'Collaborative Briefing Approach' has been developed based on Stakeholder Theory. Moreover, an ‘Integrated Collaborative Briefing Methodology’ (INTERCOM) was also developed to translate the CBA approach into a set of actionable methods and job plans for practical use and a pictorial summary is given in the following figure.

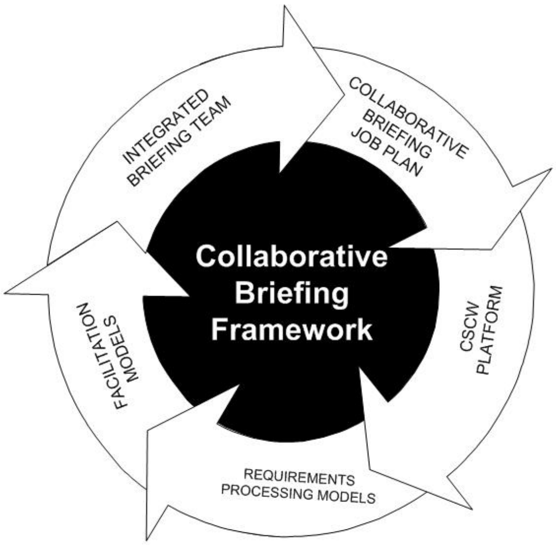

Figure 4 : *Key Elements of the collaborative briefing framework*

As shown in Figure 4, the INTERCOM comprises of five components: (i) a value based briefing methodology, (ii) a collaborative briefing job plan, (iii) an integrated briefing team, (iv) a collaborative briefing platform, and (v) facilitation service. The first four components were developed and validated by a group of well experienced multi-disciplinary industry practitioners. The fifth component merits a separate research and development exercise. Research findings reveal that the concept of collaborative briefing approach and the design of the INTERCOM are well supported by the practitioners. In addition, it is concluded that INTERCOM would contribute to improve the briefing process by facilitating team management, enhancing requirement definition and promoting consensus building. It also improves requirement comprehensiveness, decision transparency, decision reliability, and decision satisfaction, as well as the value and quantity of the requirements specified in the brief (Chung, 2010). This study comes to the conclusion that the concept of collaborative briefing approach and the design of the INTERCOM are well supported by the practitioners. In addition, INTERCOM would contribute to improve the briefing process by facilitating team management, enhancing requirement definition and promoting consensus building. It also improves requirement comprehensiveness, decision transparency, decision reliability, and decision satisfaction, as well as the value and quantity of the requirements specified in the brief (Chung, 2010).

4.2 Phase 2 study

In order to extend the research potential of the phase 1 study, a new research to study the CBA approach from a new perspective through experimental studies and action research and thereby investigate the extent to which we can apply collaboration technology for the purpose of improving briefing output. This phase 2 study aims to investigate the extent to which we can apply collaboration technology to improve the briefing output by capturing stakeholder values through the enhanced collaboration between clients and stakeholders in the briefing process. Thus, the objectives of this study are to:

- investigate the extent to which the use of CBA approach can improve the effectiveness and efficiency in the processes of briefing in construction projects;
- investigate the extent to which the use of CBA approach can improve the quality of outputs of briefing; and
- identify critical success factors that lead to effective implementation of CBA approach in briefing.

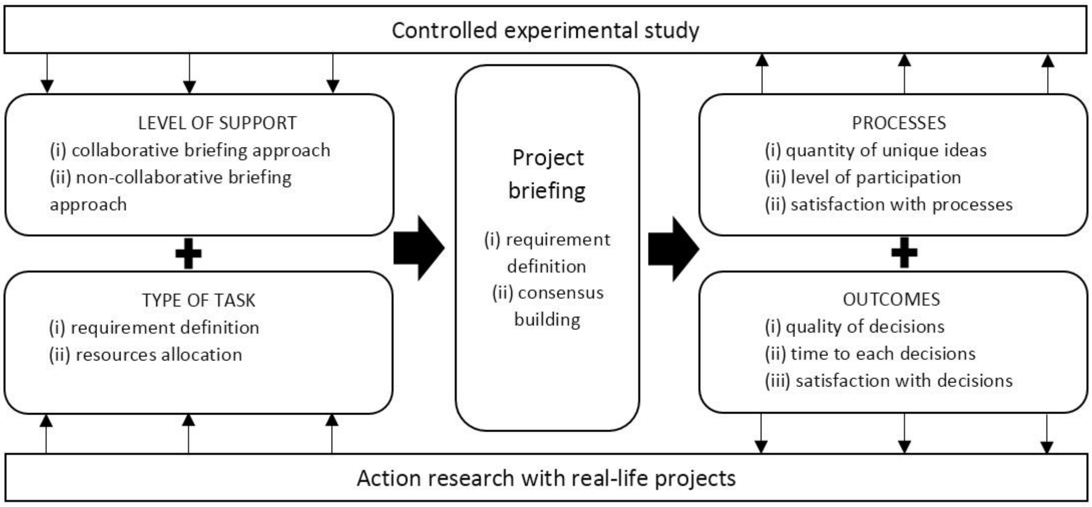

Figure 5 : *Proposed research framework*

Figure 5 illustrates the framework for the proposed research. In order to achieve the research objectives, two research methods, namely (i) controlled experimental study and (ii) action research will be adopted and the details of which are summarised in Table 1.

Table 1 - Summary of research methods

Method	Description
Controlled experimental study	A controlled experimental study with 2 x 2 factorial measures will be adopted, under which independent variables are expected to be controlled and thereby the consequent changes in the dependent variables can be observed. In addition, experimental variables can be isolated more easily and their impact can be evaluated more effectively than other methods. In the proposed research, there are two independent variables, namely (i) level of support, and (ii) type of task. · The support variable has two levels: CBA approach and non-CBA approach. · The task variable also has two levels: requirement definition and resources allocation. Statistical test and analysis of variance will be used to examine the likelihood that the means of the experimental and control groups are derived from a single-parent population and can be compared for possible differences.
Action research	Real-life construction projects will be conducted to examine the real effect and impact on a number of key issues including the levels of task difficulty and user satisfaction in the research process. It is characterised by involving researchers as part of the situation under exploration. The applicant will play the role of a facilitator to design and deliver the project briefing exercise for these selected projects. Moreover, focus group will be used a supplementary instrument to facilitate the research team to obtain valuable views and insights from participants of the exercises. During focus group meetings, the research team members can ask and adapt questions as necessary, ensure that questions and responses are properly understood by repeating or rephrasing them, and pick up non-verbal cues from the respondents.

4.3 Research contributions

The proposed research is one of the pioneer research studies in exploring the concept of team collaboration in construction briefing. It aims to introduce a shared digital workspace that serves as a collaborative platform and enables all members to work together remotely and asynchronously so as to achieve greater stakeholder participation. Following the success of the previous study on CBA approach described before, the proposed research will study the approach from a new perspective by using the methods of experimental studies and action research. It is anticipated that this will lead to new knowledge on the real effectiveness of adopting the CBA approach in improving the process and the output quality of construction briefing in a practical manner. Such knowledge will help to justify the real benefits of the approach and thus, determine a “benefit to cost ratio” so as to identify the most suitable project type for using CBA approach. Moreover, a set of critical success factors contributing to the implementation of CBA approach in briefing will be identified in the research. These factors will help to increase our understanding of some hidden factors such as group dynamics, and facilitation, contractual barriers and politics etc. that emerge in real life application. In summary, the proposed research will strengthen the connection between the knowledge of construction briefing and the domain of team collaboration through the “CBA approach”.

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Contradictions of interests in early phase of real estate projects – What adds value for owners and users?

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Abstract

In the last decades, Norwegian real estate projects have traditionally focused on cost minimization rather than value optimization. The main intention of the research project "OSCAR – value for Owners and Users of buildings" is to develop competences, methods and analysis tools that makes it possible to optimize the design that creates value for owners and users throughout the buildings' lifetime. This paper aims to elucidate what adds value for owners and users as well as looking at what are the main contradictions of interests in early phase planning of buildings. The research is approached by a literature review and a questionnaire survey among a wide range of stakeholders (N = 799) in the Norwegian building Industry. The survey focus on the four dimensions of sustainability, namely social, economic, environmental and physical aspects of the building. In this paper, we focus on the economic and social value aspects, and look at how these contribute to value creation for owners and users of buildings. The literature points towards need for increased competence in value management and new co-creative collaborative working models as a continuously part of the building process. We suggest using a structured network role to better understand and safeguard the owner, user and FM needs, and to improve the users' influence on the decision process in early phase of constructions projects. We believe this this is a successful way of finding innovative designs and technical solutions. Exploratory principal component analysis (PCA) of the responses gave many interesting findings. The owners and users have significantly different views concerning financial issues and efficient operation of buildings in the use phase. These findings are topics for further research.

Keywords: Early phase involvement, owner, user and Facilities Management involvement, co-creation models, value management, building process

1. Introduction

This paper aims at elucidating contradictions of interests between owners and users of buildings. Equally, it examines how co-creation and co-collaboration models can be useful to ensure better building quality and usability, and to increase the owners and users' involvement in the early-phase of real estate projects.

This paper includes the main findings of a survey conducted among a broad range of stakeholders within the construction industry in Norway. Norwegian real estate projects during the last decades have had more focus on cost minimizing than value optimization. The main ambition of the survey is to find out what in the early phase planning process and what in buildings add value for owners and users. The survey is a part of a Norwegian research project OSCAR.[1] We discuss how user involvement is handled and how collaboration models can improve the quality of buildings and add value for both owners and users.

In order to address this general query, this paper search to answer the following questions:

- What contradictions of interests are there among owners and users in an early phase of real estate projects?
- How is user involvement in the early phase of real estate projects handled today?
- How can co-creation and co-collaboration improve the adding value processes in early phase of real estate projects and solve some of the contradictions?

The first question is addressed through both the literature review and by the survey (examined in the theoretical framework section and the findings section respectively). Question 2 is covered by the survey and examined in the findings section. Question 3 is discussed according to a theoretical point of view and from experiences in practise.

2. Theoretical framework – How do buildings add value?

A building creates economic and social values in many ways. For an owner the building creates a positive or negative cash flow. For the user the building works both as a social arena and a place for production and value creation. Depending on the personal and organizational values we talk about, which values are important to the core business, and how can the building be supportive to the organizations' values and help them to achieve their goals? For the actors involved in the construction process focus rather on the value creation than what adds value for the user. The concept of *value* is complex and varies depending on the perspectives taken. Value is exceptionally difficult to measure. Drevland and Lohne (2015) talk about nine tenets of the nature of value while Haddadi et al (2015) explores the concept of value in different context and points out the need of change of value perspective in FM and Real Estate. They present a simplified

1 OSCAR – Norwegian research project "Value for User and Owners of Buildings" (www.oscarvalue.no)

image of the involved actors but an easy way to understand the drivers and ambitions that the actors are striving to reach in order to create value.

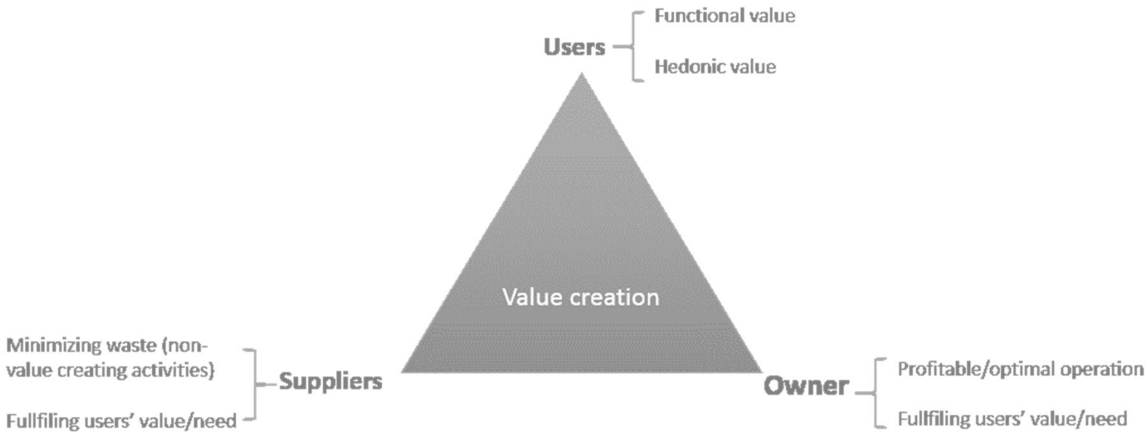

Figure 1 Real estate projects main roles and their values to to be fulfilled in order to enhance value creation (Source: Haddadi et al, 2015).

A more sophisticated model (CRISP in Spencer and Winch, 2002) shows the complexity of stakeholders involved in the whole building process. This model categorizes the factors according to different key performance criteria and points out that the stakeholder´s view point, power and value systems influence the decisions. The stakeholder's viewpoints and values has a tremendous effect on the product and the users and the way they can create value in the operational phase.

2.1 How buildings add value for owners and users?

A building adds value when it facilitates value creation for the user organizations during the building´s lifetime. Therefore, the building should function according to its appropriated need Based upon our own experience we find that owners and users focus on various issues and aspects of a building's performance, presented in Table 1.

Table 1: What properties and factors are of importance for the buildings' value creation (authors' experience)?

Sustainability	*Economic issues*	*Social issues*	*Environmental issues*	*Physical issues*
Owner	*Investment cost* *LCC and FM costs* *Profit*	*Tenant relationship* *Market*	*Energy, water and waste*	*Operational and Maintenance* *Total adaptability*
User	*Rental cost* *FM costs*	*Facilities services* *Market*	*Indoor environment* *Profile and branding*	*Location* *Flexibility of space*

In this paper, we focus on the *economic and social dimension.* We look at how these factors are affecting the buildings' value creation for owners and users, further explored in the survey partly presented in section 3.

2.2 Stakeholder involvement in early phase planning

Stakeholders in a real estate project can be both internal and external. Who are involved in the decision process and who are the stakeholders in the surrounding environment that are affected by a new building? Since the involvement process can be complex, it requires leadership and facilitation skills. Sometimes important groups are excluded due to lack of knowledge or experience with new technology, or because they not necessarily know or are not able to articulate what they want. The management of the process is therefore of huge importance (Heitel et al., 2015; Storvang and Clarke, 2014). Jensen and Maslesa (2015) developed a tool suitable for big projects for systematically involvement of stakeholders in the project. This is an interesting tool that is relevant to be tested in the OSCAR project. Artto et al. (2015) maintain that increased involvement of the stakeholders that actually are users of the building has vital importance for the usability. They suggest to initiate a stakeholder network in early phase of the building and to start a value management process early due to the stakeholder's different values and attitudes. This will require a change of the building and work process of particularly the early planning and design phase, but also challenge the traditional way of executing real estate project. Such a network can easily fill the "Structural Role" as suggested in the CRISP model (Spencer and Winch, 2002)

The researchers discusses user involvement widely and conclude with that this is important but very complexed. Some good examples from the Norwegian context of user involvement that have resulted in buildings with high usability is the Power house of Kjørbo in Sandvika[2], and the Sparebank 1 building[3], a bank quarter in Trondheim. The owners state that they succeeded because of their clear and ambitious goal, namely involvement of a broad competence in the design phase, hereunder users and facilities managers (Meistad, 2015).

A view from researchers and practitioners involved in construction of Norwegian hospitals is that the tradition has been broad user involvement from both the hospital units and patient groups. The trend is now going towards a more specialised involvement of the clinics and hospital units rather than patient groups. In the hearing process, the patient groups involved have possibility to respond with views and statements as they are represented by their patient organizations (Sintef Helse[4]). The Norwegian Heath authority [5] developed for early phase planning that describes the processes and decision gates of the early phase in hospital projects. Several large hospital projects have used

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[2] Kjørbo Powerhouse (http://www.powerhouse.no/en/prosjekter/kjorbo/

[3] Sparebank 1 (http://www.arkitektur.no/sparebank-1-smn?tid=158202)

[4] Dialogue with senior researcher Marthe Lauvsnes, Sintef Helse Nov 30, 2015

[5] The Norwegian Health authority (www.helsedirektoratet.no)

this guideline but it does not say anything about the involvement of user groups. In a revised version that is to come, user involvement will be an important issue, we hope.

2.3 Co-creation and collaborative models

Co-creation is a popular concept of innovative thinking, more precisely how business and clients can cooperate to develop new products that can create mutual value. This concept has been recognized especially when developing new products. The mind-set however, is highly relevant for real estate projects today. In the construction context, we do not only promote co-creation in order to obtain a sustainable building with good use qualities. We do believe that co-creation processes have a huge potential to increase the understanding of the users' needs and owners concerns. It has successfully been used to processing involvement of several stakeholders and necessary competences. Frow et al. (2015) presents a framework for a structural approach when doing co-creation processes that includes diagnosing needs, designing solutions, organizing the process, managing conflicts and implementation. The framework aims to facilitate the questions: What are the critical resources? What are the roles in the joint activities? The need for a more collaborative approach in order to achieve a sustainable practise with high a degree of user satisfaction is also emphasised by others (Meistad, 2015, Støre-Valen et al., 2014, Gemser and Perks, 2015). This is highly relevant in the early design phase.

3. Research approach and methodology

This research is based on a comprehensive literature review and a national online survey among a wide range of stakeholders (N=799) in the Norwegian building industry. The survey was conducted from May to September 2015.

The literature search was based on search in databases like Google scholar, Iconda and Scopus with the search words like “Value management”, “Stakeholder involvement” and “Early phase planning”. The literature review looked for obstacles and barriers concerning which factors that add value for various owners and end-users of buildings. The literature review also examined what the literature says about involvement of stakeholders in the early phase of real estate projects.

The aim of the national survey was to identify which aspects of a building provide value for owners and users. The questions in the survey are based on extensive literature studies. The questions and the questionnaire was pretested on various stakeholder groups before the final version of the survey was sent to professional associations that organize stakeholders in private enterprises, public administrations and non-profit organisations involved in planning, construction, and provision of parts, services, and owners and users of real estate. The survey measures four dimensions of sustainability, namely the economic, social, environmental and physical dimensions. The analysis presented in this paper focus on the two aspects: namely *economic and social aspects.* The respondents were asked to score the statements from one to four (1 = none weight, 2 = some weight, 3 = strong emphasis and 4 = very strong emphasis).

The respondents' answers have been analysed through descriptive statistics and exploratory principal component analysis (PCA) with IBM Statistics SPSS version 22. The general purpose of exploratory PCA and other kinds of exploratory factor analysis is to summarise the information in a number of questions (variables or items) into fewer (latent) composite dimensions with the smallest possible loss of information to identify the fundamental or theoretical constructs underlying the survey questions (Hair et al., 1998:95).

In PCA and other kinds of factor analysis, it is common to rotate the matrix in order to achieve a simpler and more meaningful solution. The rotation is a mathematical manipulation of the factor axis. VARIMAX rotation (orthogonal rotation) often gives a clear separation of the factors (Hair et al., 1998:89-90, 107-111). Our exploratory PCA is based on VARIMAX rotation. Barlett's test of sphericity and Kaiser-Meyer-Olkin's (KMO) measure of Sampling Adequacy are two commonly statistical tests used for the data's appropriateness. KMO for our data are 0.665 or better, and the p-value for Bartlett's test is 0.000 for all of the categories.

The respondents answer from an owner or a user perspective. They also answered from whether or not they had been involved in early phase planning of real estate projects. The aim of our statistical analysis is to elucidate whether owners, users and those who have or have not been involved in early phase development of buildings answer different on questions concerning the economic and social dimensions.

4. Results from the Statistical analysis

In this section, we first present the findings from the descriptive statistics of the respondents and thereafter the findings from the exploratory PCA of the answers about the questions concerning the economic and the social dimension from respondents with an owner or user perspective. We distinguish between those respondents who have been or not have been involved in early phase planning of building projects. Interestingly enough, both those with an owner and user's viewpoints indicate that financial issues and cost efficient operational services has most value. More details will be discussed in the forthcoming section.

Table 2 shows the number of respondents distributed on their employment role, from an owner and user perspective as well as their role in the early phase development of real estate projects.

Table 2: The respondents' perspectives, employer and roles in early phase development

		Owner				*User*			
		Early phase - development				*Early phase – development*			
		No		*Yes*		*No*		*Yes*	
		Count	*Row N %*	*Count*	*Row N %*	*Count*	*Row N %*	*Count*	*Row N %*
Respondents' employer	*Public sector owned enterprise*	*36*	*54.5%*	*30*	*45.5%*	*5*	*45.5%*	*6*	*54.5%*
	Privately owned enterprise	*116*	*41.4%*	*164*	*58.6%*	*76*	*50.0%*	*76*	*50.0%*
	Public authority	*40*	*58.8%*	*28*	*41.2%*	*26*	*63.4%*	*15*	*36.6%*
	Municipality or county municipality	*73*	*52.9%*	*65*	*47.1%*	*15*	*65.2%*	*8*	*34.8%*
	Total	*265*	*48.0%*	*287*	*52.0%*	*122*	*53.7%*	*105*	*46.3%*

Among the 779 respondents in the survey who answered the questions about their employer and perspective 552 or 70.9 percent answered the survey with an owner perspective, while 227 or 29.1 percent answered with a user perspective. Among the owners 52.0 percent have been involved in the early phase of real estate projects. 46.3 percent of the 227 respondents with a user perspective have been involved in the early phase. Table 2 also provide a detailed overview of the respondents' employers. 77 (10 percent) of the respondents are employed by enterprises owned by the public sector. 432 (56 percent) respondents are employed by private enterprises. A public authority employs 109 respondents (14 percent). A municipality or county municipality employs 161 respondents (21 percent). Table 2 shows that a majority of the respondents employed by enterprises owned by the public sector have answered with an owner perspective. Table 2 also shows that the majority of respondents employed by private enterprises have answered with an owner perspective, and that a majority of these have been involved in early phase development. Table 2 even show that a majority of those employed by public authorities have answered with an owner perspective, but the majority of these have not been involved in early phase development. This is also the case for the respondents employed by municipalities or county municipalities.

Table 3 and 4 show the results of exploratory PCA of the respondents' answers of the questions concerning the economic and social dimensions.

Table 3: Main findings from PCA (VARIMAX rotation) of the data concerning the economic dimension (Cronbach's alpha > 0.6)

	Component with items and factor loadings	***Explained-total variance (%)***	***N***	***Reliability (Cronbach's Alpha)***
Owner perspective – Respondents who have been involved in the early phase	***#1: Cost efficient operations*** *Cost efficient cleaning (.749), Life cycle costs (.736), Energy costs (.663), Cost efficient services (.653), Total costs per workplace (.630), The building's economic life span (NPV of cash flow) (.564), The building's effect on core business (.554)*	*27.8*	*209*	***0.788***
	#2: Financial issues *Yield (.886), Economic risk (.839), Investment costs (.487), The building's market value in case of sale (.851)*	*25.2*	*207*	***0.797***
Owner perspective – Respondents who not have been involved in the early phase	***#1: Cost efficient operation*** *Cost efficient cleaning (.808), Cost efficient services (.777), Energy costs (.715), Life cycle costs (.704), The building's economic life span (NPV cash flow) (.600), Total costs per workplace (.529)*	*28.5*	*181*	***0.823***
	#2:Financial issues *Yield (.906), The building's market value in case of sale (.873), Economic risk (financial and market risk) (.846)*	*26.9*	*185*	***0.877***
User perspective – Respondents who have been involved in the early phase	***#1: Financial issues*** *Yield (.890), Economic risk (financial and market risk) (.887), The building's market value in case of sale (.799), ,Investment costs (.408)*	*24.6*	*58*	***0.797***
	#2: Cost efficient operations *Cost efficient cleaning (.820), Cost efficient services (.783), Total cost per workplace (.774), The building's effect on core business (.510), Life cycle costs (.433)*	*22.9*	*69*	***0.751***
User perspective – Respondents who not have been involved in the early phase	***#1: Financial issues*** *The building's market value in case of sale (.833), The building's economic life span (NPV of cash flow) (.792), Yield (.680), Life cycle costs (.642)*	*25.0*	*51*	***0.800***
	#2: Cost efficient operations *Cost efficient services (.847), Cost efficient cleaning (.844), The building's effect on core business (.653), Total cost per workplace (.550)*	*23.2*	*65*	***0.754***

Table 3 shows that PCA of the answers from the respondents with an owner perspective who had been involved in early phase came out with two reliable components, namely the first, which we denote; *cost efficient operations,* and the second one, which we denote, *financial issues*.

PCA of data from the respondents with owner perspective who not had been involved in early phase development gave similar results This was also the case for respondents who answered with a user perspective that had not been involved in the early phase. The Bartlett's test of sphericity indicates sufficient correlation between the questions; the constructs derived through PCA are thus acceptable with regard to both sampling adequacy and reliability.

A tentative conclusion concerning the economic dimension is that respondents who answered the survey with owner and user perspectives have different opinions concerning the economic dimension. The findings are somewhat contra-intuitive, because those who answered with an owner perspective seems to be more concerned with cost efficient operations than financial issues, while those who answered with a user perspective seems to be more concerned with the financials issues than cost efficient operations. These findings are actual for further studies.

Table 4: Main findings from PCA (VARIMAX rotation) of the data concerning the social dimension (Cronbach's alpha > 0.6)

Category of respondents	***Component with items and factor loadings***	***Explained total variance (%)***	***N***	***Reliability (Cronbach's Alpha)***
Owner perspective – Respondents who have been involved in the early phase	***#1: Workplaces facilitation social interaction*** *Workplaces facilitating flexible ways of working (.831), Promoting pride (the organization's cultural values) (.744), Areas facilitating formal and informal meetings (.728), Architectonic qualities (.637), Interior qualities promoting well-being and tidiness (.607), Facilities for physical exercises (.556), Individual management of sun screening, lights, temperature, etc. (.491)*	*27.8*	*196*	***0.816***
	#2: *Safety and security (protection against unwanted incidents) (.830), orientability (intuitive signs, etc.) (.798), user involvement (.514), corporate governance (.395)*	*21.2*	*218*	***0.652***
Owner perspective – Respondents who not have been involved in the early phase	*#1 : Interior qualities promoting well-being and tidiness (.740), Promoting pride (the organization's cultural values) (.699), Workplaces facilitating flexible ways of working (.693), Areas facilitating formal and informal meetings (.664), Safety and security (.661), Architectonic qualities (.615), User involvement (.601), individual management of sun screening, lights, temperature, etc. (.595), Facilities for physical exercises (.568), Corporate governance (.470)*	*41.2*	*182*	***0.859***
User perspective – Respondents who have been	***#1: Workplaces facilitation social interaction*** *Workplaces facilitating flexible ways of working (.863), Areas facilitating formal and informal meetings (.823), User involvement (.603), Facilities*	*33.8*	*63*	***0.858***

involved in the early phase	*for physical exercises (.602), promoting pride (the organization's cultural values) (.598), Safety and security (protection against unwanted incidents) (.598), Interior qualities promoting well-being and tidiness (.581), Individual management of sun screening, lights, temperature, etc. (.562)*			
User perspective – Respondents who not have been involved in the early phase	***#1: Workplaces facilitation social interaction*** *Areas facilitating formal and informal meetings (.855), Workplaces facilitating flexible ways of working (.831), Interior qualities promoting well-being and tidiness (.782), Safety and security (protection against unwanted incidents) (.713), User involvement (.652), Promoting pride (the organization's cultural values) (.630), Facilities for physical exercises (.600), Safety and security (protection against unwanted incidents) (.598), Individual management of sun screening, lights, temperature, etc. (.583), Orientability (intuitive sign, etc.) (.551)*	*40.2*	*66*	***0.882***

Table 4 shows the factor loadings of the PCA of the answers for the social dimension. Even these data are found adequate for PCA. The respondents who answered the survey with an owner perspective who had participated in the early phase

The component that is found reliable (Cronbach's alpha > 0.8) for both respondents with owner and user perspective is denoted *workplaces facilitating social interaction*. The principal component analysis uncovered also a common factor with acceptable reliability for those respondents with owner perspective who not had been involved in the early phase, namely the entire battery of questions concerning the social dimension (11 items).

A tentative conclusion concerning the social dimension seems to be that most respondents in our study prefer well-designed workplaces that facilitate social interaction and various ways of working, no matter whether they have answered the questions with user or owner perspective and whether or not they have been involved in the early phase of building projects.

5. Discussion

5.1 Literature review

Based on the literature review, we maintain that the CRISP model is an interesting framework for processing complexity of the stakeholder involvement. The model shows how different stakeholder's interests, value systems and power influence the decisions and choice of solutions. In sum, these factors influence the final product, time and money spent as well as the final usability of the product. The CRISP model suggests using a structural role and sophisticated measures for the social impact to handle value management and user involvement. This is in line with other findings from the literature review, suggesting using broad network groups and broad competence involved in early phase (Spencer and Winch, 2002, Frow et al., 2015, Gemser and Perk, 2015).

The user roles have many opinions and the users do not always clearly understand what their needs are. Spencer and Winch (2002) assume that users may under-value design of the building as they find it difficult to communicate clearly their needs and vision for a building. They do not necessarily understand the value of a good building design; find it difficult to define their organizational values and to agree upon how to measure them (both tangible and intangible benefits). Spencer & Winch (2002) suggest a structured role to coordinate network groups, balancing power and help facilitating the creative process to find the best solutions for both client/owner and customer/user. A key question is what competence is necessary in the stakeholder groups in order to optimize the benefits of the involvement. We believe this will be a sensible approach concerning how to involve important stakeholders and to define the users' needs.

5.2 Survey

Our data show that the owners are more interested in user involvement in early phase development of buildings than the users themselves. This finding indicates that the process of being involved in early phase development gives both ownerships to the decisions and opportunities to influence the decisions. This finding corroborates the literature that show positive results from use of collaborative models for involving more stakeholders in early phase development (Frow et al.,2015, Meistad, 2015, Artto et al., 2015).

In the survey, we look at how different stakeholders perceive value in real estate projects. We discuss whether there are contradictions in values among owners and users. Surprisingly the owners think that user involvement is more important than the users do. It depends on who have responded to this question and what is their understanding of how user involvement can add value or not. The respondents' educational background, how they understood the questions and what they actually believe what choices and decisions they can influence in the early phase, are probably some explanations.

The literature also suggests co-creation models for involving users in early phase and design phase s of a building project. There is a trend in the literature that recommend co-creation processes and collaborative working models in early phase. The Kjørbo project is one such a successful example on collaborative co-creation processes. This point towards a field of interest for further studies in the OSCAR project that is possible to y explore in demonstration projects. Further research will be presented in the future.

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Linking Activities During Construction to Inter-Organizational Value Co-Creation During Operations

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Abstract

Value of construction projects is traditionally evaluated by the capability to use the facility for the planned purposes. In business premises, however, recent research highlights the creation of value in a project through establishing inter-organizational networks that have the capacity to create long-term value for the businesses in the facility. This article analyzes the lifecycle of a facility, which involves two major phases: the project phase and the operations phase. In regard to the content of these phases, the facility and the inter-organizational network is established in the project phase, and the facility and the network organizations co-create jointly the use value in the long-term. The purpose of this paper is to look at different types of logic on how value co-creation among multiple organizations can take place in the operations phase of the facility. Furthermore, the purpose is to identify activities in the project phase, which facilitate the development of such network that contributes to value co-creation in the operations phase. The empirical study is a qualitative single case study of a lifecycle of Rehapolis health and wellbeing campus facility in Finland. We identified five types of value co-creation logic in the operations: 1) integrated business operations, 2) shared use of premises and facility services, 3) organizational integration, 4) shared brand and marketing efforts, and 5) shared knowledge. We then identified five activities in the project phase that facilitated the creation of the network: I) creating a shared vision among stakeholders, II) building a focused campus concept, III) engaging external third party and public stakeholders, IV) creating distinctive brand and name, and V) designing and adjusting of spaces jointly. This research highlights that activities during the construction project could also include the development of an inter-organizational network which involves co-creation of value among multiple organizations using the facility in the operations after the completion of the project. By understanding the different types of logic of value creation among different operators and users, developers and investors can focus their activities already during the project on enhancing the value creation in the long term, over the whole lifecycle of the facility.

Keywords: Facility, Project Lifecycle, Inter-Organizational Network, Value Co-Creation, Activity

1. Introduction

Property developers and construction companies have continuous need to develop their businesses by providing users and tenants additional value that goes beyond the traditional value of physical premises. One trend is to create business premises for selected actors that benefit from close proximity between each other and therefore see the specific premises as strategic locations for their businesses and operations (Borgh et al., 2012; Cheng et al., 2014). According to the existing research, co-location of actors allows building trust, which in turn is a prerequisite for collaboration (Becker et al., 2003). Again, co-located facilities that enable collaboration between occupants promote knowledge sharing (Haynes and Sailer, 2011; Inalhan and Appel-Meulenbroek, 2010). Localized networks are valuable as they in addition to enabling value creation between organizations, also offer additional value for customers, especially in consumer service and retail businesses in which co-location makes possible for organizations to integrate their products and services for potential customers.

Despite of the highlighted role of built environment to provide value for inter-organizational networks, little is still known about exact co-creation logics in those networks. It could be hypothesized that additional value of premises to networks is somehow connected to the interplay between tangible aspects of the shared premises and intangible aspects of the operating organizations and their relationships. If that is true, crucial question is also how the formation of the unique network and value co-creation among multiple organizations in the operations phase could be considered already in the project investment phase? Previous research about construction projects highlight the activities to materialize physical construct for planned purposes. However, previous research says little about what are the activities during a construction project that can contribute to later inter-organizational value co-creation in the operations phase.

This article investigates a facility lifecycle from the perspective how value co-creation among actors in the operations phase is established through activities during the construction phase. The paper aims at linking the construction project to the operations phase by identifying different types of logic in value creation in the inter-organizational network identified in operations phase of a healthcare campus and further investigating how activities in the construction phase enabled realization of value co-creation. The research questions are: RQ1 – How value co-creation among multiple organizations can take place in the operations phase of the facility? We address RQ1 by analysing the lifecycle of the case facility and identifying five different types of logic for the co-creation of value among multiple organizations in the operations phase. RQ2 – How the development of such inter-organizational network can be managed during the construction project, which contributes to the value co-creation logics in the operations phase of the lifecycle? We address RQ2 by identifying activities in the management of the project that facilitate the development of such network that contributes to value co-creation in the operations.

2. Theoretical background: value of construction projects

Value is the fundamental purpose of exchange. In classic economic theories value refers to utility theory which states that consumers spend their money so as to maximize the satisfaction they get from products and services (Bowman and Ambrosini, 2000). In construction projects this means that clients or owners consider the balance between investment costs and estimated profits of the buildings through e.g. rents or resale value as a starting point for the investment.

In existing research about value of construction projects, additional value is typically approached from the cost minimization perspectives. Research about lean construction and target value design mostly concentrates on developing methods and practices to reduce construction costs (e.g. Zimina et al., 2012), and potential to improve benefits or profits of investments are typically less considered. However, in the book of “How Buildings Add Value for Clients” (Spencer and Winch, 2002) the authors argue that well-designed and constructed buildings have several value adding components for clients, including financial value, building’s contribution on productivity, indoor environment quality and spatial quality as well as even symbolic value of buildings in its relationship with the external environment. The value of construction has at least three dimensions: the contribution to client’s business processes (McGregor and Then, 1999), the contribution to supplier’s business processes, and the contribution that the asset makes to society as a whole (Winch, 2006).

A construction company can adopt different value creation logics in its operations. Bygballe and Jahre rest on the three dimensions of value logics - value chain, value shop and value network logic (Stabell and Fjeldstad, 1998) - as they argue that in construction the value chain and the value shop logics seem particularly relevant (Bygballe and Jahre, 2009). The value network logic describes companies that facilitate exchange between different clients and customers, for example retail banks, insurance companies and transporters. The authors suggest that “even if these services are important for the functioning of the construction industry, they do not represent what are usually considered construction activities”.

As research about construction has not highlighted the value network logic, the research on campuses and business parks, instead, sees high value in business premises that are shared among networked organizations. Science parks can support creation of formal and informal networks, which are valuable for growth of new technology based firms (Cheng et al., 2014; Dettwiler et al., 2006). Co-location with similar companies facilitates innovation processes and creation of innovation community (Borgh et al., 2012). The studies suggest, that especially for high tech companies and SMEs, the construction of shared business premises has value that goes beyond boundaries of single firms.

If we accept the notion that value created during operations in facilities has also intangible and inter-organizational nature, the crucial question is how this value creation is facilitated earlier in the project phase. Project lifecycle consists of distinctive phases, such as front-end, conceptualization, execution, and start-up of operations (Morris, 2013) which in a post-project stage provides value for several stakeholders (Turner, 2014). Parallel creation of inter-organizational networks has been seen as a source for long-term value (Artto et al. 2016). Inter-organizational campuses are examples of low hierarchy networks in which proximity can lead to value co-creation among actors through many mechanisms, such as knowledge sharing (Inalhan and Appel-Meulenbroek, 2010), integrated supply-chains or shared resources.

Based on the research about value of construction, value of local networks, and project phases, we illustrate the development of the multi-organizational business premises through an analytical framework (Figure 1). The framework highlights the parallel creation of an inter-organizational network during the construction project. This research aim to identify the value co-creation logics of business premises in the operations phase and activities establishing them during the investment project phase.

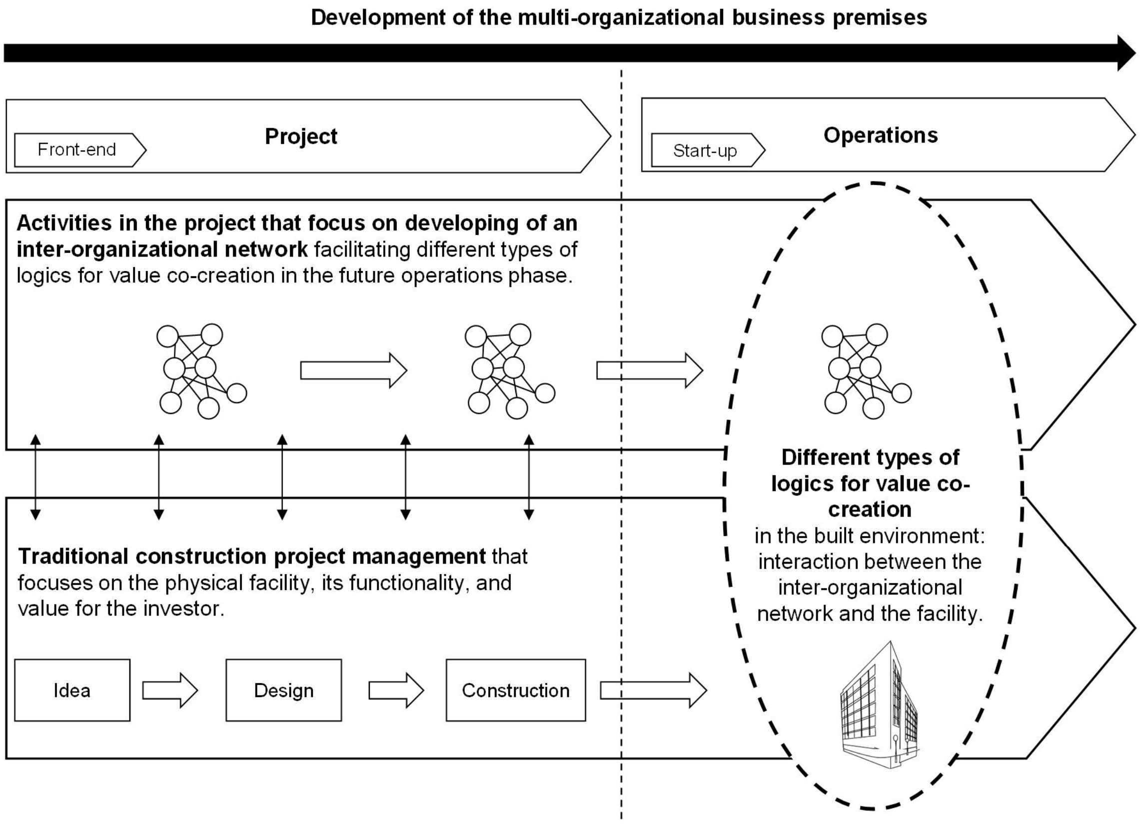

Figure 1: The research framework

3. Method

Due to an explanatory nature of the research question (*'how'*), and purpose to investigate contemporary value co-creation during operations and its connection to the past project phase, a case study method was selected to gather a full variety of evidence within a real-life context (Yin, 2003). We conducted a qualitative in-depth single case study, which analyses the lifecycle of Rehapolis health and wellbeing campus facility in Finland. The lifecycle of Rehapolis campus forms suitable unit of analysis because it included various public and private organizations which participated during the campus development project and which co-created value also during the operations phase.

3.1 Case description

The Rehapolis campus lies in the district of Kontinkangas next to the Oulu University Hospital and Oulu University of Applied Sciences' School of Health and Social Care, creating a close proximity of health care operators inside the district. Rehapolis consists of two buildings comprising 8500 m2 of rented space and currently hosts 19 different actors ranging from private companies to public health care operators and third party associations. The main actors are operating in the field of disability health care providing all the public and private services required for acquiring assistive devices and rehabilitation services for persons with physical disabilities.

3.2 Data collection

The investigated construction phase including also a front-end phase spanned six years between 1998 and 2004, and an operation phase up until 2015. We collected empirical data through history documents, meeting memos, marketing materials and semi-structured interviews of representatives from 15 organizations, which had participated in the development of the facility and/or had operated on the campus. In total we conducted 24 interviews (Table 1) that ranged between 51-110 minutes. In the interviews, informants were asked to freely tell their story about the campus project, crucial events, activities and people during the project lifecycle and collaboration and activities in the operation phase.

3.3 Data analysis

In the analysis, we first inductively identified value co-creation logics among participating organizations in the operation phase. We identified all the features of the network or the buildings which informants mentioned valuable for them (1st level coding). After that we combined those features to the five groups which reflected different value creation logics (2nd level coding). In the second phase, we inductively mapped the crucial events and activities during the lifecycle of the Rehapolis from the front-end to the current operations phase. The importance of the event or activity was evaluated based on how often it was mentioned among informants, and how they connected the event or activity to the network formation or the establishment of value co-creation during operations. We also used deductive reasoning to identify mechanisms between activities and value co-creation if an activity had a clear outcome and if that same outcome was evidently crucial to establish a mentioned value co-creation logic.

Table 1: Interviewed organizations and individuals.

	Organization	*Description*	*Interviewee role*
Public operators	*Assistive Device Unit*	*A public actor providing assistive device services for special health care. Representatives included in Respecta's advisory board.*	*Unit manager*
	University Hospital Prop. Management	*A public actor responsible for University Hospital's property investments and management.*	*CEO*
3rd party	*ORTON Foundation*	*Foundation providing various services for orthopaedic health care, rehabilitation, scientific research and education supply.*	*CEO, Former CEO*

	Oulu's Disabled Association	*An association representing the rights of people with physical disabilities. Among the first actors participating to the development of Rehapolis and bringing customer's perspective to the project. COO was the member of advisory board.*	*COO* *Former COO*
	The Finnish Rheumatism Association	*An association supporting rheumatic patients by offering guidance, help and education. Among the first users in the Rehapolis.*	*COO*
Private companies	*Respecta Inc.*	*Private actor providing all the services for assistive devices. Focal company in the creation of Rehapolis and the developer during the construction of both campus buildings.*	*General manager, Ex-CEO (2 interviews), Regional Manager, Former admin.*
	Provider 1	*A company owned by the student union of University of Oulu, provides restaurant and catering services in Rehapolis campus.*	*Service Manager*
	Provider II	*A private company providing various physiotherapist services.*	*CEO*
	Provider III	*A private company providing solutions for hearing-impaired (hearing aids and other products & services).*	*CEO*
	Provider IV	*A private company focusing on wellness tourisms and operating a rehabilitation and wellness centre.*	*COO*
	Provider V	*Private company providing medical, social and professional rehabilitation services (e.g. occupational and speech therapy).*	*CEO*
	Provider VI	*Private company providing assistive devices. Main focus in movement aids such as wheel chairs and walkers.*	*Regional manager*
	Provider VII	*Facility management company, which took over the facility management of Rehapolis 1 premises during the year 2014*	*Regional manager*
	Provider VIII	*Private start-up developing innovative bone implants through in-house R&D project.*	*CEO*

Note: Private companies are anonymized due to request of the informants.

4. Findings

4.1 Lifecycle of the Rehapolis

The origin of the campus idea dates back to the late 1990s (Table 2). The advisory board of Respecta consisted several experts from the field of physical disabilities from public, private and third sector organizations. The experts met a few times a year and discussed about the needs and development trends in the field. Major concerns related to the fragmented service chain from customer point of view (e.g. in cases in which amputated patient needed assistive devices), unsound premises of several organizations.

Table 2: Key events in the lifecycle of the Rehapolis

Year	*Key events*
1997	*First discussions about the campus concept among Respecta advisory board members during the shared trip to the fair.*
1998	*First concept plan and organizing document signed by crucial public, third party and private stakeholders.*
1998-2002	*CEO of Respecta coordinated fund-rising, and design of concept and premises with support of other parties.*

2002	*Final decision to build Rehapolis 1. Funded by Orton Foundation and City of Oulu.*
2004	*Rehapolis 1 was opened. Respecta and City of Oulu as major operators.*
2004	*Former CEO of Oulu's Disabled Association was nominated as a Director of Rehapolis (salaried by Respecta). He launched an internal coordination body and joint marketing activities.*
2008	*Rehapolis 2 was opened. Hospital District moved in with Assistive Device Unit and occupational health centre.*
2011	*Hospital District and City of Oulu merged their Assistive Device Units.*
2012	*Director of Rehapolis retired. After short period with new Director, the CEO of Respecta took responsibility of Rehapolis.*
2013	*Orton Foundation sold Respecta to an international company. CEO of Respecta retired.*
2013-	*Occasional campus events organized. No systematic management. Actors launched new joint services.*

During one shared conference visit in 1997, the board members came up with the idea of a new campus dedicated for rehabilitation aid and service providers. The CEO of Respecta and COO of the Association for the Physically Disabled took leading roles in developing the campus concept and marketing it to regional public players and other potential operators. Convincing the public actors about the idea was necessary for gathering financial resources for construction. The idea took five years to mature, and the first building was erected in 2004. An innovative contracting method in which Orton Foundation financed construction phase and after that sold 20% of the premises to the City of Oulu based on the reported costs was used to speed up the project. The organizations moving on the campus had possibility to affect the design phase and customize their own offices based on the needs of their customers and operations.

The actors that moved on the campus highlighted how they felt like they belong to a same organization. That feeling was connected to the shared experience about the new premises but also to new activities mentioned by several informants: Shortly after the start of operations, Respecta recruited the COO of Disabled Association as a Director of Rehapolis. He started to organize internal marketing board meetings that focused on shared marketing efforts as well as more recreational activities among the actors. The Director was seen as a father of the whole campus and he emphasized that he was working for Rehapolis and not for Respecta.

The hospital district was not pleased with private companies leading role in the development work. However, after good experiences with the first premises, the hospital district participated in the construction of the Rehapolis 2. The hospital district moved its assistive device unit to the new premises as well as its occupational health provider. The directors of Rehapolis recruited other organizations to the building and allowed also Respecta’s competitors to participate in the campus network. Several examples revealed that the network was creating value to the members as planned: The City of Oulu and hospital district merged their assistive device units which led to better management of devices and easier business environment for private providers. Respecta and Assistive Device Unit developed integrated service-chains for patients, and providers II and V launched new therapy service. The Director of Rehapolis continued to organize stakeholder events for disabled patients, potential new customers and health care professions. In summary, the Rehapolis campus may be considered a success. Nowadays, altogether 19 organizations from the health and wellbeing sector operate on the campus.

4.2 Five types of logics for value creation in the operations phase of Rehapolis

We identified five value co-creation logics in the operation phase (Table 3): 1) integrated business operations, 2) shared use of premises and facility services, 3) organizational integration, 4) shared brand and marketing efforts, and 5) shared knowledge.

Table 3: Identified inter-organizational value co-creation logics

Value creation logic	*Description*	*Conclusion of evidence from empirical analysis*
1. Integrated business operations	*Organizations innovated new value adding offerings to shared customers by joining their core capabilities.*	*A joint development project of service providers (SPs) 1 and 6. The Assistive Device Unit and SP1 had common days for disabled customers to fit devices. SP 5 occupies a shop-in-shop office within SP 1 facilities. SPs 3 and 4 launched a new collaborative therapy service.*
2. Shared use of premises and facility services	*Improved cost efficiency through shared premises.*	*Common coffee rooms, meeting rooms and parking lots. Orton provided free office spaces for Disabled Associations Open doors and corridors to improve space efficiency. Restaurant working as a reception desk.*
3. Organizational integration	*Proximity wot overlapping offerings facilitated mergers.*	*Assistive Device Units of the City and the Hospital District merged soon after re-locating on campus. SP 1 bought part of the operations from SP 3.*
4. Use of shared brand and marketing efforts	*Brand helped actors to market cost-efficiently, attract new customers and increase reliability of their services.*	*The name Rehapolis was launched. Brand was used to market network to new actors. Monthly money was gathered from actors for joint market campaigns and websites. Organizations highlighted Rehapolis brand in their marketing due to its identification with high-quality and familiar location.*
5. Shared knowledge	*Organizations increased their knowledge about shared customers and their needs through formal and informal collaboration.*	*Educational events were organized to customers and professions. Director organized internal coordination bodies and collaborative activities (e.g. evening events, joint visits, parties, guest introductions) among campus participants.*

Integrated business operations were seen especially important as shared campus location enabled providing customers more comprehensive service packages than what would be possible in scattered premises. Organizations were even able to joint their resources so that customers could not recognize any interface between the providers. *Shared use of premises* represented more traditional value co-creation logic. However, informants highlighted that joint use of corridors, coffee rooms and meeting rooms was motivated due to the fact that most of them were operating in the same field, disabled patients. *Organizational integration* created value to actors that during the operation phase perceived that they could be stronger and more efficient if they joint their organizations. This role of shared location as a facilitator was extremely evident in the merger of the City's and Hospital District's Assistive Device Units as before the co-location the organizations had deep mistrust to each other. Shared location and shared field of services enabled also creating Rehapolis *brand* and using it in *joint marketing efforts*. Brand was especially useful for small private companies which could scale their marketing efforts and increase the reputation and quality image of their services. Finally, informants saw all informal and formal collaboration among actors valuable as it enables *sharing knowledge* across organizations and individuals. Professional knowledge about needs and services of shared disabled patients helped the actors to develop their own capabilities and offerings.

4.3 Activities in the construction phase for developing the network with inherent co-creation of value in the long term

The five activities were identified in the construction project phase that established value co-creation in the operating phase: I) creating a shared vision among stakeholders, II) building a focused campus concept for a shared customer segment, III) engaging external third party and public stakeholders to the concept, IV) creating distinctive brand and name, and V) designing and adjusting of spaces jointly already in the project phase. The analysis identified several mechanisms that connected the identified activities to the value co-creation logics (Table 4).

Table 4: Activities in the construction phase for developing the network.

Activity	*Description and evidence from empirical analysis*	*Connection to the value co-creation during operations*
I. Creating of a shared vision among multiple organizations in the future 'operations ecosystem'	*Organizations belonging to the Respecta advisory body discussed regularly about the crucial issues of the disabled field and came up to the need to improve customer-centeredness of the services and efficient use of devices, such as wheelchairs.*	*Creation of shared vision about the field built ground for organizations to start discussions about joint operations.* ***à 1. Integrated business operations*** ***à 3. Organizational integration***
II. Building of a focused concept for a shared customer segment among the involved organizations	*The CEO of Respecta took the leading role of building a concept about the physical campus in which all the crucial organizations providing services to disabled people have premises.*	*Sharing the same customer segment helped organizations to design common spaces and decide how to use them* ***à 2. Shared use of premises and facility services***
III. Engaging of external third party and public stakeholders to the concept jointly already in the project	*Assistive Devices Units of the City and Hospital District, Disabled Association and Rheumatism association were committed to the construction project and to relocate offices to the new campus. The*	*Participation of the organizations already in the construction phase to develop the concept and finance the investment increased and tested trust between organizations and individuals.* ***à 1. Integrated business operations***

	city of Oulu accepted open book policy to pay part of the realized investment costs.	***à 5. Shared knowledge***
IV. Creating of distinctive brand and name	*The name Rehapolis was created in a very early phase when the building was designed in order to market the campus as a highly focused network to carefully preselected potential tenants.*	*Early creation of the campus brand facilitated selecting appropriate organisations to the campus in order find areas for collaborative marketing.* ***à 4. Use of shared brand and marketing efforts***
V. Designing and adjusting of spaces jointly already in the project phase.	*Open door layouts, and shared meeting and coffee rooms were designed in order to enhance chance encounters between individuals and to increase the feeling of unity among organizations.*	*Design solutions supported informal and formal collaboration among actors.* ***à 2. Shared use of premises and facility services*** ***à 5. Shared knowledge***

The shared vision in the field of disabled services was already created in the project front-end phase. Different private and public actors met occasionally and discussed about needs to improve service chains. They also finally came up to the idea about the shared premises under which customer could get all crucial services and devices. Early discussion about the shared vision among organizations in the project phase created fertile ground for later discussions about detailed joint operations and organizational integrations. Building of a focused campus concept in the early phases of the project enabled to design premises that were tailored to specific needs of disabled patients and service providers. One of the service providers took leading role in developing the campus concept and also to involve other organizations in the space design. That enabled design of tailored spaces and shared rooms which were considered valuable and unique in the operating phase. The target customer group was also focused enough in order to design specific accessibility solutions.

Engaging external third parties and public stakeholders to the concept design and campus construction were crucial activities that built legitimacy for the project among society in the Oulu region. Public-private partnership was also used to speed up the project development phase and finance the delivery innovatively based on the open book practice. The collaboration already in the project phase created trust between the organizations and helped them to create joint services in the operation phase. Different stakeholders also brought their own expertise to the project and the network creating basis for the knowledge sharing in the operation phase.

The campus brand was created in the project phase and used to recruit appropriate organizations to move to new premises. That made possible to ensure that actor mix of the campus had enough coherence which was seen crucial in joint marketing efforts. The development of the brand early enough improved also the image of the new premises enabling campus developers to select carefully most suitable actors to the localized network. The role of campus premises as a platform for collaborative value creation was taken into account in space design phase. Open corridors and shared meeting rooms were designed to enhance chance encounters between individuals and organizations. This activity also established value co-creation through shared knowledge. The layout supported informal encounters and sharing of crucial information among actors.

5. Discussion

The investigated case study represented the development of the business premises in which the end result was a unique network of actors which operated in the unique premises designed and constructed for their specific purposes. The campus was success both for its owners and tenants as actors in the campus were willing to pay extra rent on the additional value they got from the network and surrounding premises. Through an in-depth analysis of the campus lifecycle we could identify five value co-creation logics and five activities to establish them in the project phase. The analysis was conducted in single case settings and exhibits “the force of example” (Flyvbjerg, 2006) about the links between project phase activities and value co-creation during operations. We argue that the findings have at least two contributions to the existing research.

First, the study shows how value of construction and buildings could be materialized through a development of unique network of organizations operating in shared location, and through a support of project outcome to the value creation in the operating phase. A building or shared location can catalyse several logics contributing to value co-creation. Some of those logics have tangible dimensions, such as shared premises, whereas others are more intangible or even strategic, such as organizational integration. Compared to previous research that has separated value logics mostly from a single organization perspectives (Spencer and Winch, 2002), this research broadens understanding about inter-organizational value creation in built environment.

Second, the study identifies five distinct activities in the investment project phase that were connected to the value co-creation in the operating phase. As the design of campuses and science parks with inter-organisational networks has been on the agenda for decades (McAdam and McAdam, 2008; Quintas et al., 1992; Kyrö et al., 2016), the study increases understanding about details how that value co-creation can be already affected through design solutions and collaboration in the project phase having direct implications on the success of the local network. We argue that in successful investment projects and in successful network development, the tangible development of the premises is tightly connected to the network formation through collaborative activities that both make premises more suitable for the network and also formulate network and relationships between its organizations early enough to maximize value creation in operation phase. The commitment of the network organizations to achieve the physical outcome of the project commit them simultaneously together for the purpose of value co-creation.

6. Conclusions

The aim of this paper was to identify what are the value co-creation logics among organizations in localized inter-organizational networks and what are the activities during the investment project that establish such value co-creation. The research provides new knowledge about value of buildings which is related to collaboration among actors in shared premises. This knowledge is especially important for facility managers that develop new value-adding services in existing facilities and for developers and construction companies that in the early phases of the project want to establish high value of the premises during operation phases. For those organizations the study provides detailed knowledge about activities that contribute to lifecycle value of buildings. By understanding the different operators' and users' value creation logics, developers and investors can orchestrate activities during the whole project lifecycle in order to maximize value in the inter-organizational network.

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An exploratory study of the practice of stakeholder participation in densification projects

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Abstract

Background: For decades, densification has been adopted and enforced by policy makers and other stakeholders to achieve a more sustainable built environment. However, scholars argue that densification is merely a tool and alone is not sufficient to achieve sustainable development. Furthermore, densification projects can bring negative as well as positive impacts for stakeholders. Negative impacts include increased housing prices and construction cost, pollution concentration in urban areas, reduction of public and green space, and unhealthy living environments. On the other hand, urban densification can contribute to a more attractive environment by increasing the efficiency of transportation, concentration of services, social integration and reduction of buildings footprint. A holistic approach to densification is needed which takes into account social, economic and environmental sustainability aspects.

Objectives: Stakeholder participation contributes to sustainable densification by taking into account the needs and concerns of a wide range of stakeholders throughout the different stages in the development projects. The aim of this study is to explore the current practice of stakeholder participation in order to identify the challenges, opportunities and best practice of stakeholder participation in urban densification projects.

Methodology: This paper explores the current practice of stakeholder participation in densification projects and its potential benefits and hindrances, through a literature review and interviews with stakeholders in the public and the private sector as well as the affected community.

Results: The results of this study show that best practice of stakeholder participation in densification projects is characterized as proactive actions taken by individuals and groups rather than at an institutional level. Moreover, the impact that these proactive actions have on project success can contribute to the promotion of stakeholder participation at an organizational and institutional level.

Keywords: Built environment, densification, participation, stakeholders, sustainability

1. Introduction

The concept of sustainable urban development refers to the process in which social, economic and environmental issues are actively considered throughout the stages of the development project, i.e. planning, design, construction, and operation. Sustainable urban development is characterized as a means to achieve more than just built environments that reflect the needs and interest of a wider society. The lack of collective understanding of sustainability among the wide range of stakeholders in the planning, design, implementation, operation and maintenance of property development projects has been identified as a hindrance to achieving sustainable urban development (Curwell et al., 1998). Recent studies on sustainable urban transformation show that only a few powerful initiatives are driving urban development in a sustainable direction and conclude that key aspects for achieving sustainable transformative change are planning and governance (McCormick et al., 2013). Furthermore, evidence shows that collaboration between local government and cultural institutions increases local government capacity by strengthening resources and improving political efficacy and governance, thus leading to better credibility with the citizens and increasing networking and political capacity (Gough & Accordino, 2013).

Densification is proposed as one of the essential strategies to achieve a more sustainable living environment in cities. Although there are benefits to a more compact urban form, there is evidence that densification might lead to gentrification of existing urban areas, thus contributing to inequality and social problems (Quastel et al., 2012). Therefore, methods are needed to balance the social, environmental and economic sustainability aspects in urban densification projects.

The purpose of this study is to obtain explanations of how stakeholder participation potentially could solve the social sustainability problems that densification projects may infer. By preforming an inductive literature review and a qualitative interview study we study the current state of the art and the current practice of stakeholder participation in densification projects in Sweden. The results shows that many practitioners are working in some level with participatory processes, however, only a few have institutional and organisational support for these processes. Furthermore, there are a lot of benefits to involve stakeholders; however practitioners are finding stakeholder participation complex and challenging. In spite of the complex nature of stakeholder participation, however, it was noted that taking the risk to implement a stakeholder participation process can contribute to project success. Moreover, the impact that these proactive actions have on project success can further promote stakeholder participation at an organizational and institutional levels in organizations.

2. Stakeholder participation

Inadequate management of the concerns of stakeholders can lead to controversy and conflict about the implementation of the project (Olander and Landin 2008). Community attitudes are one example that has been shown to be an important factor when planning for, and locating, a development project (Rogers 1998). The demands of different stakeholder groups vary and a project can benefit one stakeholder group whilst simultaneously having a negative impact on others. Understanding the viewpoints of different stakeholders helps the project manager build relationships and thus avoid preconceived ideas and assumptions (Watson et al. 2002). To ensure stakeholder participation, especially by stakeholders in the external environment, various analyses and mapping techniques are available (e.g. Olander and Landin, 2005, Bourne and Walker, 2005, Olander, 2007). Different stakeholder groups have been analysed depending on their possibility to influence project decisions, and the potential consequence, for the project, if they choose to do so. An understanding of stakeholder theory is relevant in order to fully understand the numerous trade-offs that exists in sustainability-related problems (Hörisch et al. 2014). Stakeholder theory implies that successful organizations recognize stakeholder interests in a continuous process with the aim of creating value for a broader perspective of stakeholders (Strand and Freeman 2015) through, for example, a participatory process.

Arnstein (1969), argued that participation is the redistribution of power to those excluded from the political and economic arena to take part in the decision-making process. It is often argued in the participation literature how participatory practices are often proven inefficient. An inefficient participatory practice leads to failure in meeting the needs and concerns of the public and hence failure in improving the quality of the decisions and incorporating a wide range of stakeholders (Innes and Booher, 2004). With her work from 1969, Arnstein argued that approaches to genuine participation must safeguard stakeholders' needs and concerns in the decision-making process. Yet, even best-intentioned experts are prone to be unfamiliar with the problems and aspirations of stakeholders (Arnstein, 1969). Furthermore, scholars argue that there is not one universally effective method to participation as different methods are highly dependent on the contextual and environmental factors embedded in the project (Smith et al., 1997).

Three approaches to justify public participation have been identified in the participation literature (Stirling 2006; Fiorno, 1990) these are categorized as normative, substantive and instrumental. As opposed to the substantive arguments, normative reasoning focuses on the democratic rationale and is considered an end in itself. The focus is on equality rather than on the quality that comes out of the process. The substantive arguments look at participation instead as a means to an end, with an emphasis on improving the quality of the decisions made i.e. by incorporating local knowledge into the decision-making process. The third ground for public participation, the instrumental reasoning, considers public participation as a means to re-establish credibility and trust, and how to make decision more legitimate through public participation.

Innes and Booher (2004) mention how participation models exclude the participation of a broader range of stakeholders. Participation is often perceived as a dual system that involves citizens and the government but fails to integrate other stakeholders in the model. Innes and Booher (2004) argued that participation must be perceived as a collaborative process that engages a wide range of stakeholder's citizens, special interests groups, non-profit organizations, private and public sectors where communication, learning and action are essential for meaningful participation. However, as argued by Brody (2003), broad participation in the planning process does not necessarily lead to better plans; it is instead the involvement of specific stakeholders that significantly increases the quality of plans. Instead of engaging as many stakeholders as possible, Brody (2003) suggests that focus should be placed on identifying and involving specific stakeholder groups that are likely to enhance the quality of decisions. For example, a study in participatory urban planning in Helsinki by Kyttä et al. (2013) presented a SoftGIS methodology for the production of location-based, experiential knowledge from residents and found that contextual and experiential information from residents can be valuable for planners and further serve as a new layer of 'soft' knowledge in the planning of urban densification projects.

3. Urban densification

During the last 50 years, the suburban footprint has been expanding much faster than the core city (EEA 2006). This suburban expansion has been called urban sprawl, because the urban footprint is big but scattered. Frumkin (2002) and Ewing et al. (2013) have shown that there are many negative aspects to an urban sprawl development, both on its inhabitants and the environment. Urban sprawl removes the previous functions of the land, be it agriculture, industry or nature, and replaces it with single-family houses with garden plots. Because this sprawl is so widespread, inhabitants are more prone to use cars as a primary means of transportation, which in turn causes CO_2 emissions, pollution and obesity. The solution to the problems caused by urban sprawl is a densification of the built environment. Studies reveal that compact, mixed-use, and high-density development served by public transit produces lower carbon emissions than conventional low-density suburban development (e.g. Senbel and Church, 2011).

Densification remains a heavily contested concept (Quastel et al., 2012) and its complexity and multidimensional view causes misinterpretation among practitioners and proponents of densification. Due to the many interpretations, densification often leads to conflicting requirements and different results. Despite the benefits that urban densification projects bring, these kind of projects are often socially conflicting and require planning strategies and solutions that are tailored to the local context and respects the residents' local experiences (Kyttä et al., 2013). Furthermore in order for cities to accommodate an increasing population, socio-economic changes need to be taken into account than simply providing housing and promoting densification (Turok, 2011). Density is one of several components to achieve a more sustainable urban environment. Overlooking other important factors such as distribution of employment opportunities and planning of transportation systems reduces the potential for lasting sustainable solutions (Dodman, 2009). Urban development projects have negative effects and the likelihood increases when sociocultural dimensions of the urban environment are not taken into account. Thus, if the compact city is to be adopted, urban infill such as housing must be tailored and comply with the people's perceptions about the developed area (Vallance et al., 2005). Densification as the means to achieve sustainable development has faced increased opposition from residents, community groups and social activists concerned with gentrification and housing affordability (Quastel et al., 2012). Moreover, the goal to achieve compact transit-oriented urban environments is seen by residents and other stakeholders as a vision that is imposed against their wishes and without their consultation (Senbel and Church, 2011). To create attractive cities where people from different socio-economic backgrounds can cohabit requires new and improved services, amenities and public spaces that are tailored to the needs and desires of a wide range of stakeholders. Furthermore, it is proposed that a participatory planning approach can contribute to enhanced cooperative relationships and help create more stable and cohesive sustainable communities (Turok 2010).

3.1 Densification process in Sweden

The population continues to increase in urban areas and there is a clear trend towards densification of cities. Moreover there is a trend towards mixing different functions: living, commercial, work and leisure activities. Parts of most of our cities undergo transformations related to commercialization, land use and increased density of buildings. The fact that an increasing proportion of the Swedish population lives in urban areas has resulted in the development of cities to achieve the national goal of sustainable development. A recent parliamentary report notes that densification and increased mixing of the city's various functions is a current trend in today's urban development (Swedish Parliament, 2011). Concentrating cities increases the resource efficiency in several ways (Hansson 2011, Swedish parliamentary investigations, 2012).

The Swedish National Board of Housing, Building and Planning monitor the function of the legislative system and proposes regulatory changes: they also represent Sweden in the European Commission. In 2012 they published their vision of Sweden in 2025 (Swedish National Board of Housing and Planning, 2012). In this vision, one of the ways to achieve a more sustainable living environment in and surrounding cities is through densification. There are also plans for densification in local regions (WSP, 2013). Each of the three largest cities in Sweden - Stockholm, Gothenburg and Malmö - have developed individual plans for densifying their built environment (Ståhle et al., 2009, Brunnkvist et al., 2014 and Jönsson et al., 2010). From these documents, it is clear that there is a governmental, regional and municipal willingness in Sweden to densify. Several of the key factors in the concept of densification are mentioned in the documents such as: local business, improved infrastructure, more efficient recreational space, reduction of car traffic and increased pedestrian and bicycle traffic. Nonetheless, these documents do not fully explain how and why these measures are necessary to achieve a more sustainable development, neither do they explain the positive and negative aspects of densification in cities.

4. Methodology

The research reported in this paper used interviews as the main mean of gathering data. A total of ten interviews were conducted with people who are actively working with densification projects and stakeholder participation. Ten interviews were conducted with city planners, civil servants, municipal developers, facility managers, private developers and housing cooperative members. In order to obtain realistic knowledge of the current practice of stakeholder participation in densification projects we needed a method of data gathering which allowed a more flexible approach than most methods offer; therefore we chose interviews as the means of data gathering (Alvesson, 2011). Semi-structured interviews allowed us to gather their experience and observations through a partially open discussion about the subject, thus providing richer descriptions than if we had used another means such as questionnaires. Because the interviews are semi-structured, data are both inductive and qualitative. A data-driven coding of the interviews was chosen as suggested by Kvale and Brinkmann (2009).

The transcribed interviews were structured in a bottom-up approach in four steps: transcripts (bottom), codes (lower middle), categories (higher middle) and themes (top). The transcripts are the written interviews. The codes are short and like keywords they summarize a sentence or a small paragraph, thus reducing each transcript from a few pages to something like 30 codes. When categorizing the codes, we searched for links between the codes, where each category consists of a few codes. Finally, we searched for overarching themes for the categories, searching for relations and synergies between our categories. Thus, we created explanations that are logically compatible with our set of data. The results and analysis of the study are structured under seven themes identified from the interviews.

5. Results and analysis

Theme 1: Challenges and opportunities for urban densification

The majority of the project proponents said that when densifying in existing areas, ideal land for development is usually on existing hard surfaces, parking space or demolished building sites; however densification can also occur on existing green areas. The challenge for project proponents is to strategically choose potential areas for densification by selecting areas not used efficiently and not those cherished by the residents. Densifying in green areas that have a significant value for the residents could result in a strong opposition towards the densification project. Another challenge related to densification in existing green areas is that of high-rise building to increase high-density environments. One interviewee stated that high-rise housing development requires larger areas around the buildings which can result in dysfunctional areas. Moreover, high-rise building can create wind problems and blocks access to direct sunlight, which people may find objectionable.

Many of the interviewees stated that densification does not lead to sustainable development in general and there is uncertainty about what densification will lead to. Doing densification on a sustainable basis varies and it is after several years that one can see if densification has been successful or not. Nevertheless, the project proponents have a shared view of the opportunities and advantages to a denser city; these include the reduction of car traffic, increased use of public transport and increased attractiveness of the area.

The majority of the project proponents felt that densification has the potential to convert homogeneous residential areas into more attractive areas by filling gaps and deficiencies through a mix of housing types and functions. These, in turn, can bring a better socioeconomic mix of residents and high-social diversity.

Theme 2: The Importance of collaboration among a wide range of stakeholders

Another key theme that emerged from the interviews is the need for a wide range of stakeholders to collaborate in densification projects. The project proponents seemed to share the view that urban densification is complex and requires innovative solutions in the allocation of land and functions; therefore, planning for sustainable solutions should be given appropriate time and resources. According to some of the interviewees, it is uncertain if urban densification will lead to sustainable development, although it has the potential to do so. Densification strategies were implemented in the areas affected by the “million homes program” built in 1965-1975, with the purpose of revitalizing them to make them attractive by solving the prevailing inefficiencies. At the same time, there are political goals for doubling the housing stock in these areas. The complexity of densification projects rises when these are developed in existing built-up areas. Because of the increased complexity, it is vital that a wide range of stakeholders are involved in the development of local plans. The process may require more time and resources, but the end-result will be better.

Theme 3: The Swedish Planning and Building Act and stakeholder participation

The majority of the interviewees linked the stakeholder participation process to the Swedish Planning and Building Act. The Act states that when a proposal for a development plan is drafted, the municipality should consult a wide range of stakeholders who have an essential interest in the development plan. The purpose of consultation is to give stakeholders an opportunity to influence and provide insights to the decision-making process. A number of public officials in charge of procedural planning issues have made strong efforts to engage stakeholders from the different city planning administrations in the planning process. In addition, initiatives for dialogue have been employed to engage other stakeholders outside of the organization such as developers, land owners, property owners, contractors and the public. Stakeholder groups such as citizens, co-operative tenant owners, residents and community organizations are traditionally involved during the public consultation period when municipal officials present and inform them about their plan proposals.

Stakeholder participation initiatives differ among the various municipalities. While some municipalities have focused on trying higher levels of participation by means of different methods and activities of engagement, other municipalities have focused on following what is required by the legislation in the public consultation period. The period is a minimum of one month with one public meeting where public authorities present the plan proposals in front of a wider audience. Even so, public meetings are insufficient as there is a risk that conflict may arise from a discontented public which may need to employ other means of dialogue. Another challenge is that certain groups of individuals often dominate the meeting while other groups do not dare, or bother, to participate.

Theme 4: Stakeholders and purposes for stakeholder participation

In general, the interviewees pointed out that it is vital to involve a wide range of stakeholders at different levels and stages of development projects. Planners have made efforts to engage with property owners, land owners, developers and different administrations in the municipality early in the planning process. In addition, efforts have been made to collect the opinions from the community within the affected areas. Housing and commercial developers, as well as facility managers, highlighted the importance of engaging with a wide range of stakeholders early in the development process.

Further, it was mentioned that opponents to the project and their concerns needed to be considered early in the development process. The developers and facility managers mentioned that they had made efforts to engage with residents, costumers and businesses. Although there is an interest in involving a wide range of stakeholders early in the development process, it can be challenging for municipal organizations and property development companies to identify and engage residents, neighbours, potential residents and community organizations.

Theme 5: Individuals and groups experiences and abilities as driving forces for stakeholder participation

Another key theme that emerged from the data was the individuals' and groups' abilities to leverage support in the organization to conduct stakeholder participation processes in planning and projects. From a city planner's perspective, certain project leaders and project groups in charge of planning processes were identified as strong enablers of more ambitious stakeholder participation processes that aim to engage a wide range of stakeholders. These participation processes are generally implemented in parallel with the public consultation procedure which is mandated by the Planning and Building Act. The majority of the interviewees from the municipal organizations reiterated their determination to perform such ambitious participatory processes on an individual level rather than on an organizational level. This driving force is linked to the individuals' personality, experience, interests and resources.

From a developer and facility manager perspective, individuals and groups within the organization have developed methods and strategies for participation in the development and refurbishment of facilities. These initiatives include methods for different levels of participation, customer plans and activities to get to know their customers and residents. Most of these initiatives are implemented in small scale projects or renovation and maintenance.

Theme 6: Stakeholder participation practices, contribution, enablers and challenges to the organization

The municipal organizations interviewed have recognized that in certain cases, traditional public consultation practices are not enough and demand new methods and practices to involve stakeholders. Civil servants within the municipalities have a shared challenge of conducting extra activities as public consultation can demand more than one public meeting. Such activities vary and can take the form of engaged focus groups, meetings and outreach in the neighbourhood to inform people about the planned proposals. Furthermore, the majority of interviewees stated that they are trying to move away from the traditional practices of one-way communication to more engaging forms of participation. Some of the interviewees explained that recently, they had started to influence the design of public consultation activities to include more engaging practices. For example, instead of holding a presentation of the project in the form of one-way communication, they hold dialogue forums, workshops and transect-walks in the affected area. These activities have proven to be highly beneficial as they facilitate better dialogue between the stakeholders and help to increase mutual understanding and knowledge about plan proposals. Moreover, there is an ambition for the municipality to inform and engage more stakeholders, especially those on the periphery of the decision-making process. These efforts include the distribution of invitations and information through different means of communication.

Early involvement has been identified by the interviewees as an important factor to successful stakeholder participation. The involvement of stakeholders in the early stages of the development process can contribute to good dialogue and lead to positive effects such as better project outcomes and legitimacy. On the contrary, not involving stakeholders early in the process can lead to conflicts and resistance to the desired change. According to an interviewee from a property development company, actions to involve the residents and other affected stakeholders are taken during the later stages of the project with the purpose of seeking project acceptance. However, there are plans to work more proactively by involving stakeholder groups earlier in the process.

Proactive actions to stakeholder participation in new building production seems to operate at an information level where meetings are held to present plan proposals to tenants and residents as well as to listen to their opinions. Some of the reasons for the information levels of participation are the project complexity and the decision making process. It is the public consultation period in the formal planning process where the residents, neighbours and other affected stakeholders have the possibility to provide their comments on plan proposals.

According to the interviewees, some of the challenges to participation processes are associated with the lack of experience from stakeholders such as residents and neighbours to work on this set. Consequently, the lack of experience and understanding of participation processes makes it hard for these stakeholder groups to understand the motives of the process, their contribution, procedural practices and a visionary perspective. Furthermore, participation processes can be time consuming and there is a risk for participants to suffer from participation fatigue. In addition, the inability to implement the outcomes of participation processes in a short time can cause disillusion among participants for not being able to see their contribution implemented in a short period. The lack of experience in development processes and time consuming development practices can make it difficult for participants to handle participation processes.

Theme 7: Institutionalizing stakeholder participation

Another key theme that emerged from the interviews was the need for stakeholder participation to be part of the organizational culture to leverage support to the institution. It was pointed out that without the support of management; it is difficult to introduce new working practices and new ways of thinking in the organization. However, there have been cases where ideas originated from grassroots' levels in organizations have influenced managerial practices. It was pointed out that stakeholder participation initiatives and competences remains at an individual level within organizations; thus, it is vital to collect and systematize these practices in order to make them part of the organizational culture.

The interviewees seemed to share the view that stakeholder participation requires reshaping the way that institutions are organized and further identified different suggestions and capabilities to achieve this. Furthermore, it was mentioned that it is essential that project initiators feel able to apply stakeholder participation practices and further inspire individuals in the organization to believe in it by showing the benefits achieved from conducting early stakeholder participation. Another suggestion is the need to build on existing competences in stakeholder participation practices within organizations. One way is to conduct participatory approaches in small scale projects to acquire a foundation of practical knowledge and skills that are essential when working with all types of projects. In turn, the outcome of this knowledge development can contribute to the organizational culture.

6. Conclusions

Efforts have been made to implement collaboration platforms to engage various stakeholders in urban development processes. These range from external dialogue processes with private actors and community groups to internal dialogues to coordinate the interests of different administrations in municipal organizations. It is also evident that municipal organizations follow the Swedish Planning and Building Act procedural requirements to coordinate the interests of the general public in formal planning processes. Moreover, developers also depend on the legislation procedures to engage the general public in the development process. However, the lack of clear guidelines in the legislation on how to conduct a stakeholder participation process requires municipal organizations as well as developers to conduct participation processes in parallel with the procedural requirements from the legislation. These proactive measures are the result of municipal organizations' initiatives as well as joint collaborative actions where municipalities, developers and even the community sector have joined forces to conduct stakeholder participation processes.

From the developer's perspective, the project manager has the responsibility to identify and manage the various interests that will influence the project. On commercial building projects, customers are involved early in the development process as opposed to new-build housing projects. It is a challenge to involve future residents in the development of housing projects as they are often unknown. However, it is more common to involve residents in housing renovation projects as the users are known. According to developers, it is important to involve residents and the public in the making of plans and proposals. Failure to do so can create mistrust about the plans and further bring opposition to the development project. Furthermore, it was important that the formal planning process is able to balance and coordinate the interests from the developers, the wider public and other stakeholders.

Municipal officials recognized that when conducting a planning process they should consider all potential stakeholders right from the start. Today, municipal officials are discussing the involvement of a wide range of stakeholder groups, especially those that are normally underrepresented early in the planning process such as residents, local organizations and citizens. Therefore, it is vital to be open-minded when identifying and involving the stakeholders. Developers have also recognized the importance of involving known and unknown customers, residents and authorities, as well as possible project opponents to get their input early in the planning process to increase the quality of plans and projects. It is believed that the outcome will be a more efficient project process in terms of quality, time and cost.

Due to the complexity of densification projects and the requirements with respect to sustainable development and climate change, traditional public, private and community sectors roles will need to expand. Different sectors will be required to collaborate in their developmental activities in order to reach solutions that comply with the needs and concerns of various stakeholders and those responsible for the environment. A collaborative approach to stakeholder participation that combines forces between the public, private and community sectors will be necessary. The next step of the research will be to conduct a study of the practice of stakeholder participation in urban densification projects in Scandinavia and further evaluate best practice stakeholder participation processes.

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Identifying client roles in mainstreaming innovation in Australian residential construction

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Abstract

Adopting sustainability as an innovation in the Australian residential construction sector is constrained in an industry characterized by mass produced standardized new home production. Traditionally perceived as supply-led the residential construction procurement model inhibits the ability of consumers to demand change, or for innovation to be consumer demand-lead.

This research adopted Heywood and Kenley's consumption-based demand and supply model for corporate real estate as a framework for understanding the roles and relationships in the Australian residential construction industry, in particular the volume homebuilder as a key client for innovation from its supply chains.

The investigation provides an informed understanding of demand and supply-side structural relationships in the residential procurement process. The research identifies how innovation and change, particularly towards more sustainable homes, can be enabled through the Australian residential housing industry's current mechanisms.

Keywords: Australia, clients, demand-supply model, innovation, residential construction

1. Introduction

The Australian residential construction sector produces over 180,000 dwellings worth AU$33 billion per annum (HIA, 2014; Australian Bureau of Statistics, 2014) and is also worth approximately 4% of Gross Domestic Product (Dowling, 2005). Currently sustainability's limited wide-spread incorporation constitutes an innovation inhibited by industry structures – a mix of relatively few large Volume Builders and relatively many small or micro businesses. Small construction business' innovation was studied by Thorne et al. (2009) and while small firms can innovate with sustainability, by market share their effect is minimal. If large-scale innovation by way of sustainability is to be achieved then engaging with mass production players and processes is necessary.

While there is debate about costs of sustainability and consumers' willingness to pay, Australian consumers have shown a propensity over many years to pay for additional 'lifestyle' features that do increase housing costs. This was seen in the 1970s' and 80s' with the inclusion of 'rumpus room' innovation offering visions of bucolic family recreation and in more recent innovations features like 'media rooms', 'alfresco' outdoor dining areas, and parents' retreats offering similar visions. Whether these are 'demanded' by customers or 'supplied' by providers as part of their competitive strategy is an open question for this paper. Nevertheless, given this consumer propensity this research proposes that sustainability innovations can become latent demand by the way they are incorporated into product offerings, particularly those from Volume Builders.

This suggests a new perspective is needed to examine the key stakeholders that can enable and drive change through the construction-property supply chain, whilst engaging the end-user, the housing consumer, in the process to create latent demand for sustainability. That perspective is provided here by applying Heywood and Kenley's (2010) consumption-based demand and supply model to the Australian residential sector to isolate opportunities for innovation and sustainability's integration into mainstream provision of housing in Australia. Three case studies demonstrate this model's effectiveness and to draw out key elements of the model's application.

2. Volume Builders in the Australian Market

Large Volume Builders are dominant housing suppliers across Australia, though much is made in the literature about the number of businesses in the industry – 320,000 cited by Dalton et al, (2011a) and 30,000 by Dowling (2005) – and their small size – an average of 1.4 and <2.5 employees, respectively. Volume Builders are the sector's powerhouse providers as can be seen in their market share and economic performance. Over different but overlapping ten year periods the top 100 builders accounted for between 37% and 41% of all new housing (Dalton et al, 2011a; Dowling, 2005). Within that top 100, the top 20's share was typically between 56 and 61% and the top 5's share was about 40% of the top 20's share and increasing over time (Dalton et al, 2011a). By economic performance, businesses worth more than $10 million averaged operating income per employee of more than $1.2 million compared with $0.15 million for the many small businesses valued between $100,000 and $500,000. By economic value adding these large firms do so at 4.0 times the rate of the small firms (Dalton et al, 2011a, Figure 38). Taken together, these characteristics point towards an oligopoly operating (Coiacetto, 2006), despite the plethora of small to micro-firms in the sector. Oligopolic behaviour is evident in the Volume Builder's ability to tell housing consumers what they want, how they want it and they do this by providing limited choices to maximise efficiencies of scale and profits (Reardon, 2013). In Australia though, this is subtly disguised as marketing a 'lifestyle', as evidenced by trends in various additional features that have been offered over time.

Typically, the process of buying from Volume Builders does two things. One, it reflects Volume Builders' dominant competitive strategy which is to create a standard set of plans, often containing attractive 'features', with some choice in materials, finishes and options enticing consumers to build with them, whilst providing what appears to a wealth of options (Barlow, 2003, p. 92; Dalton et al., 2011b). Two, is to give infrequent purchasers with limited knowledge of residential construction processes, a sense of empowerment while guiding them in their choices of dwelling, features, finishes and certainty of the price and product to be delivered (Barlow et al. 2003; Dalton et al., 2011b). These houses can be built as 'speculative' houses often as 'display homes' ahead of customer purchase or in response to customer orders (Dalton et al., 2011b).

Traditionally and theoretically (as discussed below), Volume Builders are considered as part of the supply of housing products procured by consumers. However, their relationship and interaction with other stakeholders suggests otherwise. Their size and market dominance means they can dictate to consumers and the other stakeholders in their supply chain (up to 108 trades and suppliers exist in this supply chain (Dalton, et al., 2011b, Tables 3 to 9)) their needs, requirements and to an extent price commanding cost efficiency, quality and timely delivery. The power relationship is established in the quantity and size of financial contracts with their supply chain which are not for a single house, but for 100s or 1,000s of homes. Consequently, for the trades and the suppliers (some of those 30,000 or 320,000 business noted above), this contract maybe their sole business. As a result, the requirement to perform in terms of cost, quality and time is imperative to maintaining their contracts. The Volume Builders also have a power position in choosing suppliers and trades, with a few notable exceptions where some products, like Colorbond metal roofing material, have sole or limited suppliers.

The standard residential building process in Australia comprises a variant of the *Design and Construct* procurement approach. This is utilised generally across the industry from the small contractors meeting localised demand (traditional 'Master Builders') to large state or national businesses (Volume Builders) operating across several geographic regions. Innovation in this model, theoretically, can originate from consumer demand but more realistically is dependent on the contractor, or to a lesser extent their design consultants. This is indicative of engagement in innovation within the construction sector which commonly focuses on supply-side initiatives with relatively limited evidence in the construction literature examining the consumer and client perspectives. Tombesi (2006) explores procurement, mainly in the commercial sector, and discusses stakeholders' engagement in innovation, their different roles and innovation's integration into the supply side. He also examines consumers', clients' and users' different roles in terms of their engagement in innovation. This has implications for understanding the residential property sector and its adoption and production and integration of sustainability in new home production.

This contemporary Australian approach to new housing has proven problematic in mainstreaming sustainability in new housing (Pitt & Sherry, 2014). However, if viewed with a different lens, opportunities can be identified where sustainability and innovation can be integrated into the system that drives change in products available to end users and down the supply chain. This may then achieve long-term change within the sector. This suggests that a revised model for the relationships in new housing is required and will be useful in mainstreaming sustainability.

This research focuses on the broad scale practice in the residential property industry which is dominated by Volume Builders. Innovation in the residential property sector is either, incremental – channelled indirectly from homebuyers' preference for products, or mainstream in response to mandatory requirements and legislation. However, to engage in sustainability's incorporation into housing's mass production, a new perspective is needed to examine the key stakeholders that can enable and drive change through the supply chain, whilst engaging the end-user, the housing consumer, in the process to create latent demand. This involves understanding the roles of key demand drivers in the residential property sector and how that different perspective creates levers to drive sustainability as innovation in the sector.

When viewed from a power dynamics perspective founded in the oligopolic industry structure and the Volume Builders' substantial financial and contractual power with supply chain stakeholders, Volume Builders shift from the supply-side to a key demand-side stakeholder. Then they actually operate as a sophisticated 'client' in the supply chain in their procurement relationships for construction products and services. Consumer demand theory supports this approach (European Commission, 2012), where the Volume Builder as a key demand-side stakeholder will and does have the opportunity to drive change, in this case the ability to mainstream sustainability into the volume housing sector. Therefore, the research proposes that both the homebuyer and the Volume Builders are demand-side stakeholders; with the homebuyer being the ultimate housing consumer or user (Figure 1).

3. Method

Based on the dominant procurement model in Australian residential construction, its power relationships and consumer demand theory this research proposes that Volume Builders shift from being part of the supply side as assumed in typical *Design and Construct* models to a key demand-side stakeholder. This suggests that a revised model for the relationships in new housing is required and will be useful in mainstreaming sustainability (Figure 1). This alignment of key demand stakeholders has been adapted from Heywood and Kenley's (2010), commercial property framework which identified an '*Integrated Consumption-based Demand and Supply Framework*'. It has been modified here to reflect the new residential property sector.

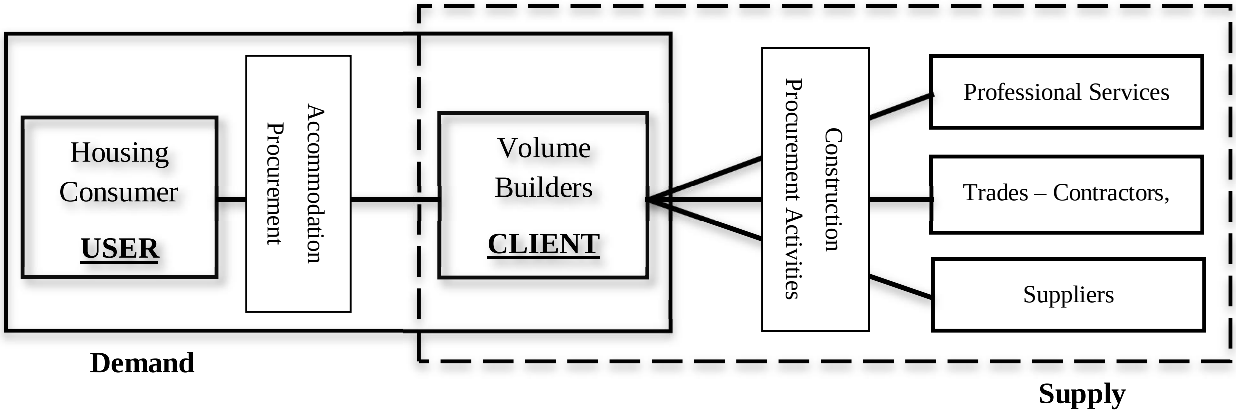

Figure 1.A framework for demand and supply players and relationships
Adapted from Heywood & Kenley (2010) Figure 1.

The research investigates whether a consumption-based demand and supply framework is applicable in the residential building sector; whereby demand stakeholders include both the home purchaser as the ultimate consumer (User) and Volume Builders as the Client. It is imperative to understand stakeholders' roles and relationships in order to develop an appropriate and effective framework to enable innovation towards sustainability.

The research uses semi-structured interviews with the Volume Builders that include process mapping where participants are asked to graphically depict and describe their organisations, roles and responsibilities; contractual, product and customer relationships; and the flow of information and power associations. This shows, on analysis, the various structural relationships in their procurement models and identifies how innovation and change are enabled through the current mechanisms operating in the residential housing industry. This paper is from a research project in progress. Consequently, the model is explained using three revelatory case studies (Yin, 1994) representative of different types of mainstream, Australia-wide Volume Builders. The first participant is classified as a 'Community' Volume Builder where they develop whole communities integrated with housing products, hereafter referred to as VB1. The second is a smaller scale Volume Builder that is a franchisee of a major Volume Builder group that provides single houses for individual land parcels, and is hereafter referred to as VB2. Finally, a smaller Volume Builder (VB3) who specialises in sustainable dwellings described their key drivers and inhibitors in mainstreaming sustainability in their building process. VB3 is an interesting case, because they were a traditional style builder in a small town. However, when the town suddenly underwent substantial growth (mining town – the opening of a new mine and requirements for lots of new housing), the Volume Builders arrived in town. VB3 found themselves without work, so in order to differentiate themselves to win work they began incorporating sustainability initiatives as standard into their homes. This was very successful in their region and they have subsequently expanded Australia-wide with their housing/business model.

4. Findings and discussion

4.1 Australian Volume Builders' approaches to home building

The case study Volume Builders exhibited approaches to home building consistent with the analysis above about the sector's nature. In their relationship with housing consumers, consumers were offered limited choices from standardised options, in effect dictating to consumers what they want and how they want it, whilst providing controlled choice. For example, in the case of VB1, as a consumer, you can choose a dwelling in their development – a three, four or five bedroom home. There may be a choice of facades and internal finishes, however, for the consumer that is where the choice ends. VB1 designs, builds and develops that dwelling without further discussions with the housing consumer. VB2 and VB3's approach is to have a standard set of plans, with options for facades, internal finishes, and other options. However, VB3 as a standard then takes the consumer's selection and ensures that the site selection and the dwelling envelope achieve passive house design standards and maximise opportunities for sustainability and energy efficiency. Whichever approach is used, the Volume Builders provide a standard approach to the provision of various forms of plans, façades, interior features and the like. Essentially this is what would appear to be a wealth of choice, from the purchaser's perspective. Only VB3 actually considers, as a standard in their housing process, the dwelling's siting on the lot and ensuring a high quality, more efficient home. However, if a unique, let alone an innovative home is requested or there are changes to the standard set of plans, this incurs substantial cost to the homeowner, regardless whether it was VB2 or VB3 and in the case of VB1 it was not possible at all. Consequently, the user has limited demand power, and influence is only achieved indirectly through preferential choice of products supplied. There is greater discussion and communication of requests in the case of VB3 and to a lesser extent VB2, whilst no option at all in the case of VB1. VB1 did indicate they do a lot of market analysis and customer surveying to identify what consumers are seeking. However, if consumers are unaware of what could be offered, if they are uneducated how do they know what to direct the Volume Builder to incorporate in such surveys.

4.2 Roles and relationships: Demand-side

With the paucity of end-user capacity to demand change and sustainability, the cases show that the housing consumer (user) is not the only actor in the 'demand' phase of the residential building process. This is clearly expressed by responses from all three Volume Builders, in that they saw their customer as the user who was seeking a finalised product/package in the form of a completed dwelling. This contrasts with traditional theory that the housing consumer is essentially both the user and the client (see for example Boyd &Chinyio, 2006; Love, 2002; Wilkinson & Schofield, 2003). This research supports Tombesi's (2006) classification that the housing consumer is the customer of the Volume Builder and is the end user, choosing a 'known' product from a selection of products which only indirectly affects supply products through preference selection.

This supports this paper's proposal that in current Australian residential building processes the Volume Builder is the actual client. Clients are the initiators of the project (Atkin and Flanagan, 1995). Tombesi (2006) concurs that clients 'prescribe the program, set the characteristics and define the ideal traits of what is yet to be produced' (pp. 277).This is supported in the evidence.

VB1 clearly identifies this role for themselves in the development, designing and production of their homes. They saw themselves as initiators; they clearly define the programme and traits of the development and homes that they produce. VB1 have minimal options allowable beyond colour option selections which align with a profile of choices throughout the dwelling. VB2, due to how they operate within the sector, provide more options and choice to the consumer, however, *“the purchaser doesn’t deal with the contractors, we deal with the contractors.”* When asked how their organisation operates VB2 drew a diagram very similar to the Figure 1 framework.

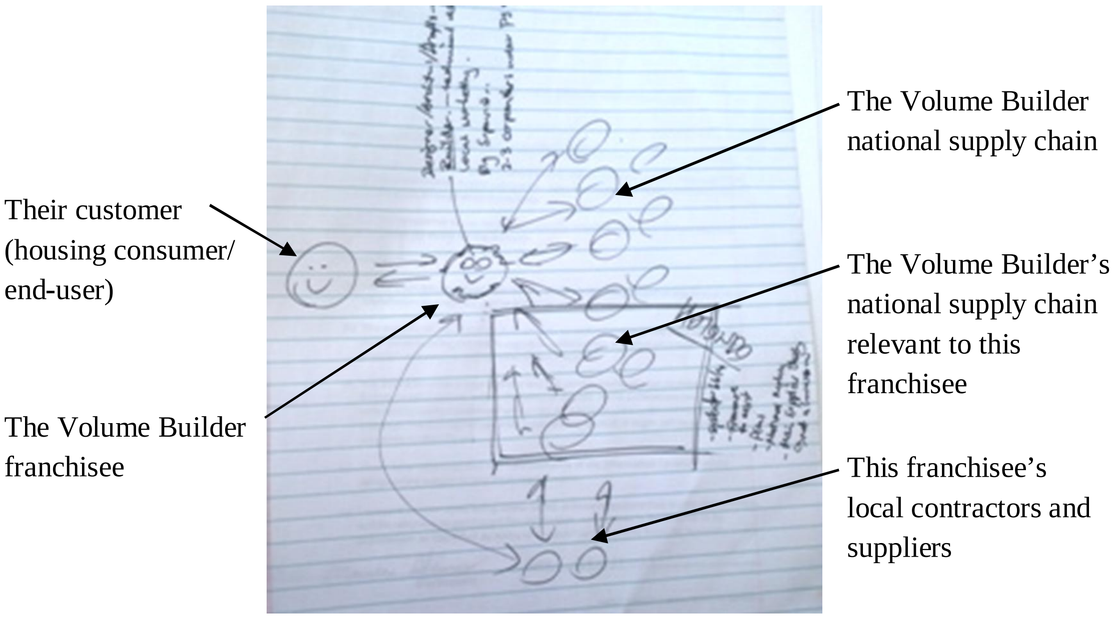

Figure 2 Volume Builder 2’s process map

The Volume Builders interviewed agreed that while the consumers sought out their business, they (the Volume Builders) had the ultimate control of the dwelling development, with contracts with various suppliers and contractors which were utilised to build more than one dwelling. Their supply side contracts were large and significant. Whilst VB2, due to its franchise status, had an interesting set up, whereby a number of the material supply contracts (like metal deck roofing, roof tiles; plasterboard) were negotiated and organised by their head office, all contractor type work was undertaken at a local level with contractors and some material suppliers. However, VB2 stated the local engagement was built on long, trusting relationships and consequently they had only one or two key preferred contractors for particular roles within the area; so all work would be done by those contractors. Interestingly, VB3 found their customers tended to by 2nd or 3rd homebuyers who were generally older, heading for retirement, were fiscally driven and had a rational conscience. Although these homebuyers did not use the term ‘sustainability’ they saw and preferred the services of VB3 because of the realities of cost minimisation in a quality product. As VB3 had difficulties communicating and attracting first home buyers in their markets, it was surmised by VB3 that first home buyers were attracted to the cheapest, base options provided by the general Volume Builders.

Similarly, under consumer theory (European Commission, 2012) Volume Builders were shown to be empowered with the ability to be knowledgeable or to bring the knowledge to drive the market for change, given the right motivators – financial and marketing edges. This was demonstrated by VB3 who in a market with substantial competition, found their edge in the market by differentiating through offering a more sustainable product. They approached their suppliers and contractors and indicated what they wanted to do and were able to negotiate excellent rates which meant that costs of moving to a more sustainable product did not demonstrate significant additional costs. Their existing relationships and contractual agreements meant that VB3 were able to bring sustainability innovation into the new home building process, and due to the collective approach of the demand side (in conjunction with their own consumer demand), VB3 provided the mechanism to drive the change. The common perception of Volume Builders in the sector is mass production, minimal cost, high profits, which makes it challenging to encourage changing their approach. However, as demonstrated by VB3 to gain a competitive edge over competitors' sustainability innovations provided the ability to attract more consumers to their products, whilst providing "*houses that look like, feel like those provided by the other builders, but are more energy efficient*" (VB3).

Consequently, this construes the Volume Builder as the client responsible for demand creation in the supply chain while providing product to the individual user or housing consumer. The Volume Builders' contractual and financial relationships with the supply chain are the demand forces of production requirements. Due to the nature of the Volume Builder's supply chain relationships there are no singular contracts for one house, but an agreement for the mass production of multiple homes. Due to this size the Volume Builder really is the essential 'consumer' and the one who has the control in the building process, as they can dictate to the supply side what they want and how they want it.

4.3 Roles and relationships: Supply-side

As discussed above, Volume Builders are the key demand-side stakeholder, as clearly demonstrated in the Australian residential property market as an oligopoly; where, as oligopolic players, they behave and move together offering comparable products, limiting and minimising consumer choice. Consistent with that in their relationship with the supply-chain, they wield enormous power in terms of their relationship, requirements and innovation.

The current design and construct theory presumes a singular contractual relationship between the housing consumer and the builder with numerous contracts with the various supply-chain stakeholders (Wilkinson and Schofield, 2003). All three case study participants confirmed this aspect of the contractual relationship; consumers entered into a single contract with the Volume Builders, to produce a single dwelling. However, current practice in the Australian residential property sector differs from the theory, in that Volume Builder supply-chain contracts are generally not for a singular dwelling (project) but for potentially hundreds of dwellings. Again, all Volume Builders confirmed the relationship between themselves and their suppliers and contractors, in that arrangements existed in the building of multiple dwellings. So, the contractual agreement financially is significantly larger overall than the contract between the housing consumer and Volume Builder. Consequently, this transfers the power balance to the demand side, as the Volume Builders can dictate to an extent their requirements to the supply chain stakeholders. Although Thorpe et al. (2009) suggests innovation from the supply side is limited and the upwards push from it is often met with substantial limitations. This is particularly so in the aspect of knowledge transfer, where it was discovered here that suppliers will tend to approach and display new products to the Volume Builders. However, the engagement with the product was limited, unless the Volume Builder saw a direct reason or purpose for the product or suggestion to be included (VB2). More often, the Volume Builder took the role of initiating the need for innovation and would contact the supply-side stakeholders – be it material suppliers or contractors and seek their advice and whether they could supply and at what price (VB2). VB1 also indicated a similar approach. However, they would approach supply-side stakeholders with a ‘problem’ rather than general requests and innovation would evolve from problem solving rather than directly seeking ‘innovative’ ideas. However, both VB1 and VB2 indicated that if the product quality or price did not satisfy their requirements they did not engage with or utilise the product and would continue seeking appropriate priced or quality services or product. In this case, the Volume Builder can dictate their requirements, be it an innovative solution in the design and construction process, or a sustainability initiative, but it is up to the supply chain to supply the product at a price and quality acceptable to the Volume Builder, otherwise the Volume Builder will choose a different supplier or provider.

4.4 A framework for sustainability innovation

Recent research shows the Australian home building resists the wide-spread adoption of sustainability innovation for a variety of reasons (Pitt and Sherry 2014). Examples of those reasons can be seen in previous theorisation about the problem, which identified issues primarily with housing consumer-users' ability to demand through willingness to pay for such innovation. Issues have also been identified with the construction supply chain's capacity to 'push up' innovation into more sustainable housing. However, much of this previous work is limited because it examines only part of the system rather than as a whole. This suggests that a new whole-of-system perspective is required, particularly for mass produced housing which makes up a significant proportion of new residential construction in Australia.

This paper adapts a consumption-based demand and supply framework proposed by Heywood and Kenley (2010) to provide a whole-of-system perspective and as a basis for driving wide-spread adoption of sustainability innovation. The case studies tested the framework in the Australian Volume Builder context where the mass production of new housing occurs. On the basis of that testing it can be argued that the model is applicable and that it provides a basis on which to argue for its usefulness in mainstreaming sustainability innovation. It is applicable for several reasons. One reason is that it shows the Volume Builders' traditional theoretical positioning as a supplier of housing. For this study's Volume Builders their housing supply was restricted to standardised designs with limited opportunity for consumer-users to demand other than from a controlled set of options. A second reason is that it shows the supply occurring within a Design and Construct procurement system and a construction supply chain to support that system. In the Volume Builders' construction procurement the traditional assumption in Design and Construct theory of a unique supply chain for each construction contract was varied with supply-side contracts applying over multiple houses and in VB2's case multiple Volume Builder franchises. A third reason is the framework shows Volume Builders at the central position in the demand-supply system at the overlap between the demand and supply sides, a position that becomes crucial in the innovation argument. In that position the Volume Builders not only supply to consumers but also demand from the supply chain. This makes them the crucial client in the system.

This central position is key, formally or structurally, and also through power dynamics in the Volume Builders' demand-supply arrangements. From this position of knowledgability and the restricted product offering Volume Builders have a power to shape products supplied to consumer-users. From their contracting position with supply-side stakeholders, generally being small to medium sized operators, they have power over what is demanded from their supply chains. With this demand-supply framework formally showing the whole-of-system relationships and from knowledge of power dynamics it can now be argued that Volume Builders are the place where the drive for sustainability innovation needs to occur. This is in the creation of innovative, truly sustainable housing products to create a latent demand that allows Australian housing consumer-users, with a propensity to pay for perceived lifestyle, to take up a more sustainable lifestyle. It is also the place to demand improved products and construction practices to deliver the innovative, sustainable housing products. This was demonstrated by VB3 who used their power to drive sustainability through the supply chain, overcoming the commonly known barriers for sustainability like: cost, quality of product and quality of installation. Interesting, VB3 indicated that a lot of the efficiencies in the dwelling were resolved through increasing quality standards and requirements, using better materials and careful initial siting and design considerations; meaning minimal costs implications for the housing consumer.

By using this paper's demand-supply framework to change perspective on achieving sustainable new housing there are opportunities for using the power of the oligopoly in mass produced housing to drive widespread market change through the system. Often this has been the basis of past, regulation-driven approaches whereby it is thought that more stringent rules for builders will result in greater amounts of more sustainable housing. The Pitt and Sherry (2014) work show that the regulation-driven approach is not succeeding. A demand-supply approach utilised here suggests a more market-focussed approach could be useful. There is the capacity and ability to drive a more, innovative, sustainable product into the market place without incurring additional cost, providing a product that looks and feels the same as current conventional housing but is significantly more sustainable. The Volume Builders' strong relationships, contractual and financial power over the supply-side stakeholders means that should Volume Builders engage with and take the opportunity to mainstream sustainability initiatives into their housing provisions, the supply chain will then need to respond, which is clearly demonstrated by VB3's experience. The size and power of the Volume Builders means they can enable cost efficient solutions due to contract sizes and volume of houses. This should mean that issues identified by homebuyers, like cost effectiveness and quality of workmanship and product, can be achieved through the actions of the Volume Builders in mainstreaming sustainability.

5. Conclusions

This paper examined key stakeholders' roles in mainstreaming sustainability innovation in Australian residential construction – particularly for mass produced housing where Volume Builders dominate to the point of constituting an oligopoly. The demand-supply framework proposed a whole-of-system approach which was confirmed in the case study firms showing Volume Builders occupying a central, powerful, demand position and acting as the 'real' client in driving innovation. From that central position there are also opportunities to innovate and supply more sustainable housing and through their market power and scale to mainstream sustainability in their products offered to their customers.

An ongoing project using practice evidence from Australia provided the basis of this paper. The cases analysed here are revelatory of the phenomenon in Australia and have generalisability from that revelatory capacity. Work is underway to expand the number of cases to provide a larger representative sample of Australian Volume Builders. The framework considered here would also benefit from its use in studies in other countries' new housing supply to see how it holds there as a theory, generally, and for how it assists in mainstreaming sustainability as necessary innovation.

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Customer roles in a business ecosystem– A case study in health and wellbeing campus

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Abstract

Business ecosystem refers to a co-evolving, self-organized value constellation where mutually dependent actors create value propositions to diverse set of customers. Ecosystem customers can be characterized as multi-dimensional actors. They take part in the value creation and consume the value that ecosystem provides. This study examines how the ecosystem end customer requirements define the core set of service providers and their relationships in a health and wellbeing campus. An individual service provider's definition of customer may be different than the ecosystem's end customer, especially if the end customer role and involvement into the value creation is not deployed across the ecosystem. Identification of customer value consumption processes and the requirements relevant for the ecosystem value propositions provide a baseline for sustainable ecosystem planning. This study presents how multiple customer roles and logics define the scope of a health and wellbeing built environment campus in its start-up phase. We conducted semi-structured interviews of suitable campus resident candidates to identify the end customer requirements for the case ecosystem service elements. Ecosystem core service providers and their relationships were modelled based on the most relevant requirements. The findings of the study increase knowledge on how diverse actors contribute in different roles to the built environment ecosystem value, and how the customer relationships in the ecosystem can be modelled as tiers in the ecosystem hierarchy. The findings indicate a need to build deeper understanding of value proposal definition, and how the stakeholders' activities are to be aligned towards the end customer value processes. The study outcome emphasizes the importance of the central actor's role as an ecosystem key architect (initiator). Managers can use the findings to align internal activities with the business ecosystem's goals, to identify the ecosystem external drivers and to improve efficiency of the value creation processes.

Keywords: Business ecosystem, business in built environment, customer roles, value proposal.

1. Introduction

Business ecosystem as a concept to define interacting, self-organized and evolving value networks has different interpretations in academic discussion. Positioning the ecosystem concept with other value constellation models is not unambiguous. Ecosystems are not strictly defined, they are not systematically managed and they have multiple business and non-business actors either directly or indirectly impacting the value creation (Moore 1993; Iansiti & Levien 2004). Ecosystems such as Apple's developer platform emerge in fruitful conditions around new technologies or business models. They provide opportunities for business model adaptations and new business emergence (Moore 1998; Gawer & Cusumano 2014). Their emergence can be facilitated, but as self-organizing entities the evolution is organic based on actors' interdependencies, complementing capabilities and abilities to adapt to changes through innovations (Corallo 2007).

Value of business ecosystem is service driven as all actors – including the end customers- contribute actively to value creation and consumption (Vargo & Lusch 2004). Interdependencies between the actors involve customer relationships (Moore 1998; Corallo 2007). System level value of the ecosystem is defined by the end customer whose requirements and processes drive the value creation and consumption (Eichentopf et al. 2011). Service and customer dominant logic concepts illustrate how the customer internal processes determine their perception of the value (Vargo & Lusch 2004; Hakanen & Jaakkola 2012).

This study aims to illustrate business ecosystem as a customer centric value constellation. Modelling the ecosystem through the customer requirements is expected to identify different levels of customer roles in the ecosystem as the actors have different customers based on their position in the ecosystem's value process. The end customers' requirements define the system level value proposals and actors derive their requirements and relationship types by reflecting the requirements against their business models.

Built environment projects can be seen as bases for ecosystems where service providers co-operate to provide benefits for the end customers, the built environment residents. Value is created as joint activity when the service providers have complementing capabilities to consolidate unique offerings (Pinho & Fisk 2014; Frels et al. 2003). This requires transparency on residents' needs and requirements. Understanding the customer role hierarchy in a very early phase of a business ecosystem has positive contribution for efficient ecosystem planning (Aapaoja et al. 2013). Central actors who host ecosystems, or projects implementing them, can utilize this study findings as an actor planning framework. Involving the core service providers and complementing stakeholders through a customer tier based model improves efficiency for the campus design as a flexible and sustainable built environment that can support diverse set of people with health and wellbeing services.

The main aim of this study is to enhance understanding on stakeholders and their roles in ecosystems. For this aim we have set the following research questions: *Who are the service providers that should be involved into the campus ecosystem* and *how the customer relationships between residents and service providers form the ecosystem*. At first we review literature on business ecosystems, customer role in it and value for customer to outline how customer requirements can define an ecosystem. We identify and interview suitable resident candidates to determine most relevant requirements and their service providers. As a result we conceptualize ecosystem modelling from customer relationship perspective and contribute to business ecosystem application field and positioning in context of other network descriptions.

2. Business ecosystem customer definition

Business ecosystems as evolving networks consist of multiple actors. Interactions between actors are based on customer relationships where value proposals are transferred and consumed. The customer relationship type changes based on the actor position in the ecosystem. This literature review introduces key characteristics of business ecosystem concept, customer role in ecosystem and how value proposals are defined and transferred through customer relationships.

2.1 Key characteristics of a business ecosystem

Ecosystem concept was introduced into business by James F. Moore (1993) in his seminal paper "Predators or Prey". Business ecosystem seeks analogies from biological ecosystem to explain complex phenomenon and value constellations. For example a value chain of an ecosystem can be modelled as a supplier-customer network like a food web in biology. (Moore 1993: Corallo et al. 2007)

Business ecosystem is an extended system of mutually impacting and evolving organizations. Indefinite timing, dependencies between actors and self-organization extend the ecosystem to be a wider concept than value constellation models like business networks or value chains (Iansiti & Levien 2004; Moore 1998). Ecosystem actors interact with one another either directly or indirectly to produce goods and services. Ecosystem actors share a common goal and are dependent on each other in contributing towards it (Gossain & Kandiah 1998). Successful business ecosystems have novel end user value, economies of scale, continuing innovation and willingness to invest to expand with allies. Ecosystem boundaries are not explicitly determined and the contributing parties change over time (Moore 1998).

Ecosystems as interdependent actor networks operate on service dominant logic, where service is defined as application of specialized competences through deeds, processes and performances for the benefit of the acting entity or another entity within the scope of the ecosystem (Vargo & Lusch 2004). Sharing of knowledge, focus on system level customer experience and managing interfaces with stakeholders as continuous processes are elements from the service dominant logic that support the business ecosystem concept (Moore 1993, Vargo & Lusch 2004).

2.2 Customer role in business ecosystem

Each ecosystem actor operates in a customer role through the relationships they possess with each other. Customers that consume the system level value proposition and participate into creation of it are considered as the ecosystem end customers. Pinho & Fisk (2014) identified three types of interdependencies between ecosystem actors: dynamic role interdependency (roles change), temporal interdependency (interactions occur sequentially) and self-interdependency (value creation depends on actor's own actions). The distinctiveness and nature of interdependency has implications into designing of actor roles in the ecosystem.

Success of a business ecosystem is defined by its capability to deliver unique value for the end customer. End customer participates into the value creation through personalized interactions with the ecosystem service providers. End customer feedback and its deployment over the ecosystem drive co-evolution. Co-evolution is essentially about triggers from the end customer that travel through the population and cause new triggers to be sent. (Hakanen & Jaakkola 2012; Pralahad & Ramaswamy 2004).

Ecosystem actors need to understand how active role the end customer plays in the value creation and consumption. They are connected, informed and empowered to influence the services they utilize, as the services are often highly complex consisting of interaction, exchange and performance. The ecosystem end customers should not be treated as passive consumers of the products the supplier provides. (Prahalad & Ramaswamy 2004; Wu 2008)

Business ecosystem can be visualized through its actors. The actors with most dense relationship network lead the ecosystem operations as value integrating actors. They enjoy both efficiency and control benefits as they hold positions between the actors that are not directly linked. In case these actors are removed, the ecosystem would be dissolved into disconnected subnetworks. Through visualization the actors can make an assessment on how to preserve, protect or transform their position through potential alliances and strategic partnerships (Lacoste 2016). Visualization can also provide an immersive environment for what-if scenarios as well as support for strategic and operative decisions. (Basoule 2009; Iansiti & Levien 2004)

2.3 Value proposals with customers drive success

Involving end customers into the value proposal definition make them part of a reciprocal process towards equitable exchange (Vargo & Lusch 2004; Payne et al. 2005; Ballantyne et al. 2011). In business ecosystems the actors' relationships have multiple dimensions integrating the services for richer value propositions (Iansiti & Levien 2004). The service dominant logic emphasizes the potential of joint value proposal creation and knowledge sharing in a customer relationship. (Ballantyne 2006).

Analysis of customer relationships in a business ecosystem should be extended to cover the multidimensional dependencies between ecosystem actors. Understanding the dynamics will often unleash a considerable potential for co-learning in the ecosystem that is critical for sustainable co-evolution (Ballantyne et al. 2011). Nätti et al. (2014) define how the intermediator role in triadic relationship contribute to the value co-creation. In business ecosystem planning it is important to understand the relationships and processes where an intermediator has significant contribution either through making promises or acting on behalf of the service provider. (Nätti et al. 2014)

Vargo and Lusch (2004) state that the specialized skills and knowledge are fundamental exchange units in service dominant logic. This is similar to Iansiti and Levien (2004) view on how the ecosystem actors bring specialized resources and competences to the ecosystem. Ballantyne (2006) challenge the unique knowledge or resource assets as critical exchange element by classifying those merely as enablers. The actual transaction is built by the interfacing actors on top of the enablers brought in by the parties. (Ballantyne 2006). The interaction needs to be spontaneous, collaborative and dialogical in order to set up a value processes of a prospering business ecosystem.

Effectiveness of business ecosystem's value processes depends on how much value can be jointly created for end customers. Major contributor for the effectiveness comes from the ability of ecosystem actors to select and exploit opportunities with highest potential to improve customers' satisfaction, business revenue and new competitive advantages (Romero & Molina 2011). Both ecosystem internal and external relationships need to support long term profitability of the ecosystem and adaptability to changes (Lacoste 2016).

Ecosystem actors need to change their culture to utilize innovation of other actors, especially if they have successful track record of internal innovation (West & Bogers 2014). In business ecosystems the actors need integrative competences to link external innovations into their value propositions. Actors should develop the network of compatible external competences of other actors in multiple dimensions (Frels et al. 2003). In order to create effective value proposals, the ecosystem actors need to create fit not only between the proposal and the end customer but also between the goals, preferences and resources of the other service providers (Hakanen & Jaakkola 2012).

Payne et al. (2008) define customer value creation as an outside-in process. It starts from understanding the customer's own value processes (outside) and aims to define a value proposition that complements and enriches the customer perceived value (in). The process is cross-functional requiring alignment between the actors. By developing early concepts of the value proposals the ecosystem actors can test the feasibilities of co-creation options already in planning phase. (Shafer et al. 2005; Eichentopf et al. 2011).

Committed interplay between the actors is a prerequisite for ecosystem success. Actors can introduce a value proposal, but customers need to be involved into further development of it (Romero & Molina 2011). The customers commit to the value proposal when they understand the benefits and are able to utilize those in their internal processes (Frow et al. 2007). Customers appreciate being able to influence and control the value process even if they do not use the outcome (Eichentopf et al. 2011).

Customer is more involved in service based value proposals where the value creation and consumption overlap and take place at the same time. Chakraborty and Kaynak (2014) summarize the service characteristics impacting customer involvement as ease of service generation, value of service and ease of assuring service quality. Complexity of the service, relevancy of it to the customer and frequency of the service consumption are some attributes used to assess the service characteristics (Chakraborty & Kaynak 2014).

2.4 Summary: Customer relationships make an ecosystem

A business ecosystem can be modelled through the actors' customer relationships. Based on the customer requirements the joint value proposals can be defined enabling mapping of the service providers as a value creation network originating from the end customer. End customers should be integrated to the ecosystem value processes in order to understand their true preferences. In a dynamic ecosystem the actors are interdependent in value creation. They interface with internal and external stakeholders through customer relationships forming a hierarchical structure with both business and non-business driven service providers and active end customers.

3. Health and wellbeing campus core service providers

Customer relationships in a business ecosystem were illustrated with a single built environment project case study. The case study subject was a health and wellbeing campus 'Health City Oulu'. Campus is in planning phase in Oulu, Finland. The campus will consist of ten apartment houses and a service center for the campus residents. The concept introduces a novel housing set-up in Oulu, where the health and wellbeing services support physical activity and ease the everyday life. The Health City concept owner's target is to have wellbeing and everyday life supporting service providers -such as kindergarten, training gym or grocery store - operating on the campus and that the service providers would provide together value proposals not possible in other environments.

The campus as a business ecosystem consists of resident candidates - potential end customers- and service providers. Service providers integrating the value proposals have internal customer roles in value process. They also gather inputs outside ecosystem. Customer relationships as ecosystem value process is illustrated in figure 1.

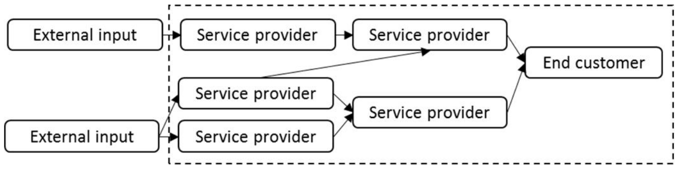

Figure 1. Customer relationships as ecosystem value process

Resident candidates' insights on how they would like to live on the campus and what services they wish to use provide insights about value proposal and related customer relationship types. Figure 1 presents how value proposals can be traced back in the ecosystem from end customer. Modelling the ecosystem based on the customer relationship types support efficient ecosystem planning as it enables suitable service provider selection and complementary capability definition (Romero & Molina 2011).

The campus target is to have residents from all stages of life for a rich environment and for innovative value propositions. Diversity is one of the key characteristics of a sustainable business ecosystem (Iansiti & Levien 2004). The campus fosters interactions amongst the service providers and end customers integrating the actors into mutually benefitting value constellation that protects the ecosystem against external impacts and competition (Gossain & Kandiah 1998).

Public data such as reports and documents about living trends in Finland and Oulu and statistical data about Oulu inhabitants was used to determine suitable campus resident candidates. Public data sources used are presented in table 1. To determine their requirements for the service providers we interviewed 50 persons as the resident candidates to hear how they would like to live on the planned campus and what types of services they would wish to consume. Profiles of interviewed persons are presented in figure 2. The interviews provided information about the service element requirements and relates providers. The interviews were conducted in June-October 2015 in Oulu as semi-structured interviews.

Table 1. Public data sources used to identify resident candidates

Name	**Source**	**Published**
Citizen barometer of Oulu 2011	City of Oulu, Finland	2011
Commercial report on Hiukkavaara Oulu suburb	City of Oulu, Finland	2007
Constructors role in residential area branding	Jenna Taajamo, University of Tampere, Msc. Thesis	2014
Future of senior housing based on living preferences	School of Arts, Future Home Institute, Finland	2005
Health and wellbeing campus initiative - call for partners	City of Järvenpää, Finland	2014
Home in downtown - City center as living environment for families with small children - Stockholm and Helsinki	Johanna Lilius, University of Helsinki, Msc. Thesis	2008
Living environment preferences - Resident views on environment, housing and services in different life stages	Consumer research center Finland	2008
Living preferences, opportunities and life cycle	Anneli Juntto, Ekoelias seminar	2009
Predicting the future of housing	Ministry of Environment, Finland	2007
Resident driven housing development	Matti Kuronen, YIT construction company, Finland	2009
Service housing as an option for senior citizens - questionnaire and interview	Ministry of Environment, Finland	2005
Sustainable community structure and living environment	Communal research and education center, Finland	2010
Townplan report (Toppila, Tuira, project 100169)	City of Oulu, Finland	2014
Update on commercial report on Hiukkavaara Oulu suburb	Colliers international Oy	2013

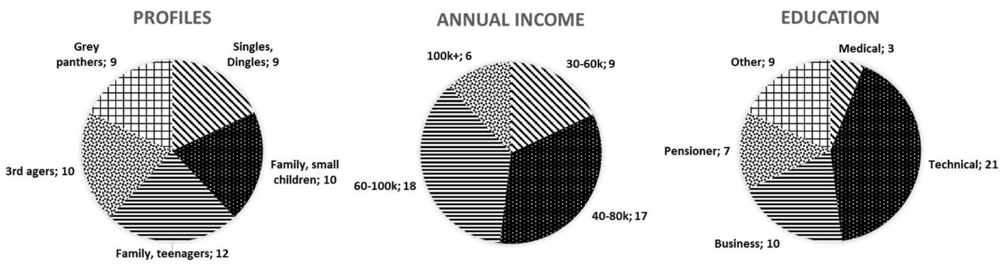

Figure 2. Profiles of interviewed persons

In the semi-structured interviews we asked about the service elements for the campus ecosystem the interviewees would see contributing most to the fluent everyday life and physical wellbeing. Furthermore we asked them to prioritize three of them. Figure 3 presents the service elements the customers preferred to have on the campus.

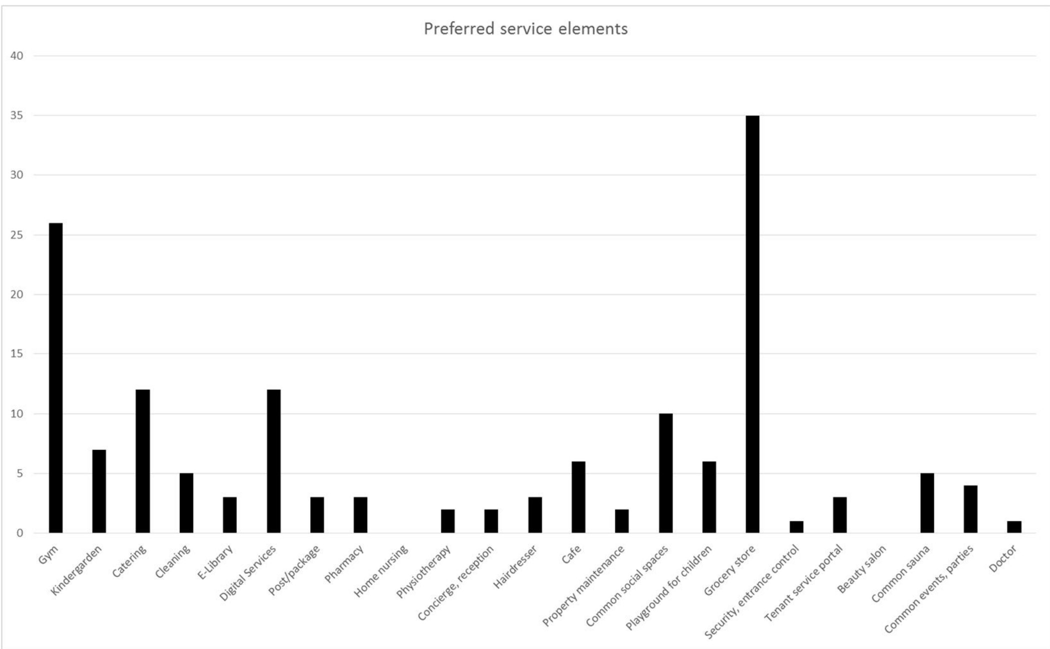

Figure 3. Preferred Health City Oulu service elements.

The interviews were recorded and analysed. Training gym, grocery store, catering and digital services were considered as the most valuable elements common to all profiles. We consolidated these elements to core service providers together with the campus concept owner in an iterative process. The process included several meetings to filter appropriate content and observations from the interview data. Consolidation of the service elements to core service providers follows the business ecosystem (Moore 1998; Iansiti & Levien 2004) and customer dominant logic (Hakanen

& Jaakkola 2012; Pinho & Fisk 2014) characteristics where integration of the service value proposals define ecosystem key value elements.

Based on the consolidation we formulated four core service providers as service element integrating ecosystem actors: *Grocery Store*, *Training Gym*, *Senior services* and *Kindergarten*. They have capabilities to integrate, deliver and iterate the ecosystem value proposals to the end customers. They involve other service providers to the value creation processes. Core service providers act as intermediators (Nätti et al. 2014) in the ecosystem facilitating the joint value creation. For example Kindergarten could offer catering services on the campus while providing meals for the children as part of day care.

4. Customer tiers in a business ecosystem

Aapaoja et al. (2013) presented a tier based model to categorize a built environment project stakeholders. Consolidation of the core service providers and joint value proposals in this study enable designing a tier based model for ecosystem customer relationships as hierarchical layers. The core service providers form the inner circle of a campus ecosystem hierarchy around the end customer. Their interdependency with the end customer is dynamic and temporary (Pinho & Fisk 2014). As the value proposal creation-consumption is a unique experience in service dominant logic (Vargo & Lusch 2004) the self-interdependency also plays an important role in defining how the core service providers integrate the value proposals.

We present a business ecosystem customer tiers in figure 4 with selected service providers from the case study results. The model elaborates the differences between the customer roles in the value process and how the relationships are formed across the tiers. Role of the service provider for the end customer value proposal based on service characteristics (Chakroborty & Kaynak 2014) and the types of interdependencies between other actors (Pinho & Fisk 2014) determine their tier.

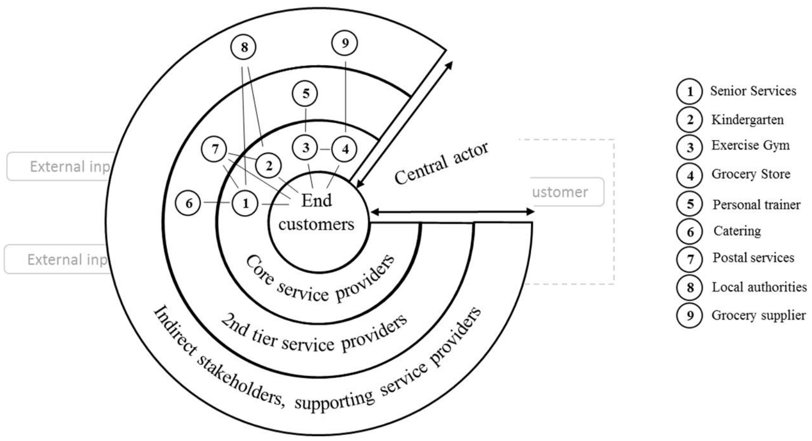

Figure 4. Business ecosystem customer tiers on ecosystem value process

End customers are positioned to the center due to their focal role in ecosystem value definition. They consume the value the campus ecosystem creates and set the requirements for the service providers.

Core service providers in the case are Senior Services, Kindergarden, Exercise Gym and Grocery Store. They are located physically in the campus. They master the system level value proposals and encounter process with the end customers. They deliver the ecosystem value proposals to the end customers in most cases.

2nd tier service providers include multiple service providers either complementing the core service providers' capabilities or interfacing directly with the end customers with own value proposals. Examples of these are personal trainer, catering and postal services. 2nd tier service providers have core service providers as their key customers. They can also operate temporarily on the campus.

Indirect stakeholders, supporting service providers are not integrated into the campus ecosystem but temporarily, or in a specific manner, influence the campus ecosystem. Their impact is through the service providers operating within the ecosystem. Actors in this category are for example local authorities or grocery supplier. These actors may also interact with other ecosystems.

Central actor orchestrates the customer relationships via the interfaces between the tiers. The central actor facilitates the ecosystem evolution by providing rules and operational practices for actors. Campus concept owner operates as the central actor in the studied case. In the start-up phase the central actor can set up the baseline for the customer relationships by involving the key end customers and core service providers in to the planning. Once operational, central actor takes a facilitating role to support the ecosystem as a self-organizing entity.

5. Discussion

We identified different ecosystem customer relationships with the case study 'Health City Oulu'. The customer tier model presents how the ecosystem actors can be described as hierarchical layers on top of ecosystem value process. The core service providers are the value integrators. Actors on the other tiers consider the inner circle actors as the customers of their own value proposals, or are being facilitated by them. These findings support the multifaceted customer role as an ecosystem defining characteristic presented by Moore (1993, 1998), Iansiti and Levien (2004) and Gossain and Kandiah (1998).

Different types of interdependencies (Pinho & Fisk 2014) impact how the tiers of the ecosystem customer relationships are formed. Dynamics of both value proposals and involved actors make customer tier model a dynamic concept applicable to certain ecosystem phase. Central actors of life cycle built environment projects would benefit from tier model as a project scoping tool.

Generalizability of the customer relationships roles would benefit from further research. The key contribution of this single case study is a conceptual model on the customer relationship tiers and how the tiers describe the campus ecosystem. Method on how to identify core service providers applies in this study to a campus ecosystem planning. Once it is operational, a similar study could bring up different actors as the residents would base their priorities on experienced value instead of expected. Furthermore, a research on o phase would provide insights about how external inputs impact the ecosystem.

For the business ecosystem research this study introduces a novel conceptual model that follows the Payne et al. (2008) value creation process driven by customer internal processes and requirements. End customer as the central point expands the role of technologies or innovations as the driving forces for business ecosystems (Moore 1993; Gawer & Cusumano 2014). Modelling the ecosystem from the end customer perspective unveils the ecosystem value integration and control points. Research on customer centric ecosystem structures and their evolution would complement the knowledge on ecosystem drivers. Such research could also identify how the business and information transactions in the ecosystem may be enhanced.

The customer tier model describes the central actor as the orchestrator of the interfaces with limited substance value contribution. Central actor defines the strategic targets for the campus ecosystem and facilitates the ecosystem relationships. Central actor in the start-up phase involves the core service providers so that the promise given by the campus to the resident candidates can be fulfilled. Development of the central actor role would also be another subject of further research on built environment projects and ecosystems.

6. Conclusions

This case study research responds to the defined questions about core service provider identification and customer relationships. Identification of the ecosystem core service providers is an essential task in a built environment project as their contribution to the planning has significant importance to the ecosystem's successful start. Complementary capabilities of the core services providers integrate them with the campus end customers into joint value creation process.

Business ecosystem and service dominant logic concepts extend the dimensions of how ecosystem central actors or built environment project managers could approach the challenges related to resident candidates' requirement identification and key stakeholder management. Positioning the end customer into the center of the actor definition process, and categorizing the actors into tiers by their customer relationships define a customer centric tier model for the ecosystem. This model contributes on its part to streamline the ongoing discussion about complexity of a business ecosystem as a concept in context of other value constellations.

The customer tier model can be utilized to define the needed actors for initial value definition. In Health City Oulu context the initial value definition should be conducted before the campus project enters building phase. This would ensure that the apartment houses and service center provide a flexible and sustainable environment for the health and wellbeing service ecosystem to emerge once the campus becomes operational. Value definition as part of the project planning aligns the ecosystem start-up activities with its strategic targets.

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Development of students’ multidisciplinary collaboration skills by simulation of the design process

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Abstract

This paper examines the application of multidisciplinary collaborative learning in higher civil engineering education. The changes in the construction sector are setting new challenges for the higher education of the construction sector. The construction projects have become more and more complex involving numerous stakeholders. This is setting high requirements for multidisciplinary collaboration skills. Present higher civil engineering education does not develop good enough collaboration skills for those students. The first aim of the study is to present a practical model how to implement collaborative learning within course named “Simulation of building design process” with a particular attention towards multidisciplinary involvement. The course has been implemented at the Tampere University of Technology in Finland since 2006. The applied learning method has features from project-based learning, progressive inquiry learning and trialogical approach to learning. The course is implemented through the practice of design meetings, which simulate the actual design meetings. The participating students from different disciplines form a design group. Students' task is designing a building for the predefined need. Each student has a specific role meeting his/her major subject of studies. The second aim of the paper is to analyse how students have perceived the course. The empirical data consists of the feedback by students from the 2009 to 2015 courses. According to feedback students have perceived that collaborative learning has deepened their knowledge on a building design process and their collaboration skills have improved during the course. The course has been found motivating and the student-centric nature of it caused by students’ possibility to affect on the content of the course and their responsibility of their own learning. The third aim of the study is to discuss the developing of students’ multidisciplinary collaboration skills in higher civil engineering education. The course has shown that with new learning methods can make learning more context-oriented and enhance students’ motivation, which usually affects positively students’ learning. The results of this case study suggest the potential of using collaborative learning in higher civil engineering education.

Keywords: collaboration, multidisciplinary, engineering education, collaborative learning, design process

1. Introduction

The construction sector and the whole society have faced significant changes in recent years. These changes are setting new challenges for the higher education of the construction sector. The construction projects are more and more complex involving numerous stakeholders. This is setting high requirements for multidisciplinary collaboration skills. The engineers for the current and coming requirements need to be equipped with better skills and new capabilities for sharing expertise, collaboration and project management.

Literature review by Salmisto (2013) reveals that several researchers have suggested that higher civil engineering education does not develop good enough collaboration skills for those students. Many previous studies emphasise the importance of the multidisciplinary and collaboration skills in engineering education. Learning in the universities in question should be more student-centric and develop students' ability to think independently and collaboratively. This paper is about a collaborative learning in higher civil engineering education with a particular attention towards multidisciplinary involvement. The case study incorporated examines the application of multidisciplinary collaborative learning within course named "Simulation of building design process". The aim of this research is threefold. The first aim is to present a practical model how to implement the multidisciplinary collaborative course design. The second goal is to evaluate how students have found the multidisciplinary collaborative course. The empirical data consists of the feedback by students from the 2009 to 2015 courses. The third aim is to analyze how to develop students' multidisciplinary collaboration skills in higher civil engineering education.

2. Theoretical framework

2.1 Collaborative learning

According to Vygotsky (1978) social aspect is distinctive in learning. Students may achieve higher quality learning outcomes through social interaction with peers and between teachers and students. This Vygotsky's point of view is a basis of the collaborative learning. Dillenbourg (1999) define the collaborative learning, as its broadest definition, as follows: "Collaborative learning is a situation in which two or more people learn or attempt to learn something together". He argues that this is not enough satisfactory definition, because it does not define exactly what collaborative and learning means in that context. Helle et al. (2010) argue that collaborative learning is something where students solve a problem together. According to Dillenbourg (1999) collaborative learning itself is not a method. It is more the approach to teaching and learning to achieve high quality learning and meaningful learning processes. In high quality learning, students' motivation and engagement to learning are important aspects (Lonka & Ketonen 2012). Barkley et al. (2014) argue that the strength of the collaborative learning is, that it engages students of different backgrounds to work together actively for the shared aims. Because of this, collaborative learning is an excellent approach for multidisciplinary course design.

2.2 Case-based, progressive inquiry and trialogical learning

The applied learning method, to implement collaborative course design, has features from many learning methods. The basis of the course is the project-based learning, but course has features also from the progressive inquiry method and the trialogical approach to learning. Thomas (2000) defines project-based learning as a learning model that organise learning around projects. In project-based learning students engage in real life situations and solve the real and meaningful problems. Construction is principally project based activities. Therefore the project-based learning creates a good platform to implement learning which based on the real working life problems of the construction projects. In a project-based course, that has been carried out appropriate way, the students can participate in authentic practices and train skills needed in real projects (Helle et al. 2010). Activities could be similar that professionals of the discipline do in real life. Many researchers (Grant 2002; Helle et al. 2010; Thomas 2000) argue that in previous studies have presented various models of the project-based learning, thus there is not clear and exact definition about project-based learning. With qualitative literature review, Helle et al. (2010) have defined five distinctive features of project-based learning: 1) problem orientation, 2) constructing a concrete artefact, 3) the learner control of the learning process, 4) contextualisation of learning, and 5) potential for using and creating multiple forms of representation. Usually, the aim of the project-based learning is to collaboratively construct a shared outcome (Helle et al. 2010).

The method, which have adapted in our course design, also has the features of the progressive inquiry and trialogical approach to learning. Progressive inquiry learning is a pedagogical model based on the theory of knowledge building. It is designed to support typical data acquisition by the specialist and emphasises the activity of the learner and the impact of co-operation in a shared research project and the creation of new knowledge. (Hakkarainen et al. 1999.) The similarity of the project-based and progressive inquiry learning is questions, which direct students' learning process. In project-based learning guiding or driving questions creates a platform for the inquiry of the project team (Grant 2002; Larmer & Mergendoller 2010; Thomas 2000). The basic idea of the progressive inquiry is that the students themselves define meaningful research questions and their task during the learning process (Hakkarainen et al. 1999). Therefore the difference between progressive inquiry and traditional project-based learning is particularly in the presenting of questions and research problems. In traditional project-based learning the tasks and problems are given and students do not define research problems. Also Helle et al. (2010) have found similarities between project-based learning and Bereiter's model of knowledge building (see Bereiter 2002), which is a basis of progressive inquiry. The objective of progressive inquiry is to organise teaching so that there is room for students' questions and the research approach is possible (Hakkarainen et al. 1999). Inquiry oriented working is emphasising also in project-based learning (Grant 2002; Helle et al. 2010; Larmer & Mergendoller 2010).

The progressive inquiry method has been further developed towards the trialogical approach to learning where the learning process is more context-oriented. The purpose is to integrate progressive inquiry and real working life context. The trialogical approach to learning based on a knowledge creation metaphor, which Paavola and Hakkarainen (2005) have been identified by analysing three models of innovative knowledge communities: Nonaka and Takeuchi's model of knowledge creation, Engeström's model of expansive learning, and Bereiter's model of knowledge building. According to Paavola and Hakkarainen (2005) the trialogical approach to learning concentrates on the interaction through the common objects of activity and, also between people and environment. They define the trialogical approach as 'Learning is a process of knowledge creation which concentrates on mediated processes where common objects of activity are developed collaboratively.' The mediated processes of knowledge creation have become vital in our knowledge-based society (Paavola, Lipponen & Hakkarainen 2004).

2.3 Multidisciplinary collaboration skills in building process

Building project organizations are usually directed and governed by contractual arrangements. Stakeholders in cooperation and their specialist have well-established roles, relating mandates, assignments, contractual duties and payments. (Kähkönen et al., 2013). Plain formal project organizations can be rigid and produce constraints that make difficult or almost impossible value-adding co-operation and communication. Unfortunately still the movement toward more cooperative relationships is hindered by the traditional type of procurement that encourages competition rather than cooperation (Cheung 2003). This is unfortunate since the closer cooperation is needed.

According to several researchers, collaboration is not an option, it is necessity. The report by Egan (2002) recommended that process and team integration as a key driver of change necessary for the industry to become more successful. Also Latham (1994) and Bourn (2000) have challenged the industry to move away from its traditional practices towards more collaborative and integrated approaches. Kusiak and Wang (1993) presents that collaborative working is primary if design and construction teams are to address the entire lifecycle of the construction product and take account of not only primary functionality but also productivity, buildability, serviceability and even recyclability. Sanvido et al. (1992) found seven success factors for construction projects in their study. Four of them have found to be critical. Three out of four critical factors are related to collaboration. Egan (1998) reported five key drivers for improving the quality and efficiency of UK construction. Collaboration is one of them. Chen et al. (2012) reported four factors which have significant influence on the success of construction partnering. Collaboration is one of the four factors. Moore and Dainty (1999) presented that a successful construction project delivery and the performance depend on the integration of knowledge and experience of different stakeholders.

3. Methodology

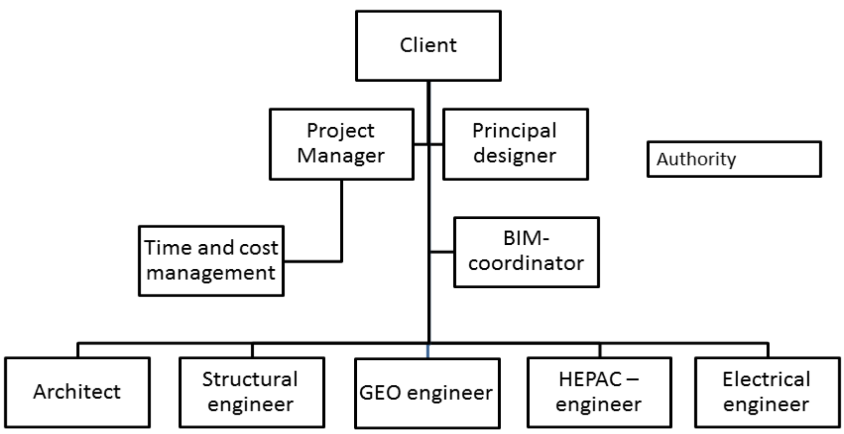
3.1 Sample and analyses

The subject of this case study, "Simulation of building design process" -course has been implemented since 2006. The course design is based on the key principles of the collaborative learning. The empirical research data of the study consist of the feedback by the students from 2009 to 2015, altogether from six implementations of the course. The feedback was collected during the last learning event of the course. Students who worked in the same role during the course have given shared feedback. Altogether 35 different feedbacks were available and were analysed in this study. The feedbacks were in written form. It has been asked for the students to write down what succeeded in the course and what should be developed. Each student groups have also presented the feedback during the last learning event of the course to the teachers and other students. The written feedbacks were analysed using inductive content analysis, which involves a process of identifying and classifying data without any theoretical assumption (Schilling 2006). First, the data was collected into the same file and was reduced to the form which is suitable for the further analyses. After that, the data were coded based on expressions which often appeared and were grouped based on the coding. With coding and grouping, were found how students have perceived the course. From the data of each group were searched the original expressions which illustrate well students' perceptions. In addition were counted, how many expressions were included in each group.

3.2 Application of multidisciplinary collaborative learning

The first objective of this paper is to present a practical model how to implement the multidisciplinary collaborative course design. The Simulation of the building design process course has been implemented since 2006. For this course the participating students from different disciplines form a design group which consists of the students from architecture, structural engineering, earth and foundation structures, HPAC –engineering, electrical engineering, and construction management and economics (Figure 1). Students' task is designing a building for the predefined need. Each student has a specific role meeting his/her major subject of studies. The course is implemented through the practice of design meetings, which simulate the actual design meetings. The teachers act as observers and provide feedback. However, the preparations of the meetings and their realizations are entirely on students' responsibility. Between the design meetings, students carry out tasks and arrange smaller meetings according to their roles.

Figure 1: The students' roles and organisation of the course



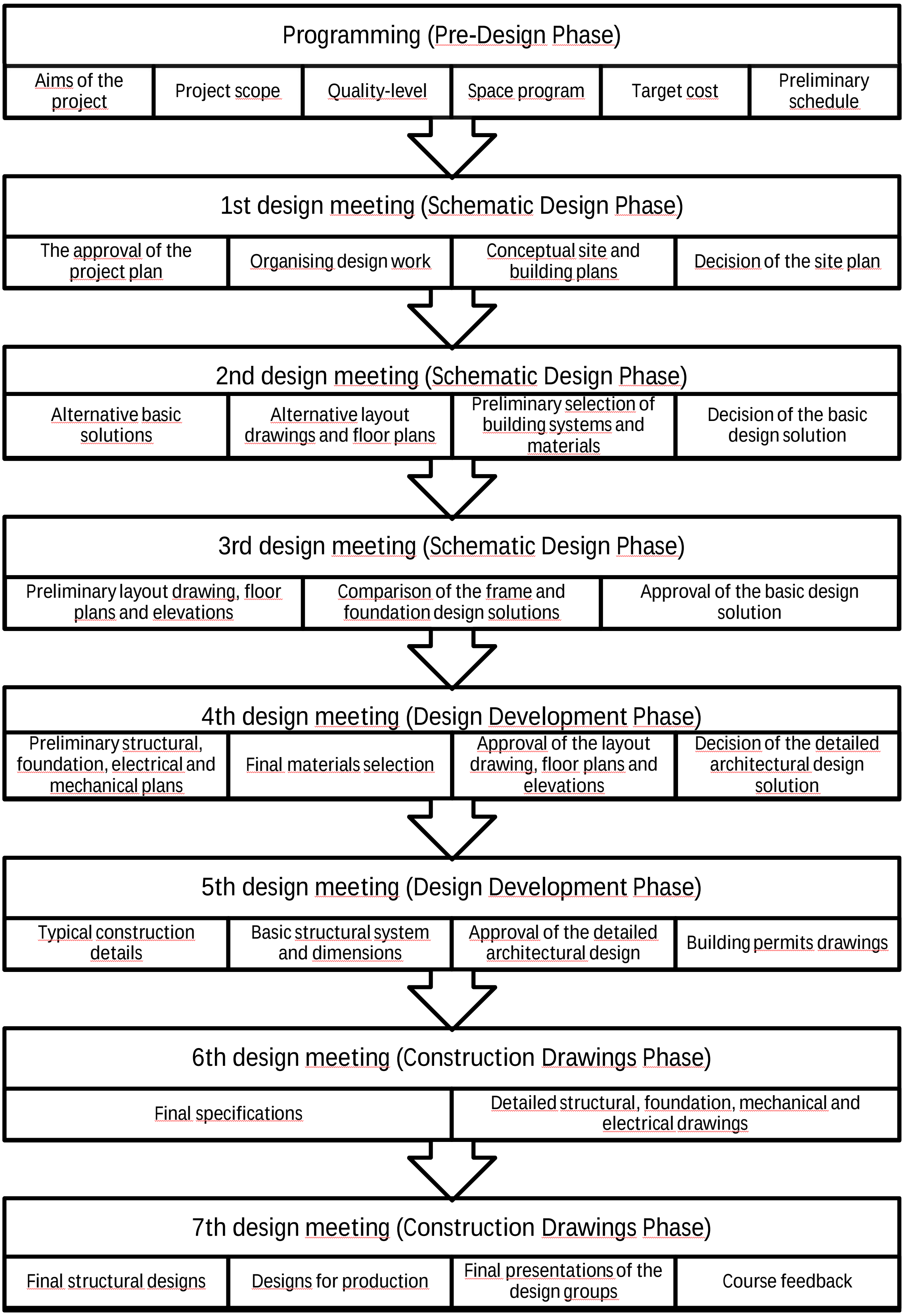


Figure 2: The design process and the progress of the course

The course design differs from the traditional teaching methods at the universities of technology. Often, the courses consist of lectures, assignments and an exam. Assignments are usually predefined by the teachers and have precise guidelines on how the exercise should do. In this course, there are no lectures and exam. Also the starting point of the design process is quite open and unlimited. The students have to define their own task by themselves. Therefore, the course has features from project-based learning, but also from the progressive inquiry learning method and the trialogical approach to learning.

Figure 3: An example of BIM-based design solution

The progress of the course is intended to simulate the real life design process as well as possible. Still, there are some things which differ from the actual design process, because the learning aims of the course. For example, the student who acts as authority participates the design meetings and there is not really the briefing phase. At the beginning of the course, each student set personal goals and define their own tasks meeting his/her role. The course starts from the programming phase. The type and approximate size of the building and the site has given to the students for the starting point of the design process. The first task of the students is to make a project plan where they set the goals of the project. They for example set project scope, quality level, a room program, target cost and a preliminary schedule of the project. The actual design begins with a schematic design phase, where students define the basic solution and concept of the building. After the schematic phase, it starts the design development phase. Students design the final solution and create building permit drawings as an outcome of the design development phase. The final design phase is a construction drawings phase, where students create final structural designs and designs for production. The progress and the outcomes of the course differ a little every year, but in Figure 2 is described the suggestive progress of the course. The course took about seven to eight months. The course begins in September and continues till April. The design meetings are arranged approximately every 3-4 weeks. Usually, the course consists of 7-8 design meetings. Recently, students' design process had been based mainly on a BIM-based design (see Figure 3).

4. Results

4.1 Students’ perceptions of the course design

The second aim of the study is to evaluate how the students have found the multidisciplinary collaborative course. The responses to questions, what succeeded in the course and, what should be developed (Table1), shows that students have found collaboration between students and the development of understanding the design process as the best parts of the course. According to feedback, the most significant improvements needs are in the role related guidance and the instructions of the course. In Table1 is presented the results of the content analyses. It shows how many times the subject was mentioned in feedbacks. The subjects, that were mentioned more than five times, are listed.

Table 1: The grouped feedback responses by the student groups.

What succeeded in the course?	
Collaboration	25
Understanding the design process	15
Design meeting practices	9
Learning method	8
Students' motivation	7
BIM	7

What should be developed?	
Guidance	12
Instructions	11

Of 35 feedbacks, in 25 was mentioned collaboration between students as a success of the course. One of the main aims of the course is to practice multidisciplinary collaboration skills needed between the stakeholders during the building design process. One student group describes the positive side of the course as follows:

> *”Development of the collaboration and interaction skills, and increase of understanding the challenges of the different construction stakeholders’ activities”*

In 15 feedback students underlined that their understanding about the design process was developed during the course. In following, there are two examples on how students describe their perceptions on course:

> *“The course demonstrated well the progress of the design process”*

> *”You can perceive the wholeness a completely different way in this kind of courses, where you work by yourself, even this widely”*

Also, the knowledge creation approach was fulfilled during the course. The following comments describe the nature of the inquiry based learning, students' motivation and their own responsibility of their learning during the course:

> *"There should be more this kind of courses, because this course is similar to the engineers' tasks in working life. At first, you have to define the problem and then solve it yourself."*
>
> *"It's good that the students have the main responsibility of the course progress. It gives a better picture of what kind of each role would be in working life"*
>
> *"The whole group had good motivation and the work was done, "like in real project"."*

Twelve feedbacks indicate that students did not get enough guidance during the course. Many students think that especially task related guidance was insufficient and they did not get feedback from their outputs. The guidance varies a little depending of the year and student's role during the course. The following comment from the BIM-coordinator describes the students' perception well:

> *"Some kind of feedback during the course would have been nice. There was not information on the success of our own task"*

Another negative aspect, which arisen from the feedback, was instructions of the course. In 11 feedbacks were mentioned that the students would have needed better instructions at the beginning of the course or more explicit pre-defined task for each role. They found that they did not know what kind of task fall into their role. Some students also found that the objectives were unclear. The following comment describes the students' perceptions:

> *"At the beginning of the course there was not a clear understanding about the design order. Better instruction at the beginning would be given a better starting point for the course"*

In general, feedback by the students has been mainly positive. In the last learning event of the course, students have been present their perceptions of the course to the teachers and other students. In these events, many students have said that learning has been more meaningful and deeper than in traditional courses.

5. Discussion

The obtained feedback is showing evidence that students have perceived that collaborative project-based learning has deepened their knowledge on the progress of the construction design process and their collaboration skills has improved. The course has been found motivating and the student-centric nature of it caused by students' possibility to affect on the content of the course and their responsibility of their own learning. Students' motivation is important in high quality learning. Motivated students use more time on studying than other students, which affects positively on learning outcomes (Lonka & Ketonen 2012). Teachers' perceptions have been similar to students' perceptions. During the years, teachers have found that course simulate the appropriate way the real-life design process. Teachers have also noticed the high quality learning and the development of the students' knowledge and competence during the course. The course has shown that with new learning methods can make learning more context-oriented and enhance students' motivation, which are related positively on students' learning (see Lonka & Kettunen 2012).

The students' perceptions that their understanding about the design process have increased during the course, was one of the main results of the study. This is interesting. The master students, who have already been studying the design process in previous courses, have not achieved deep learning in courses, where have been used traditional teaching methods, lectures and assignment. Students have perceived that the course, where students plan the progress of the project by themselves, seems to lead higher quality learning than other courses.

Also, the results indicate that some students require well-defined instructions and more supervising during the course. The open and unlimited learning tasks confused some students, which is quite common in inquiry-based learning (see e.g. Salmisto & Nokelainen 2015). Therefore, the results showing evidence that students' metacognitive skills were inadequate for open-ended learning tasks. In previous courses, students are used to solving limited tasks predefined by their teachers. On the other hand, the most important aspect in inquiry-based learning is that students themselves define meaningful problems and formulate substantial research questions. Meyers & Nulty (2009) argue that learning in authentic learning environments, which contain for example ill-defined tasks, promotes students' ability to formulate relevant task-related questions later in their working lives. According to Korhonen-Yrjänheikki (2011) the ability to formulate the research questions is a significant skill for future engineers. Engineers will run up against unstructured and complicated tasks in working life. They should be able to define the main problems and to find the solution to them.

6. Conclusions

The "Simulation of building design process" -course has been conducted in Tampere University of Technology in Finland since 2006. During the years, the teachers of the course had been noticed that course design has facilitated students learning in an appropriate way. In this paper, it was presented a practical model how to implement the multidisciplinary collaborative course design within the course. The paper has given a concrete example of the course design. The university teaching developers and teachers could use the presented model to develop teaching in construction higher education. The presented model based on project based learning and progressive inquiry learning methods and trialogical approach to learning. These methods develop learning of the contents, but also students' competency needs of the knowledge society, like presenting substantial research questions and metacognitive skills.

The empirical sample of the paper consisted of student feedback on how they have perceived the course design. Most students found that course has improved their multidisciplinary collaboration skills and the understanding about the building design process. These skills are needed in the complex construction projects of the real working life. Some students have found that they have not got enough feedback from their tasks during the course. Some students should have needed better instructions at the beginning of the course. The open-ended and unlimited tasks were confused some students. On the other hand, engineering students should be able to define problems and find solutions by themselves.

The results of this case study suggest the potential of using collaborative learning in the context of the construction process. Multidisciplinary and collaborative projects can be effectively used in higher civil engineering education to promote students' learning and develop collaboration skills which are required todays more and more complex construction projects and working life. In engineering studies, the learning methods of this kind should be used already earlier than only in master studies. If students learn needed skills of collaborative learning already in bachelor courses, they can take advantage of the new learning methods more effectively in later studies. That will affect positively learning of the contents.

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An analysis of student performance measures in newly constructed schools

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Abstract

Public school construction represents a significant portion of all construction spending in the United States, ranging from 7 to 9.5 percent annually from 2008 to 2013. This paper examines whether new construction, building age, and building condition affect applications, enrollment, attendance, and student achievement measures in a large urban school district in Texas, USA. Demographic data, including minority ethnicity (Hispanic and African American) and economically disadvantaged percentages were used to control for factors influencing the dependent variables. Twenty-eight magnet elementary schools (kindergarten to 5th grade) in one large school district were chosen for analysis. The experimental group (n = 14) included all magnet elementary schools rebuilt under the 1998, 2002, and 2007 school bond ordinances. The control group (n = 14) included randomly selected elementary schools from the 32 remaining magnet elementary schools that were not rebuilt during the same period of time in the same school district. Multiple and linear regressions were conducted, and the findings indicate no observable predictive effect on student enrollment or student attendance as evidenced by building composite score and building age. However, student achievement is positively related to having a new facility, as evidenced by the ability to predict state percentile rankings based upon building composite scores. This study demonstrates the impact facility managers and other school stakeholders may have by showing a positive connection between a school's physical condition and student performance and achievement.

Keywords: Schools, Building Performance, Student Performance, Construction, Magnet

1. Introduction

Public school construction (Pre-K to 12th grade) represents a significant portion of all construction spending, ranging from 7 to 9.5 percent annually from 2008-2013 (US Census 2014). A 1999 report for the National Center for Education Statistics (NCES) stated that public school age averages 42 years old.

Of those public schools, 28 percent were built before 1950, and 45 percent were built between 1950 and1969 (NCES 1999). From this, one can infer that the condition of public schools is of great concern due to aging infrastructure, decades of deferred maintenance, environmental factors, lack of adequate technology, and failure to meet current accessibility standards. School funding is a complex issue, with few dollars from annual district budgets earmarked for maintenance, let alone capitalconstruction. The overwhelming majority of public school construction is funded through local school bond funds requiring an election. For a bond referendum to pass, the public must understand the need for funds, know how funds will be allocated, believe students and the whole community will benefit from construction, and trust that projects will be completed on time and within budget.

Public education in the United States is more high-stakes than ever before for states, school districts, and schools, due to the standards-based movement, testing pressures and persistent achievement gaps. Penalties for not meeting Adequate Yearly Progress (AYP) are significant. The stakes and penalties are just as high for the people involved, including principals, teachers, and above all, students, who fail to meet minimum standards. The cost increase of constructing new schools to replace old ones is also steep. The average cost of a new elementary school in the Houston Independent School District (ISD), Texas, for example, is about $16 million including furniture and technology. A new high school under the $1.2 billion Houston ISD 2012 bond program will cost exponentially more, with several individual projects costing more than $100 million, depending on size. Public confidence in school districts hinges upon a number of factors, including student achievement and perceived benefits of investing in bond programs.

The basic aim of this paper is to examine whether construction, building age and building condition affect enrollment, attendance and student achievement. In doing so, the paper may provide school districts with additional information to strengthen public confidence which, in turn, may lead voters to support school bond elections. Creating an observable connection between school construction and student outcomes may strengthen the likelihood of increased spending in this sector of the construction market, thereby benefiting the construction industry as a whole. This paper uses statistical data obtained from a large urban school district in Texas, USA, for the purpose of conducting data analysis and drawing conclusions

2. Literature Review

Creating an observable connection between school construction and student outcomes is necessary for increasing public confidence in the bond election process. In turn, the construction industry benefits by way of increased funding. Efforts to reduce the achievement gap between students belonging to different socio-economic classes began with the passing of Title I of the Elementary and Secondary Education Act (1965). These were mainly centralized efforts, with federal funding provided to schools with a high level of poverty, to be used for school-wide improvement and reform strategies. Later, in 1998, with the Comprehensive School Reform Program (under title 1 part F of Title I of the Elementary and Secondary Education Act, 1965), grant opportunities were awarded to public schools willing to implement research-based school reform strategies targeted toward reducing the achievement gap. A number of studies have linked student performance with building conditions: McGuffey (1982) and Weinstein (1979) examined a total of 238 studies and 21 paper presentations to understand the effects of a number of factors like building age, building utilization, school size, etc., on student performance. In a review of more recent research, Earthman and LeMasters (1996) concluded that research has-

"…demonstrated a relationship between student performance, both achievement and behavior, and the condition of the built environment. The relationship has varied from very weak in some early studies to the most recent study which demonstrates a considerable degree of relationship. Nevertheless the preponderance of the research cited shows a very close relationship between the built environment and how well students and teachers perform in that environment." (p.11).

Schneider (2002) also reviewed the body of research around school quality and student achievement and concluded that school facilities affect learning: spatial configurations, noise, heat, cold, light, and air quality – all bear on students' and teachers' ability to perform. He also found that building age alone cannot be used as a predictor of performance, thus implying that a different measure of building quality could be measured and achieved through adequate funding and competent design, construction and maintenance (Schneider, 2002). Lyons (2001) drew similar conclusions after a review of research around facility conditions. He pointed out that changes in teaching and learning, technology, and increasing accountability and standards require changes in school facilities to be flexible enough to allow for collaboration.

In another canonical analysis, Crampton (2009) used longitudinal, state-by-state data about school spending and student achievement from the Institute for Education Sciences and the United States Census Bureau to determine the impact of human, social, and physical capital on student achievement. "Human" and "social" capital focused on the quality of teachers and professional development, examining dollars spent. "Physical" capital referred to school infrastructure, condition and adequacy with spending determined by dollars spent for maintenance and capital outlay, including construction, renovation, and debt for capital outlay. The National Assessment of Educational Progress (NAEP) scores for 5th and 8th grade reading and math were used as measures of student achievement. Over the years examined (2003, 2005, and 2007), and controlling for poverty, dollars spent on human, social and physical capital accounted for between 55.8 and 77.2 percent of the variation in scores. Human capital investments showed the largest effect over time at .890 in 2003 and declining to .648 in 2007. Social capital produced a coefficient of .158 in 2003, dipped in 2005, and rose to .299 in 2007. Physical capital was more varied in its effects, accounting for .236 in 2003, .049 in 2005, and rose back to 2003 levels in 2007. While human and social capital effects were higher overall, the researcher concluded, "…the impact of investment in physical capital…was also a significant contributor…spending on school infrastructure does matter when it comes to student achievement" (Crampton, 2009, p.318).

Based on the belief that environment affects outcome, Berner (1993) studied the impact of parental involvement on building condition by creating a regression model using Parent Teacher Association (PTA) membership, PTA budget, school condition (1=excellent, 2=fair, 3=poor), type of building, school age, percent white, mean household income, and student enrollment. In the second part of the study, regression was used to analyze if the overall building condition impacted student achievement as shown by the schools' average California Test of Basic Skills (CTBS) scores. Berner's (1993) findings supported the hypothesis that student scores improved as building conditions improved. This hypothesis was also supported by studies conducted by Uline and Tschannen-Moran (2008). Using qualitative methods, they surveyed teachers at 80 Virginia middle schools to look at links between school facility and student achievement using school climate as the mediating variable. Their study observed links between building condition and an overall atmosphere that encouraged teaching and learning; they concluded that building conditions indeed did affect student achievement. One study, the Holistic Evidence and Design (HEAD) project (Barrett et al., 2015), shows promising progress in understanding the ways in which the built environment may impact student learning. The seven key design parameters that best predict students' progress were found to be light, temperature, air quality, ownership, flexibility, complexity and color. The HEAD study focused on specific design parameters and their impact on student learning, while the study presented in this paper takes a different perspective, emphasizing building age and condition as predictors for student enrollment and achievement.

3. Research Methods

The population for this study consisted of all elementary schools in the Houston ISD. A sample of 28 magnet elementary schools was gathered. The experimental group was not randomly sampled since all 14 replacement (rebuilt) magnet elementary schools were included; however, the 14 schools in the control group were randomly selected from a pool of more than 30 other magnet elementary schools not rebuilt. All 28 magnet elementary schools in the sample were identified from the three bond elections that the school district passed in 1998, 2002, and 2007.

The study examined whether major renovation, building age, and building condition had an impact on magnet applications, enrollment, attendance, and student achievement measures. All variables and the sources from which they were obtained are listed in Table 1.

Table 1: Study variables and their sources

Data	*Variable*	*Source*	*Reference*
School Enrollment	*Dependent*	*School Digger website*	*schooldigger.com*
Magnet Application	*Dependent*	*District Data via HSS website*	*houstonschoolsurvey.com*
School Attendance Rate	*Dependent*	*School Digger website*	*schooldigger.com*
Student Achievement	*Dependent*	*School Digger*	*schooldigger.com*

		website	
Free and Reduced Lunch Percentage	*Control*	*School Digger website*	*schooldigger.com*
Minority Percentage (Hispanic & African-American)	*Control*	*School Digger website*	*schooldigger.com*
Age of Original Building	*Independent*	*District Study*	*Houston Independent School District and Parsons (2012)*
Completion Date of Building	*Independent*	*District Study*	*Houston Independent School District and Parsons (2012)*
School Composite Facility Score	*Independent*	*District Study*	*Houston Independent School District and Parsons (2012)*
Statewide percentile rankings in "Reading" and "Math"	*Independent*	*School Digger website*	*schooldigger.com*

For the set of 28 magnet elementary schools, which included experimental and control groups, multiple regression methods were used to examine the relationships among the independent variables of building age and building composite in 2011-2012, with dependent variables of magnet applications, student enrollment, student attendance and student achievement. Minority percentages of combined African-American and Hispanic student populations, and percentages of free and reduced lunches were included in the full regression model as control variables.

4. Results

Descriptive statistics for the experimental and control schools, as analyzed from the sources mentioned above, are shown in Table 2. Even though the two groups studied are significantly different from each other in terms of building age and building condition scores, they do not significantly differ in enrollment numbers for school year 2011-2012 and the number of magnet applications for school year 2013-2014. Mean 2011-2012 enrollment numbers for the experimental schools and for the control schools was 739.2 and 695.1, respectively, and mean 2013-2014 magnet application numbers for the experimental schools and for the control schools was 237.4 and 239.6, respectively. The data presented in Table 2 also emphasizes the high percentages of free and reduced lunch students and the high percentage of minorities (as measured by percentage of African-American and Hispanic students) within the two groups examined in this study.

Table 2: Experimental and control schools descriptive statistics

	Experimental schools (n=14)			*Control schools (n=14)*		
Variable	*Min.*	*Max.*	*Mean (S.D)*	*Min.*	*Max.*	*Mean (S.D)*
Building age in 2011-2012	*0*	*8*	*4.07 (2.81)*	*20*	*92*	*61.29 (23.53)*
Building composite in 2011-2012	*85*	*100*	*93.04 (6.56)*	*39*	*87*	*72.12 (11.80)*
Enrollment in 2011-2012	*607*	*918*	*739.2 (77.2)*	*518*	*916*	*695.1 (131.0)*
Magnet applications for 2013-2014	*10*	*619*	*237.4 (207.3)*	*10*	*677*	*239.6 (249.2)*
Percent free & reduced lunch for 2011-2012	*14.5*	*53.6*	*40.28 (11.24)*	*5.6*	*58.3*	*30.14 (17.66)*
Percent African-American and Hispanics for 2011-2012	*41.8*	*99.1*	*86.89 (17.85)*	*20.8*	*99.5*	*60.17 (29.19)*

First, we examined whether there was an observable effect on magnet applications by looking at building composite score and building age in the experimental and control schools. Tables 3 and 4 show the model summary for experimental and control schools: magnet applications and the ANOVA results.

Table 3: Model summary for experimental and control schools: magnet applications

	Experimental schools (n=14)			*Control schools (n=14)*		
Model	*R*	R^2	*Standard error (SE) of the Estimate*	*R*	R^2	*Standard error (SE) of the Estimate*
1	*.168*	*.028*	*222.1*	*.409*	*.168*	*247.2*

Table 4: ANOVA results for experimental and control schools: magnet applications

Experimental schools (n=14)					
Model	*Sum of Squares*	*df*	*Mean Square*	*F*	*Sig.*
Regression	*15,708.2*	*2*	*7,854.1*	*.159*	*.855*
Residual	*54,278.2*	*11*	*49,343.7*		
Total	*558,489.4*	*13*			
Control schools (n=14)					

Model	*Sum of Squares*	*df*	*Mean Square*	*F*	*Sig.*
Regression	*135,263.7*	*2*	*67,631.8*	*1.107*	*.365*
Residual	*671,945.8*	*11*	*61,086.0*		
Total	*80,209.4*	*13*			

The coefficient of determination was not significant for either the experimental schools (R^2=0.028, F(2,11)=0.159, p = 0.855) or the control schools (R^2=0.168, F(2,11)=1.107, p = 0.365). Therefore, we infer that there was no observable effect on magnet applications as evidenced by building composite score and building age in the experimental and control schools.

Next, we looked at whether enrollment can be predicted using building age and building composite score. Tables 5 and 6 show the model summary for experimental and control schools: enrollment and the ANOVA results.

Table 5: Model summary for experimental and control schools: enrollment

	Experimental schools (n=14)			*Control schools (n=14)*		
Model	*R*	*R^2*	*Standard error of the Estimate*	*R*	*R^2*	*Standard error of the Estimate*
1	*.390*	*.152*	*77.225*	*.371*	*.138*	*132.233*

Table 6: ANOVA results for experimental and control schools: enrollment

Experimental schools (n=14)					
Model	*Sum of Squares*	*Df*	*Mean Square*	*F*	*Sig.*
Regression	*11,774.1*	*2*	*5,887.1*	*.987*	*.403*
Residual	*65,602.3*	*11*	*5,963.8*		
Total	*77,376.4*	*13*			
Control schools (n=14)					
Model	*Sum of Squares*	*df*	*Mean Square*	*F*	*Sig.*
Regression	*30,780.9*	*2*	*15,390.5*	*.880*	*.442*
Residual	*192,342.7*	*11*	*17,485.7*		
Total	*223,123.2*	*13*			

The coefficient of determination was not significant for either the experimental schools (R^2=0.152, F(2,11)=0.987, p = 0.403) or the control schools (R^2=0.138, F(2,11)=0.880, p = 0.442). Therefore, there was no observable effect on enrollment as evidenced by building composite score and building age in the experimental and control schools.

In the next step, we analyzed whether student attendance can be predicted using building age and composite building score. Tables 7 and 8 show the model summary for experimental and control schools: attendance and the ANOVA results.

Table 7: Model summary for experimental and control schools: attendance

	Experimental schools (n=14)			*Control schools (n=14)*		
Model	*R*	R^2	*Standard error of the estimate*	*R*	R^2	*Standard error of the estimate*
1	*.313*	*.098*	*.386*	*.314*	*.098*	*.510*

Table 8: ANOVA results for experimental and control schools: attendance

Experimental schools (n=14)					
Model	*Sum of Squares*	*Df*	*Mean Square*	*F*	*Sig.*
Regression	*.177*	*2*	*.089*	*.596*	*.568*
Residual	*1.635*	*11*	*.149*		
Total	*1.812*	*13*			
Control schools (n=14)					
Model	*Sum of Squares*	*df*	*Mean Square*	*F*	*Sig.*
Regression	*.312*	*2*	*.156*	*.600*	*.566*
Residual	*2.857*	*11*	*.260*		
Total	*3.169*	*13*			

The coefficient of determination was not significant for either the experimental (R^2=0.098, F(2,11)=0.596, p = 0.568) or control schools (R^2=0.098, F(2,11)=0.600, p = 0.566). Therefore, we infer that there was no observable effect on attendance as evidenced by building composite score and building age in the experimental and control schools.

Last, we analyzed whether student achievement was positively impacted by a new facility as evidenced by state percentile ranking based upon building composite scores. Ranking was determined by adding total "Reading" and total "Math" scores across all grades tested on the state standardized assessment ranking within Texas public schools (SchoolDigger.com). In the experimental model, 47.1% of the variance in state percentile ranking was accounted for by building composite scores (F(1,12) = 10.686, p=0.007). The unstandardized regression equation was found to be Y= 14173.313 + -129.010 (X1). This was significant at t=-3.269, p =0.007.

In the control model, 53.4% of the variance in state percentile ranking was accounted for by building composite scores (F(1,12) = 13.772, p=0.003). The unstandardized regression equation was Y= 5570.307 + -62.448 (X1). This was significant at t=-3.711, p =0.003. Table 9 shows the model summary for experimental and control schools: statewide rank; Table 10 shows the ANOVA results. Table 11 shows the regression models for experimental and control schools.

Table 9: Model summary for experimental and control schools: statewide percentile rank

	Experimental schools (n=14)			*Control schools (n=14)*		
Model	*R*	R^2	*Standard error of the estimate*	*R*	R^2	*Standard error of the estimate*
1	*.686*	*.471*	*933.7*	*.731*	*.534*	*715.7*

Table 10: ANOVA results for experimental and control schools: statewide percentile rank

Experimental schools (n=14)					
Model	*Sum of Squares*	*df*	*Mean Square*	*F*	*Sig.*
Regression	*9,317,339.7*	*1*	*931,7339.7*	*10.686*	*.007*
Residual	*10,462,991.2*	*12*	*871,915.9*		
Total	*19,780,330.9*	*13*			
Control schools (n=14)					
Model	*Sum of Squares*	*Df*	*Mean Square*	*F*	*Sig.*
Regression	*7,053,564.4*	*1*	*7,053,564.4*	*13.772*	*.003*
Residual	*6,146,099.3*	*12*	*512,174.9*		
Total	*13,199,663.7*	*13*			

Table 11: Experimental and control school regression models: statewide percentile rank

Experimental schools (n=14)				
Model	*B*	*Standard Error*	*T*	*Sig*
Constant	*14,173.3*	*3,680.4*	*3.8*	*.002*
Building Composite	*-129.0*	*39.5*	*-3.3*	*.007*
Control schools (n=14)				
Model	*B*	*Standard Error*	*T*	*Sig*
Constant	*5,570.3*	*1,228.5*	*4.5*	*.001*
Building Composite	*-62.4*	*16.8*	*-30,711*	*.003*

5. Conclusions and Future Research

School districts in the United States are under intense pressure to perform, with significant penalties imposed on them in cases where they do not meet minimum achievement standards. Added to this pressure is the fast-increasing cost of school construction and renovations. The achievement gap continues to be an issue for at-risk, low-income, and minority students. Research shows that a number of societal and school factors contribute to this gap and a multi-pronged approach appears to be the only way to narrow it. As a result, student achievement and perceived benefits of investing in bond programs lay at the center of public confidence in school districts.

The current study examined the effects of physical building quality on magnet applications, enrollment, attendance, and student achievement. Among magnet elementary schools in the Houston ISD, this study found no significant correlation in magnet applications, enrollment, or attendance for experimental (replacement) schools as compared to a control sample of other magnet elementary schools for the year of interest. However, for the most critical question of student achievement, building a replacement school did make a difference, explaining 47.1% of the variance in scores. In this model, other previously significant factors, such as minority population and free and reduced lunch percentages, no longer held the same level of significance or else dropped from significance altogether. It is encouraging to find that the quality of the school environment can, at least in part, have an impact on student achievement and the achievement gap by creating high-quality learning environments. These results could be used to strengthen public confidence in current and future bond programs within and outside of the Houston ISD, if shared with school board members, district personnel, and public stakeholders. Successful bond programs that produce benefits beyond just construction are definitely good for the construction industry as a whole.

This study could readily be replicated and even expanded within the Houston ISD. Research could look at additional testing years or consider a longitudinal approach to see how schools and students fare in the years post-construction. While this study only looked at replacement elementary schools, a broader study could look at all schools based upon building composite scores from 2012, since the effects could also hold for well-maintained or renovated schools, not simply new ones. It would be interesting to see if the same results would be produced when Houston ISD replacement high schools are completed in the coming years. Lastly, with such robust, varied, and longstanding standardized testing within Houston ISD, researchers may also benefit from using student-specific test scores instead of overall school rankings.

Combining qualitative research methods with quantitative ones could further explain why replacement schools make a difference in student achievement. Post-occupancy surveys of principals, teachers and students could be particularly helpful, especially at the high school level, since students have a greater ability to respond.

The construction and facility management industry, along with education researchers, could and should be an active part of research in this area. Showing how new buildings positively affect students and the greater public benefits the industry financially and could also boost the morale of construction professionals who rarely get to see the difference spaces make once the punch list is complete. Even more importantly, improving student achievement affects the future lives of students and society as a whole by increasing the likelihood of high school graduation, college attendance, and earnings potential. Bettering lives, decreasing the cycle of poverty, and enhancing the national economic picture through improving school facilities is truly priceless.

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Extending Professional Fields: Architectural Research and Regional Development

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Abstract

In this article, architectural research work is studied as an effective operations model in regional innovation networks of building clusters. The study focuses on the projects of an academic research team working at the University Centre of Seinäjoki, as well as on the innovation environment of the surrounding South Ostrobothnian region in Western Finland. There is no actual university in the region, but the University Centre hosts some twenty professors and their research teams from six Finnish universities. The head of the subject team is also the author of this article. Because of this, the method applied in the article is a reflective action research approach.

The actions and impacts of the research work will be analysed through three case projects. The first case is the development of the large railway station area that will form a new 20-hectare multifunctional part of the city centre of Seinäjoki. The project has strong linkages to the economic policies of the city. The second case is related to the boom in new timber construction, which has been going on in Central Europe and Scandinavia for some time, but not so strongly in the subject region of this study. The aim of the project was to train small and medium-sized building cluster firms to take advantage of the emerging business potential in timber construction. The third case is closely related to the real speciality of the region. The city of Seinäjoki is home to one of the most complete building groups of architect Alvar Aalto, the famous civic centre that consists of the town hall, library, theatre, office building, church and the parish centre. At the moment there is a very demanding renovation project going on, which was also the main subject of the recent research and development project.

The descriptions of the projects are meant to illustrate the operational field of the research team, but the main focus of the article is to analyse the innovation environment that the researchers join as players among others, thus deviating from the more conventional role of architectural professionals.

Keywords: Architectural research, urban planning, urban development, regional development, innovation environment

1. Introduction

In this article, the possibilities of one research team to contribute successfully to regional development will be analysed. The team comprises the Urban Laboratory[1] researchers from Tampere University of Technology (TUT), School of Architecture. The geographical operations area of the team is the South Ostrobothnia region in western Finland, with a focus on the urban region of its capital city, Seinäjoki. The leader of the team is a professor of architectural and urban research. Individual team members might change during the course of the projects, but the professor will remain constant. Because of this, the professor serves as sort of an "object lens", through which actions will be observed in this study. Moreover, the leading professor is also the author of this article, so the applied research method is most akin to reflective action research.

At present, the first five-year period of the professorship has passed, and the second is well under way. Some self-evaluation is necessary for being able to improve future actions. Publishing the results enables feedback from a variety of experts. It is always problematic to reflect on one's own actions, as personal limitations and competences are difficult to assess objectively. Despite this, the work has to be done, and hopefully the results will benefit similar developers elsewhere. It is also hoped that the study presents an interesting, albeit not so typical, view of an architect's and a researcher's field of operations.

Seventy-five percent of the funding for the professorship will be collected from private companies and public organisations of the subject region. This will not succeed unless its contribution is considered of value. The benchmark for success is the benefit that the research team produces for the regional building cluster, whether directly or indirectly through urban development. The university has its own credit systems that consist of peer-reviewed articles, doctoral theses and academic research funding.

The problem is that applied research and regional activities are not taken into account in the scientific credit systems of universities. Consequently, it takes a lot of work and creativity to formulate the projects and funding applications so that they can eventually result in scientific publications. This raises critical questions of the societal role, the so called "third task" of universities, stipulated in the Universities Act. If the research is considered worthy of regional funding, why can't it be indicated and included in the credit systems?

In this study, the regional operations environment is limited to building cluster and municipal urban planning. Because the vantage point of the study is in the sphere of economic development, it is fair to use the term "innovation environment" (Mustikkamäki & Sotarauta 2008). There is a university of applied sciences in the region that gives education in civil engineering, but there is no academic education for engineers or architects. A characteristic feature of the region is the strong entrepreneurial spirit and a great number of small and middle-sized firms, but there is relatively little technological research and development typical of big companies. The planning offices of the region's municipalities are overloaded with work, allowing no resources for development there either. Considering all this, one important task of the research team has been to import the latest knowledge and to extend specialist networks to the region.

[1] http://www.tut.fi/en/alvar-aalto-chair

2. Operating environment

The professorship and the team started their work in 2009. The early stages were truly pioneering work, since the whole platform for successful research had to be constructed piece by piece: recognising partners and networks, identifying their needs, and formulating research topics so that they were relevant not only from the regional perspective, but also sufficiently appealing to national research funders. The University Consortium of Seinäjoki (UCS)[2] requires that the research should in some way support regional economic and urban development.

The original action plan of the professorship was based on the renovation problems of modernist architecture. Gradually this theme gathered more salience, and it became the conceptual "umbrella" over the diverse project portfolio, but first the theme had to be translated into wider terms. "Adaptability and resilience of the built environment" is the umbrella in this case. So far, three research lines have emerged under the umbrella: 1) new planning and design methods, 2) built environment in transition, and 3) special issues of modernist built heritage. These lines consist of several ongoing projects, as well as closed ones, some pending or under preparation.

Conceptual conjoining is necessary for fulfilling the needs of both of the background communities of the professorship: UCS requires visibility and effects in the regional context, whereas TUT has exact systems of academic credits and performance criteria concerning all professorships. Quite often regional research and development projects can be characterised as applied science due to available partners and funding instruments. It is easier to refine them into academic publications and theses, if there is a connecting framework, functioning as a conceptual "umbrella", constructed gradually on the basis of the project findings.

The projects include wide collaboration with the partners in South Ostrobothnia and in the city of Seinäjoki, as well as with the education and research institutes of the region. A remarkable part of the academic co-operation originates from the physical context of UCS, since it provides premises for six universities and 20 professors with their research teams[3]. Some projects are actually kicked off in the lobby when two researchers from different disciplines meet by chance.

The city of Seinäjoki and its development office collaborate frequently with UCS research units. This is how the city officers utilise research in their economic, social or urban development. However, the locality itself is very seldom the actual subject of research, but more usually a laboratory for diverse experiments. In this respect Seinäjoki has some advantages due its modest size with 60 000 inhabitants, dynamic and development-friendly atmosphere, and very approachable key actors and institutes. But it is also a growth city with growth problems, which makes it interestingly comparable to larger cities. In addition, its built environment matches perfectly to the team's research themes: the city centre has been built almost entirely after WWII, and furthermore, it features one of the iconic works of modernist architecture, Alvar Aalto's civic centre.

In practice, research operations will be conducted on two levels. The first level consists of research and development projects. The professor writes research plans and makes preparations for launching

[2] http://www.ucs.fi
[3] http://www.epky.fi/epanet

projects. He also hires researchers and leads the projects. The second level is based on the professor's own research benefiting from the project findings.

Practical operations include applications for funding of the research projects, engaging researchers and partners, launching and leading projects. One of the main objectives in the near term is to integrate research into international networks. This requires partnerships in EU-funded projects, joining international conferences, publishing in scientific journals, and organising international workshops. Obviously, the academic collaboration continues on a national level, but applying for EU-funds for research is unavoidable due to reductions in the allocations of national research funds.

The results of the team can be divided into three main groups: 1) scientific results consisting of new theories and applications, and publications that report the results, 2) increasing knowledge and skills of the students and partners, and consequent changes in thinking models and practices, and finally 3) such changes in built environment that improve its adaptability, transformability and resilience.

3. Innovation environment

In South Ostrobothnia the main issue is the region's economic competitiveness. Municipalities and firms should have competencies that exploit new operations models, technology and markets. In practice, the firms and organisations should be able to complement their own internal resources and competences by obtaining complementary resources from external sources. In this sense the *innovation environment* is the specific part of the operation environment of firms and organisations that provides complementary competences and resources the firms and organisations need in their innovative endeavours. However, the innovation environment is not the same for all enterprises and organisations, since their needs are different. (Cooke, 2004; Kautonen, 2008) Yet, from the standpoints of local and regional development, the regional innovation environment could be considered a common innovation environment for some specific field of industry or administration. Important elements of these environments include, among other things, education, research and development, technical infrastructure, management consultancy and financial support (Camagni, 1991; Virkkala, 2008.)

The term "regional" does not imply that all the resources and competencies will come from the local region. Local and global entities should form a fruitful collaboration to create new know-how. Local arenas are needed for close interaction, and global connections are needed for distant communication. No region is self-sufficient enough to be able to provide all the necessary competencies. In addition, the geographical scales of firms and organisations vary (see Kolehmainen, 2004; Lechner & Dowling, 2003), as some companies in South Ostrobothnia have established international trade relationships, and the city of Seinäjoki joins diverse national networks.

It is important to note that firms and organisations do not innovate alone. Innovations are developed in networks that consist of diverse actors which include, for example, clients, subcontractors, competitors, financiers, administrators, trade associations, development organisations and research institutes. The innovation network includes all those players that contribute to innovation processes (Cooke & al., 2000; Lundvall, 2001; Virkkala, 2008). If the processes take place in the normal practices of firms and organisations, they are sometimes referred to as open innovation, as opposed to science-based processes. Some studies point out that new innovations are mostly developed in practice-based settings (Harmaakorpi & al., 2011; Chesbrough, 2003a, 2003b).

Innovation networks consist of social relations. The qualities of those relations have an effect on the performance of the networks as facilitators of production, economy and administration. Network relations can be divided between those with strong ties and those with weak ties. Usually the strong ties are based on trust between parties, common goals and easy communication due to common language and similar basic access to information. However, strong ties do not necessarily encourage firms and organisations to combine different ways of thinking and acting that finally might result in new innovations. Studies have pointed out that open innovation utilises the weak ties of networks especially. Weak ties force firms and organisations to seek solutions from new kinds of reference groups, which might result in fruitful mixes of information and, perhaps, ultimately in new innovations. (Burt, 1992; Granovetter, 1973.)

It is not possible to anticipate or control the processes that take place in innovation environments, but the innovation environment itself could be developed deliberatively (Sotarauta & Srinivas, 2006). For example, regional arenas for interaction and collaboration between different competences could be organised. These kinds of settings have been termed development platforms by some researchers (see Harmaakorpi & al., 2011). Competence-based platforms are able to combine diverse knowledge and create novel variations of competences, as experts from industry, universities and municipalities gather around some common theme or technology.

Development platforms are fundamentally future-oriented arrangements (Harmaakorpi & al., 2011). Technological development by its own right is capable of creating new platforms, but usually they are based on the evolution of existing platforms. In South Ostrobothnia the development paths of, for example, timber construction can be easily traced back in the region's history. Traditional rustic houses, high-grade carpentry skills and a strong entrepreneurial culture are well-known characteristics of the region. Yet it requires a visionary mind-set to recognise the elements of evolving platforms that could merge existing potentials and global flows into a local success story. Also, innovation policies should be targeted to the specific features of regional innovation environments.

4. Action research

One very suitable method for this kind of study is, arguably, action research. Although there isn't a widely-recognised, unambiguous definition for action research, the basic principles of the method can be recognised. The main feature of the method is the researcher's ambition to have an effect on the research subject, while being simultaneously a part of the subject. The objective behind the action is to change the practices and habits of the subject community by inspiring the actors to use practical reasoning to reflect on their actions. Thus the researcher is only a visitor whose intervention will set people free to act in their own best interests. At the same time the researcher is able to collect valuable information. (Reason & Bradbury 2001.)

The other essential feature of action research concerns the target group, which is always a particular community. It is also important that the community can be defined both geographically and temporally. However, the interaction between the researcher and the community does not need to be so strictly defined thematically; it should be relatively permanent and long standing. The researcher does not work alone, but together with the members of the community. This kind of study design enables both scientific and practical approaches. (Reason & Bradbury 2001) In this sense the method applies well to the present study, where the actions are analysed principally within the overlap of academic and professional spheres.

In this case, there is one deviation from more “orthodox” action research. The study design described above has not been explicitly introduced to the target community. But, on the other hand, the whole idea of founding a regional university centre has been a deliberate method for the local development community to reflect its own actions. For example, one of the research units of the centre (the research team “Sente” from University of Tampere) aims to conduct research on innovation environments. There is also an explicit agreement with the Urban Laboratory team and the city of Seinäjoki to use the city as a living laboratory. And finally, these two units mentioned above have released joint publications on local economic and urban development in Seinäjoki (Hynynen & Kolehmainen 2011; 2016, forthcoming).

In the present study, the method has been applied as follows: The research team has actively participated in different innovation networks of construction and urban planning. The researchers have brought along their knowledge and made observations. This has mainly taken place in connection with research and development projects and different expert tasks. These activities have resulted in a multitude of research material, including project reports, scientific and professional articles, workshop and seminar presentations, as well as meeting memos and minutes. All this material has been available for the actors of the innovation networks.

5. Case studies

5.1 Case 1: SmartStation

In Seinäjoki, the railway station area was selected as the main urban development area, as the city’s administration made decisions to increase housing in the city centre. The key reason behind the decision was the fast growth of the population of the city. In past years growth has focused on the urban fringes, but now there are signs of growing demand for more urban alternatives to single-family houses. The city planners welcome this trend, for it enables improvement of service structure and urban image of the city centre, which has been considered too rural for the medium-sized[4] growth city that counts on research and the latest technology. (Seinäjoen kaupunki 2014)

Knowledge-driven development policy dominates the urban strategy of Seinäjoki (Seinäjoen kaupunki 2013), which is concretised particularly well in the goals set for the railway station area development. According to the objectives, the station area will form a third knowledge-based hot-spot alongside the Frami technology centre (UCS, SeAMK[5]) and Itikanmäki (Foodwest[6], Rytmikorjaamo[7]).

Because the city’s land ownership is very low in the railway station area, it was considered important to engage the area’s other land owners and developers regarding the development objectives. There was a danger that if they start to develop their own premises in a piecemeal manner, the whole area would

4 Population ca. 60000.
5 http://www.seamk.fi
6 http://www.foodwest.fi
7 http://www.rytmikorjaamo.com

be completed without a comprehensive and visionary master plan necessary for fulfilling the ambitious urban objectives.

Based on these ideas, the city of Seinäjoki launched the "SmartStation" project in collaboration with two universities (including Sente and Urban Laboratory), funded by Tekes[8]. The aim of the project was to organise an inclusive development process by arranging workshops for visionary goal-setting. From the very beginning the workshops were focused on urban qualities, and also on the economic profile of the area in relation to the other innovative hot-spots of Seinäjoki. The economic profile of the station area was further sharpened, as the city was included in the national "Innovative cities (INKA)" – development programme lead by the Ministry of Employment and the Economy. The South Ostrobothnia region is known in Finland as the "Food Province" due to its strong agricultural economy and advanced food technology. In the INKA-programme this kind of background justified the city's acceptance into the category of bio-economy. Based on this, it was clear that the station area should be a global shop window for the Food Province.

In the workshop discussions, work and working life were dealt with the terms of change. The developing station area should meet this challenge with flexibility of spaces and infrastructure. Some concrete ideas were proposed, like mixing small scale production with office work and dwellings in hybrid buildings. Also, different "hubs" should have platforms, as well as apartment and office hotels for mobile workers. Functional mixes, spatial flexibility and excellent accessibility were important keywords in the final report of the project. These qualities are also very compatible with the emerging ideas of open innovation (Chesbrough, 2003a, 2003b; Hynynen & Kolehmainen 2016, forthcoming).

5.2 Case 2: Puu-Hubi (Wood-Hub)

Wooden multi-story apartment buildings have been common in North America for a long time. Now, large-scale timber construction is proliferating in Europe as well. The main drivers for this development include, for instance, favourable environmental impacts of wooden building materials as well as general moisture problems associated with concrete buildings. In addition, the timber-based building industry has potential to support regional economic development (Männistö & al., 2012). This is true especially in countries like Finland, which have strong forest and wood industries, as well as long traditions in timber construction.

Based on these views, it could be assumed that there should be more development in this industry in South Ostrobothnia than there actually is. One explanation is the fierce competition in the construction business. Building firms do not easily change their familiar production platforms because of fear of economic risks. Also, producers of concrete materials are campaigning for their continued dominance. However, it is important to understand that the renewed interest in timber construction technology is only just getting started.

Our Puu-Hubi project highlighted interesting aspects of the roles of local and regional actors in the development of timber construction. In particular, cities and municipalities could promote win-win situations, as they are beneficiaries of regionally-entrenched value chains of the wood building industry. They also have authority in writing and applying laws and codes that have impacts on building costs. Municipal and regional developers could support wood building in many ways by including it in their

[8] The Finnish Funding Agency for Innovation.

economic and development programmes. In our project the central network of regional players was easily distinguishable, although not all the actors recognised their own role as an effective node in the innovation network. The key players are in most cases building cluster firms like wood-producing enterprises, construction firms, property developers, architecture offices and civil engineers.

One of the main goals of the Puu-Hubi project was to figure out the information needs of the firms in new timber construction technologies. Many different theme areas were named, and our task was to organise training for the firms to provide competences to meet their needs. However, other resources beyond purely cognitive ones are needed as well. The firms should possess a so-called absorptive capacity (Cohen & Levinthal, 1990; Zahra & George, 2002). In other words, they need capabilities to evaluate, adopt and apply new information. But even if the firms have these capabilities, the birth of an innovation is anything but a systematic process, and lucky coincidences will still be needed.

In our subject region there have been many discussions on the possibilities of timber construction. The amount of information is no longer the decisive bottleneck in the breakthrough of the industry. Instead, strategic awareness should be awakened somehow (Sotarauta & al., 2007; Heifetz, 2003). University-led projects and workshops will not suffice as the only means, but real leadership is now needed. Somebody has to get down to business with clearly-defined goals, geared with the ability to lead networks. The first task is to create a storyline where diverse players are able to identify their roles and interests in a common endeavour (Simmons 2001). For example, firms and municipal development offices, as well as education and research institutes, should perceive their interdependence in an innovation network as a positive opportunity.

As one outcome of the Puu-Hubi project, the University Consortium of Seinäjoki is preparing a new professorship with the University of Vaasa. The branch of science will be the timber construction industry. If the consortium succeeds in funding the chair, the new specialist would have an interesting role in the innovation network. Will the new professor prove to be the node with strong links that is currently missing in the network? Either way, the chair will provide permanence and continuity for the innovation environment, but its holder will also be an important storyteller.

5.3 Case 3: MARK LivingLab

A remarkably large portion of the Finnish building stock consists of post-war buildings: eighty percent of it has been constructed after 1945. Only a small number of the buildings and urban environments of 1950s-1970s have been renovated, so the work that is ahead is massive. However, the main problem is not the extent of the task, but the lack of relevant knowledge of renovation methods, as well as the confusion concerning architectural and cultural-historical values of the buildings and environments of that specific period.

A project titled “MARK LivingLab” put an effort to develop solutions to these problems. In Seinäjoki they have an ongoing renovation project of the famous civic centre of Alvar Aalto, which provided an excellent laboratory for documenting the unique construction solutions, and for developing an operations model for demanding renovation projects involving modernist architecture. Also, the city of Seinäjoki prepared a new master plan for the city centre, which made it a relevant test platform for developing principles for value-judging of modernist urban environments.

The project leader was Urban Laboratory, and the research partner was the Seinäjoki University of Applied Sciences, the School of Technology, which gives education in building renovation. The other partners were the city of Seinäjoki, which is the property owner of the civic centre of Alvar Aalto, and, obviously, the city is also the official planner of its city centre. The third partner was the provincial museum of Seinäjoki, which is responsible for protecting the cultural-historical values of urban environments all over the region.

The tasks of the project were divided into three work-packages (WPs). WP 1 was tasked to collect, document and process the material, technical solutions and new operations models produced and applied in the design and construction work. WP 1 focused mainly on the renovation of the Aalto library that was completed during the MARK LivingLab project. In WP 2, basic outlines were drafted for value-judging the urban environment of Seinäjoki's city centre. In WP 3, a new maintenance-based operations model for renovation projects was developed in tandem with the construction process of the civic centre. Successes and failures were taken into account for making the model generally applicable elsewhere.

6. Discussion

Professor Markku Sotarauta (Sotarauta 2009; 2016; Sotarauta & al. 2007) with his team has found out that leadership in regional development processes has kind of systemic character that is better able to deal with networks and emergence. Diverse tactics have been identified, here applied to the present study:

Mobilisation aims at engaging necessary competencies into development processes. In concrete terms it means encouraging and motivating actors to join the process. It is important to respect the strategies and procedures the actors are used to, as well as point out how public and private interests could be combined. In the SmartStation project our research team had an optimal arena for mobilisation in the form of the workshops. They provided for a valuable forum in which to discuss the benefits of a comprehensive and shared vision of the station area, as opposed to piecemeal development that allows optimising only the interests of private land-owners. In the Puu-Hubi –project the building cluster firms were enticed by being offered education and training for improving their competitiveness.

Envisioning is needed for outlining a shared future of the region. Although it seems efficient to put effort on one clear vision, it is more realistic to also take into account the visions the companies and organisations have as well. Sometimes it is possible to take advantage of the tensions between different visions by identifying common denominators for creating a new and shared vision. The SmartStation project was inherently an envisioning process. The research team developed a visual method for the workshops that enabled very heterogenic participants to work together. The Puu-Hubi project was first considered merely technical and business development, but as soon as the team started to highlight the wider benefits of timber construction for local urban development, it raised a new kind of interest among the city leaders.

Awakening of strategic consciousness aims to draw the actors' attention to the most important development themes. One very typical way in this is story-telling. For example, in the MARK LivingLab project the team had an occasion to highlight the cultural-historical value of Alvar Aalto's civic centre in public media. A great help in catching the attention of local media was the way the research team connected the cultural value of the civic centre to local economic development through the benefits for the renovation business.

Framing and filtering are the toolboxes for selecting the themes to be included in official development agendas. For being successful in this work, shared thought-models and vocabularies should be created. It is the very core of regional development work to separate irrelevant factors from the ones that have capability to really make a difference. In the SmartStation project the team introduced the concept of “island of agreement” (Hynynen & al. 2014) to illustrate the importance of the stakeholders’ commitment to a shared vision of the area.

Coordination means what it says: gathering together different projects and actors for exerting stronger effects and benefiting from synergy. However, single projects do not offer positions and arenas for a research team to this kind of action. Real coordination requires an official mandate to control regional actors of different institutes and organisations. Researchers can always make initiatives and try to engage, for example, the university centre or the regional council, but from this point on the officers have a say.

Entrenching is somewhat easier, even for researchers, but not by using formal power. Instead, they can launch follow-ups for projects. If some useful action prevails long enough in the area, it creates routines and long-standing practices that gradually start to seem necessary and even indispensable. All the cases presented above have different spin-offs. A good example is the Europan13 architectural competition that was launched due to encouragement of the SmartStation results. The Puu-Hubi project influenced the founding of the new professorship on timber construction in South Ostrobothnia. The project of MARK LivingLab was continued in the form of a new project that deals with renovation, but this time at the Nordic level. The project includes renovation cases from three countries. The Finnish case is Alvar Aalto’s civic centre in Seinäjoki.

7. Conclusions

Research and development projects are the research teams’ medium to participate in regional development. The projects, in a way, “license” the researchers to network and create contacts, organise workshops and seminars, as well as produce material for public discussion. The use of the media makes it possible to focus public attention to certain regional resources that might be of unique quality, but too mundane for local people. A good example is Aalto’s civic centre. Put in another way, the results of the projects are not the only way to have impacts on a local level, but the projects as such are as important, sometimes even more important.

In the previous section there was a remark about researchers’ capabilities to coordinate extensive and heterogenic development assemblages, for this requires positions in official development organisations: in the regional council, university centre or in the city of Seinäjoki. However, these institutions can be included in the research team’s network, where the researchers are able to use their expertise.

In comparison to an academic operations environment, the thematic spectrum is wider in this case. Yet the work has to be theoretically informed due to the demands of the academic background community. Only the scientific credits from peer-reviewed publications and theses justify university funding. Here also lies the Achilles heel of region-based research work. Although the majority of the everyday work of the team consists of applied research, development work and networking, this part of the task is totally ignored in the credit systems of universities and their national funder, the Ministry of Education and Culture. Nevertheless, the projects have to be launched keeping in mind the regional and local starting points. This makes the theoretical work very laborious, as there are minor chances to focus on limited conceptual horizons. From the academic standpoint, thematically broad conceptual palettes are not as appreciated as more limited and deep-diving.

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A Framework for Designing Responsive Architecture: A Design Studio Approach

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Abstract

Advancements in robotics technology combined with the demand for sustainable and user friendly environments have drawn attention from designers towards responsive architecture. However, a large number of experiments tend to be at the scale of art installations because of various obstacles. The objective of this research is to understand the challenges and opportunities of responsive architecture and describe the author's research and teaching explorations for designing such responsive applications. Through literature review common considerations of designing responsive architecture are mapped. Examples from the author's teaching show how digital and physical modelling and prototyping processes are interrelated with each other. The goal is to illustrate how responsive tectonic implications, digital design tools, and non-traditional knowledge boundaries are increasingly becoming assimilated into the architectural domain.

Keywords: responsive, prototyping, physical computing, smart, robotics

1. Introduction

An increasing number of projects have drawn attention to the emergence of responsive architectural applications that show various degrees of intelligence and new tectonic effects. Several architectural researchers and designers have examined the aesthetics of such architectural kinetics and have proposed taxonomies and design methodologies for this paradigm. Moloney (2011) offers a framework for architectural facades based on analytical diagrams and time-lapse images of dynamic and animated surfaces, suggesting a shift from designing the static architectural facade to an adaptable and interactive process.

The variety of relevant terms used in research and practice – pervasive computing (McCullough, 2002), interactive architecture, responsive architecture, transformable design and architectural robotics (Green and Gross, 2009) – illustrate the multidisciplinary aspects of robotic architecture. Fox and Kemp (2009) classified projects by practical needs such as environmental sustainability, aging, changing lifestyle patterns, new sensual experiences, and discussed kinetic methods such as folding, sliding, expanding, shrinking, and transforming in size and shape, and means for actuation such as pneumatic, chemical, magnetic and electrical. In this paper, a literature review and the author's research and teaching strategies of responsive architecture are examined towards developing design methods of process-driven kinetic constructs.

2. Research Approach

The objective of this paper is to offer insights into the barriers and opportunities of developing responsive architecture. The paper begins with a background section that defines the scope of responsive architecture explored in this paper. A review of relevant precedents follows to outline the challenges and opportunities. The next section describes the design process and tools used for designing and prototyping responsive architecture with examples from the author's research and teaching. Aspects of design activities, workflows, evaluation, and the role of virtual simulations are discussed.

3. Background

Responsive architecture can cover a wide range of applications from large urban scales to building skin applications and small scale installations.

Moloney (2011) reviews a range of spatial kinetic precedents and categorizes operable structure, kinetic screen, surface, and other kinetics. He lists operable or kinetic structures such as the umbrella-like structures by Güçyeter, pneumatic responsive structures by Kaas Oosterhuis, and folding/unfolding structures by Chuck Hoberman. Kinetic screens involve motion of translation, rotation and scaling. Examples include adjustable louvers, rotational screens, or small shutters. Oftentimes the purpose of these systems is to track sunlight or provide shading, and the systems are operating on pneumatic, electromagnetic, mechanical actuation. The surface category considers surfaces that operate as relief such as the undulating Hyposurface by dECOi, or Flare façade prototype by WHITEVoid, and animated relief by Ned Kahn. These systems are driven by pneumatic pistons or motorized rotations whereas Benjamin and Yang have explored shape memory alloys in gill-like apertures creating undulating surfaces. Moloney also categorizes other kinetics schemes that do not fall into any of the previous three types such as Stephen Gage's wall-climbing robots, or the Zaragoz Digital Water Pavilion, or Diller and Scofido's Blur Building of water mist at the world media expo at Lake Neuchatel in Switzerland.

Chiu (2009) characterizes tectonic themes of responsive architecture by lightness, morphing, modes of activation, and networking modes to relate materiality, construction techniques, and responsive mechanisms. He lists projects that integrate responsive lighting patterns (Toyo Ito's Tower of Wind), integrated media displays (AG4's T-Mobile Bonn Headquarter's LED media façade), or sprays of water (Blur Building by Diller and Scofidio), and dynamic shape changing surfaces and structures that communicate information or interaction such as the Hyposurface by dECOi, oframBFRA's flexible and pliable structures presenting transformable physical surfaces. Remote social interactions can be facilitated by embedded video walls, and virtual spaces can augment physical counterparts such as the Delft University based hyperbody prototype. Various sensing and activation patterns can involve human participation, ambient environmental information and result in diverse actuation patterns.

Other categories of kinetic surfaces are built with engineered materials, such as a homeostatic façade system integrating engineered dielectric elastomers-based ribbons sandwiched into a double-skin glass façade to adapt to sunlight and temperature variations2. Klooster (2009) reviews architectural applications of smart surfaces which are taking advantage of nano-technology to respond or produce energy, light, and climate.

Pask (1969) and Frazer (1993) led design investigations of cybernetics in architecture exploring the notion of homeostatis, reflexivity and emergence which are important in the design of control systems of kinetic architecture (Moloney, 2011).

A growing number of architectural educators have explored design and teaching approaches for responsive architecture. Grinham and Ku (2012) investigated the potential of interactive architecture integrating virtual and physical spaces and described their prototyping approaches. Davis et al. (2011) describe a teaching method using input-process-output diagrams and parametric modelling to prototype responsive architecture. Meyboom et al. (2010) studied the impact of collaborations between architecture and mechanical engineering students to design responsive architecture applications.

3.1 Opportunities

Many examples have demonstrated the possibilities for novel interactive aesthetics and tectonics in building skins or art installations. Involving motion, morphing of shape, color, perforations, etc., responsive architecture can engage and educate humans about changes in the environment or the relationship to other humans and the building. Sensing technology (i.e., accelerometer) used in gaming devices such as the Xbox Kinect or Wii Remote is incorporated into wearable smart devices to sense and track user movement and offer information on user activity duration, intensity, and sleep quality. More benefits than seen in smart devices and appliances can be achieved through architectural applications by selecting appropriate sensors, actuators combined with smart algorithms. Depending on the type of sensors, the architectural applications can be responsive to human or environmental inputs, in order to facilitate social or cultural interactions, or environmental performance. While some systems involve microcontrollers that can be programmed with different levels of intelligence and changing responses, others depend on pre-engineered smart characteristics of materials or nano-technology resulting in homeostatic, thermo- or photo-active, phase change material. This paper excludes such applications that are non-programmable.

Responsive architecture can be individual units or locally networked to exhibit swarm like behavior, or linked over the internet with other systems (i.e., the internet of things), in which case the collective intelligence of systems and humans can be harvested. The vast data collected via kinetic systems, can offer feedback on user behavioral patterns, environmental performance, and assist analyzing building performance as part of a regional network of neighborhoods. Self-learning algorithms have the possibility to recognize patterns over time and offer suggestion for improving the relationships between the user, the environment, and the architectural system.

3.2 Challenges

At the same time, these opportunities pose challenges to the architect and students. Robotics technologies offer new tools for the designer to understand the dynamic relationships between the environment, the user, and the architectural systems. Using the new toolsets of robotics, the architect needs to design a process that allows identifying the relationships that are most important and helps finding adequate forms.

The primary challenges include: (1) the wide range of technologies offer endless opportunities to be embedded into various scales and scopes of the built environment. This openness poses challenges to the designer determining the appropriate applications, adequate technologies, feasibility of the new systems, and implementation challenges; (2) kinetic architectural systems require integrative design processes with new compositional systems, cybernetics, and mechatronics, which are external to the traditional boundaries of architecture; (3) the application of real-time sensing and actuating and wired or wireless connectivity requires design process and tools that can incorporate the vast amount of data. While kinetic systems offer exciting visual characteristics, without properly understanding the balance and relationship between the user, environment and the architecture, the solution may be reduced to an artistic installation.

As outlined above, a few architectural researchers have focused on classifying applications (Fox and Kemp, 2009) or defining tectonic implications of kinetic or responsive architecture (Moloney, 2011; Chiu, 2009). However, there is a general lack of frameworks that integrate process and product of responsive architecture into architectural design and teaching. The next sections explain the authors' design research and teaching efforts attempting to establish approaches and frameworks that would help addressing these challenges.

4. Design Research and Teaching

The author started in the spring of 2010 design research and has taught over the past four years design studios focusing on architectural robotics. Each year a different topic has been selected to facilitate the students' investigations in order to identify potential areas to be studied, to define and develop knowledge of key robotics technology, and to establish prototyping approaches:

- 2012 Spring Design Studio: Responsive bus/train shelter (architecture students)
- 2013 Spring Design Studio: Responsive building skin (architecture students)
- 2014 Spring Design Studio: Smart campus interventions (architecture & industrial design students)
- 2015 Spring Design Studio: Smart home of the future (architecture & engineering students)

These studios were taught in one semester typically divided into two parts starting with skill-building of robotics utilizing the Arduino microcontroller and Processing or Rhino Grasshopper/Firefly programming interfaces, followed by applying those skills to a team project involving design and prototyping for an architectural design.

Figure 1 illustrates a framework overlaying architectural robotics on a framework developed by Hensel (2010) for performance-oriented architecture. Four agencies are redefined, reinforced and rearranged with the integration of robotics. This framework is useful in mapping four domains that effect architectural design processes and helps to explain the relationship of architectural robotics to those four domains of agency. Accordingly, the architectural design process needs to identify the relevant aspects that can be enhanced through the application of architectural robotics and define a process to integrate and implement the new technologies.

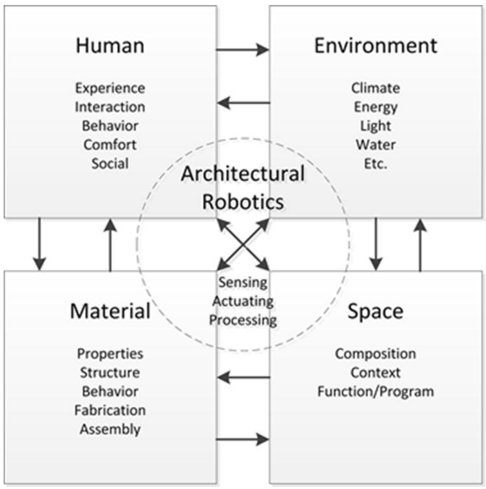
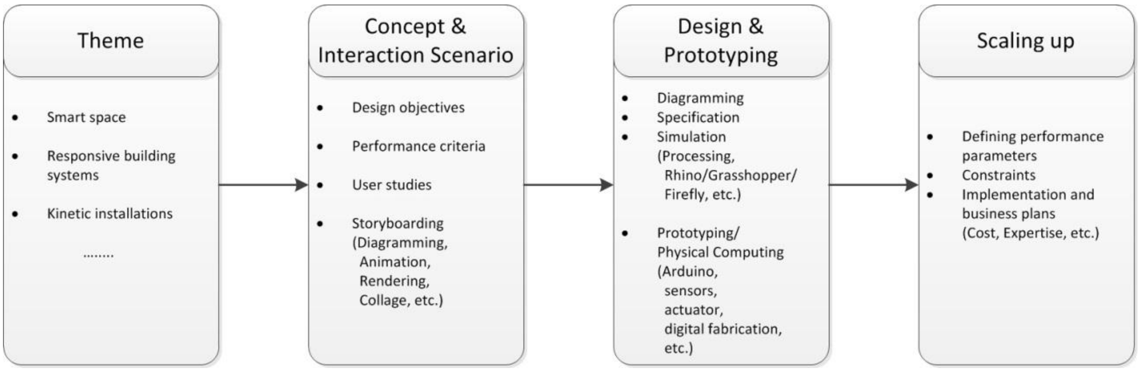


Figure 1: Four domains of agency reconnected through architectural robotics (adapted from Hensel (2010)).

Adapting the framework of Hensel (2012), the design of kinetic architectural surfaces can be structured as a matrix of interrelated design techniques with embedded feedback loops. The matrix can be entered from any point. The human subject would involve a process of defining user values, needs, experience expectations, and interactions (i.e., social, architectural, environmental). Such investigations align with industrial design strategies which attempt to identify specific market needs.

Figure 2 illustrates the author's process map used for his own design research and studio teaching. Thematic explorations such as responsive building skin, kinetic shelter, smart home, or smart campus, provide the context within which specific spatial applications, site, and program, can be established. In a studio setting the larger theme is typically assigned by the instructor. Within the theme, the next step involves establishing design goals through needs assessment and investigations to develop the concept. The spatial, environmental and human domains are studied to select, define and refine site, program, and the need for responsive applications. Architectural concepts and interaction scenario are developed through storyboarding, animations, and feedback through user experience testing. Environmental agency of the natural, social and cultural agents, are conceptually diagrammed and become part of the architectural concept.

Figure 2: Design process map for kinetic architectural surfaces.



During design development and prototyping stages, the qualitative and quantitative input and output values are parameterized, codified to be processed by the microcontroller of the kinetic system. Virtual and physical simulations are used to learn from the environments. The material domain involves form finding processes for the kinetic constructs. Through physical experiments material properties and behavior and geometric arrangements are studied.

In addition, parametric modelling tools and simulation tools are brought in to support development, analysis and fabrication of kinetic constructs. Through an iterative process of simulations, material explorations, details of kinetic connections, actuation mechanisms are developed, studied, and improved. Visualizations (renderings, collages, animations) are utilized to extrapolate material developments to larger implementations, to understand and gather material and human feedback during this process. This process ultimately often starts from prototyping individual modules that are to be replicated to build a swarm of units that show collective intelligence in an architectural context. Typically the tectonic implications of the constructs and the architectural interfaces are an important feature of the design development process. The kinetic construct incorporating the sensing and actuating components, demand programming (Arduino microcontroller and visualization interfaces, i.e., Processing, Rhino Firefly) to refine the intelligence and behavior of the responsive system.

5. Student Project Examples

The studio is offered as a fifth year spring semester studio in an accredited undergraduate architecture program. As part of the studio, students learn through weekly workshops various digital tools including Processing (a visual programming tool), Arduino programming and circuits using sensors and actuators, and research additional applications such as Firefly. In earlier years, students are taught other tools including Rhino3D, Grasshopper, 3D Studio Max, and skills in visualization, diagramming, and rendering. These skills help them to define and represent user experiences and interaction scenarios which involve storyboarding and visualizations, gathering user feedback and defining design specifications for evaluating project success.

The following stages involve implementing kinetic mock-ups which integrate the use of rapid prototyping and digital fabrication tools. Kinetic constructs are an important medium in their design explorations which progress through iterations of physical models to Arduino controlled models with sensors and actuators. When possible, the studio has collaborated with industrial design or mechanical engineering students and faculty to complement necessary knowledge and skills of kinetic architecture. Each year, in the studio context different architectural themes have been provided by the instructor. Examples include responsive façades, kinetic shelters, smart campus interventions, and smart home applications. The application can be for retrofitting existing facades, interior shades, outdoor spaces, or designing new buildings.

The themes can be concentrated on specific components such as a responsive façade or kinetic shelter, or be more open-ended designs such as smart campus or smart home which require identifying and defining application areas within a larger design problem. Within the studio context, the students are tasked to select a site for their projects. Table 1 lists the project teams and project titles and schemes proposed by students for the spring 2015 semester which explored responsive architecture concepts for the 'smart home of the future'.

The descriptions of the projects provide a brief overview of the specific functional programs defined by the students within the context of the future smart home. These concepts are developed through research identifying a specific site and defining market needs that demand or justify the application of responsive technologies. These concepts either involved remodeling of existing buildings or new construction. Another possibility is the application of smart systems that integrate spatial systems with wearable technologies such as the scheme for assisted living. Such applications require the development of various user interfaces which require different approaches than facades or spatial partitions. While the students were allowed to choose their own applications for a smart home, the table shows that six out of seven teams decided to design kinetic daylighting and/or shading systems (i.e., ceiling, screen, skylight), and only one team chose to work on an assisted living system. This illustrates that the majority of students considered kinetic systems to be beneficial and viable in improving the traditional daylighting or shading issues of residential spaces.

Table 1: Spring 2015 project teams, titles, and schemes

Projects Title	*Team members*	*Description*
Canvas	*Kevin Ryan*, Andrew Cook*, Emmanuel Nyinaku***	*Interactive ceiling for deep warehouse remodeled into residential spaces that adjust to optimize daylighting*
Responsive veil	*Anne Marie Amisola*, Stefan Lesiuk*, Mathew Germani***	*Responsive exterior screen to control daylighting and views*
Assisted living system	*Bong Hei Wong*, Bruce Garnett*, Devin Bachurski***	*Responsive living system that evolves with the inhabitants as they age*
Slide	*Iulia Cazan*, Matt Otricelli*, Thomas Attamante**, John Fredericks***	*Exterior shading system for high-rise buildings facilitating daylight and view control*
SMARTrowHouse	*Mateusz Plewa*, Emma Lindsey*, Brandon Capone***	*Integrated artificial ceiling lighting system for deep row home spaces that optimizes user control and daylighting*
Mimosa Wall	*Ha Pham*, Christian Kaulius*, Parth Patel**, Nail Rachad***	*Interactive wall screen creating for shading and exterior wall patterning*
Flex space	*Matt Fisher*, Brent McDonnell*, Wade Cassisi***	*Responsive skylight system for solar and shading control in row houses*

* Architecture student

**Engineering student

As the program, site, and massing concepts evolve, the design focus shifts to refining interactive scenarios and the specific applications of responsive systems and kinetic constructs. Interactive tools such as Processing and Grasshopper/Firefly support visualizing and studying the behavior of interactive systems in response to environmental and human inputs. About half of the design effort is spent developing a functioning prototype or mockup which incorporates real-time sensing and actuating devices and a microcontroller. Students often develop novel mechanic systems to implement motions of responsive components such as kinetic shading systems. The development leads to understanding the swarm behavior of individual modules and finally the understanding of the issues of scaling up from a prototype to a fully functioning prototype and final commercialized product. Below are a few examples that show some of the design development aspects of other studio years. The spring 2013 studio focused on designing responsive building envelopes for high-rise buildings, and the spring 2014 studio concentrated on improving existing University campus exterior and interior spaces.

5.1 Responsive Building Skin (spring 2013)

Figure 3 is a student project focusing on retrofitting the building skin of a residential high-rise in Philadelphia into a responsive shading screen. The site and building were selected by the students. The students developed animations in 3DS Max to study the kinetic pattern of the entire façade and interior renderings to evaluate the impact on daylighting. The prototype development involved multiple iterations to define the mechanisms of translating the rotation of a standard servo motor which rotates only 180 degrees into linear sliding motion of expansion and contraction of circular shading module. The modules were then assembled into nine identical units which were programmed to show a pre-programmed patterning sequence of contraction and expansion, and responsive actuation to adjacency sensors (infrared sensors) and photocells to respond to change of daylight conditions.

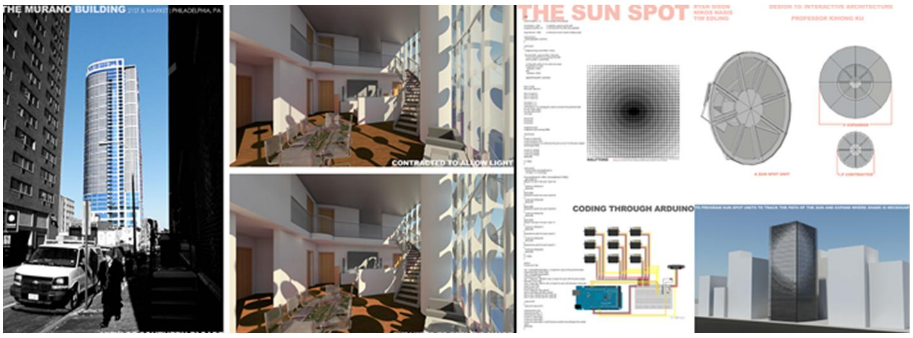


Figure 3: Responsive building skin retrofitting (by Nikos Nasis, Ryan Sison, Timothy Edling).

5.2 Responsive Interior Shading Screen (spring 2014)

This project aimed to transform the Philadelphia University campus into a smart campus. The team selected the Student Center common area and introduced a sun shading screen which interactively lights up based on the social interactions happening in the space.

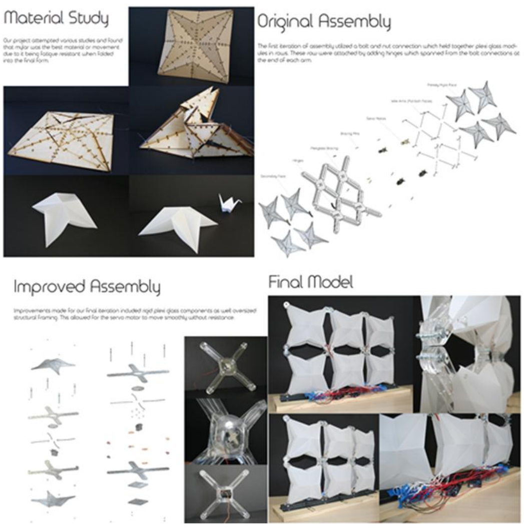


Figure 4: Kinetic construct form finding studies (by Ryan Doll and Brandon Lansing).

The system responds to users via embedded floor pressure sensors and LEDs and the shading components are activated by photocells. Figure 4 shows iterations of the kinetic construct and assembly. Form finding started with the mock-up. The overall scheme and concept was developed through sketch and renderings, followed by scale models to first develop a kinetic construct that was manually manipulated. Once material properties, behavior and assembly logics were understood, the construct was equipped with sensors and actuators connected to a microcontroller.

There are a variety of open source programmable microcontrollers (e.g., Raspberry PI, LaunchPad, Arduino). The studio adopted the Arduino platform as it provides an easy to adapt off-the-shelf platform which is built on top of the open source Processing language. Arduino and Processing are compatible with USB serial connectivity to the computer, and the Rhino3D Grasshopper Firefly plug-in. The Arduino can directly accommodate various sensors, and connect via the computer to camera, Kinect, or the internet.

6. Conclusions

This paper discussed various methods and frameworks of responsive architecture. Literature review shows the variety of kinetic effects available with current technology and the cross-disciplinary characteristics involving cybernetics, robotics, mechatronics, etc. Simultaneously, the author's research and teaching illustrated the applicability of such existing frameworks and differences in academic settings. Existing literature offer points of departure and valuable precedents for studying tectonics, kinetic patterns, cybernetic control systems, and understanding of the interrelationships between technology, architecture, behavioral aspects, and material production. The literature review highlighted the gap of design frameworks for kinetic architecture. There were questions about how to do identify and design for the many possible applications in the built environment such as specific building systems (i.e., building envelope), or specific spaces (i.e., residential, commercial), or urban scale vs. building scale.

In comparison to applications in practice, a number of issues to be addressed in the academic studio environment were discussed in detail: (1) the importance of spatial theme and concept generation in student projects. It is important to offer design problems beyond the constraints of a kinetic building façade to allow students examine the broader implications of kinetic technology. When architecture students are exposed to microcontrollers, sensors, and actuators, the technological excitement sometimes drives the architectural concepts towards a specific technology such as the use of a Kinect sensor or EEG sensor rather than carefully identified user needs and experiences. (2) Higher order cybernetics concepts beyond homeostasis, towards reflexivity, and emergence are difficult concepts for architecture students to apply and implement. Students need to be exposed to such computational concepts earlier in the curriculum. (3) There are benefits and needs for collaboration with students and faculty from mechatronics, industrial design, psychology, etc. Through personal experience, such collaborations require careful coordination to align and bridge the rational boundaries of the disciplines. (4) The impact of open source software, hardware and examples. The Arduino and Processing community encourages hacking examples and the technology to learn and share new techniques and ideas with the broader community. Students are encouraged to pursue independent research beyond the classroom to achieve their design goals. (5) The implications of prototyping: More than half of the students' semester long efforts are geared towards prototyping to design with and understand the technology, and the impact of time-based interventions. Programming, applying sensors and actuators, parametric design thinking and time-space relations of kinetic systems determine complex system behavior over time. While designing dynamic environments requires architects to rethink their role and the role of computing in design, the shift indicates that non-traditional knowledge areas can be and are gradually assimilated into architecture.

Endnotes

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Community stakeholder perspective on construction industry-related needs and skills for enhancing disaster resilience

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Abstract

Although scientific research community has shown increased interest in enhancing disaster resilience of societies, yet effort at identifying the needs and skills of stakeholders affected by disasters has not received adequate attention. Therefore, the purpose of this study is to identify and assess the needs and skills of communities affected by disasters from four different countries. Community as one of the stakeholders in disaster resilience is considered as respondent in this study, due to the fact that they are on the frontlines of both the immediate impact of a disaster and the initial emergency response. Thus, identification of specific needs and skills requirement for the community in enhancing disaster resilience becomes imperative. The study adopted literature review and semi-structured interviews. The interviews were conducted with fifteen purposively selected experts in four different countries to include the UK, Estonia, Lithuania, and Sri Lanka. Data obtained were analysed using Nvivo (version 10). The study identified different needs and skills of communities related to built environment professionals towards enhancing disaster resilience. The identified needs and skills were grouped into five disaster resilience dimensions. This includes economic, environmental, institutional, social, and technological dimensions of disaster resilience of societies. These five groups were further structured into five different stages of the property lifecycle to include preparation, design, pre-construction, construction and use stages of a property development. Also, the overall identified needs and skills at different disaster resilience dimensions were filtered to generate twenty-nine major classifications of skills and needs of communities in enhancing disaster resilience of societies. This study would be beneficial to all construction professionals and other stakeholders in developing their competencies on the main classifications of needs and skills of communities identified in this study.

Keywords: Communities, Construction professionals, Education, Disaster resilience

1. Introduction

Today, it is increasingly evident that the unprecedented frequency and costs of natural disasters and the projected increase in their severity due to climate change are posing significant economic challenges and new risks for vulnerable communities (World Economic Forum, 2008). For instance, the projections of Swiss Reinsurance Company indicates that the flooding in Great Britain and Hurricane Dean in the Caribbean cost the global reinsurance industry US$35 billion compared to US$12 billion for natural disasters in 2006 (WEF, 2008). This is corroborated by World Bank (2013) reports that between 1980 and 2012, the estimated losses due to a different form of disasters amount to about US$3.8 trillion. In which, hydro-meteorological disasters accounted for 74% (US$2.6 trillion) of total reported losses, 87% (18,200) of total disasters, and 61% (1.4 million) of total lives lost. Against this backdrop, Asia-Pacific Economic Cooperation (2010) avers that the core values of a society cannot be entirely protected at all times and the disruptions are inevitable. It is on this premise that UNISDR (2007) emphasises that communities are on the frontlines of both the immediate impact of a disaster and the initial emergency response. APEC (2010) reports that economies have shifted from a protection focus to resilience focus; thus disaster resilience is gaining importance as a core conceptual approach to building capacity in economies in the disaster-prone regions to respond and recover from impacts. This is affirmed by World Bank (2013) that disaster can be reduced by strengthening resilience: the ability of societies to resist, cope with, and recover from shocks.

Therefore, in a globalising world there is a considerable interest in disaster resilience as a mechanism for preparedness, mitigation, response, and recovery. Due to this, many countries across the globe as well as many international organisations like United Nations International Strategy for Disaster Reduction (UNISDR), World Bank among others are geared efforts toward strengthening disaster resilience, and adopting policies that emphasise the importance of community disaster resilience as a priority for preparedness. For example, in 2005, 168 countries drafted and approved the Hyogo Framework for Action (HFA) at the World Conference for Disaster Reduction, held in Kobe, Japan. The HFA provides guidance for achieving a set of outcomes and results towards reducing disaster risk over ten years (2005-2015) (UNISDR, 2005). This triggered a number of studies on disaster resilience. Many of these previous studies were focused on disaster risk reduction (see Camilleri, 2006; Jayawardane, 2006; Bosher *et al*., 2007, 2007b; Kaklauskas *et al*., 2009; RICS, 2009; UNISDR, 2009; Mercer, 2012) among others. Few researchers also focused on disaster resilience education (see Thayaparan *et al*., 2010; Amaratunga *et al*., 2011; Siriwardena *et al*., 2013; Perdikou *et al*., 2014; Zhou *et al*, 2014; Thayaparan *et al*., 2015) among others. In spite of these studies on disaster resilience very few studies attempted to identify the needs and skills of communities affected by disasters (see Perera *et al*., 2015). Having aware of this gap, this study, therefore, becomes imperative with a view to identifying the specific needs and skills requirement for the community as a stakeholder in enhancing disaster resilience. Thus, achieving disaster resilient communities require a long-term shared responsibility among the stakeholders in the wider environment. In this regard, these study findings would be beneficial to construction professionals and other stakeholders in fostering their competencies towards enhancing disaster resilience of communities at large.

2. Concept of disaster resilience

The concept of resilience has received both theoretical and empirical attention across different fields. This is corroborated by Molin-Valdes *et al*. (2013) that concept of resilience has increasingly popular across academic and policy debates as a way of reducing society's vulnerability to threats posed by natural and human induced hazards. This is further acknowledged by Alexander (2013) that the concept of resilience has been widely adopted and adapted by many disciplines. Christopherson *et al*. (2010) assert that growing popularity of research on resilience is due to insecurity and uncertainty afflicting people across the world. This is affirmed by Modica and Reggiani (2015) that the uncertainty due to the interconnections between economic and environmental crises in the current global networks necessitated the growing attention being paid to resilience. Martin (2012) identifies four major reasons why researchers focusing on the concept of resilience: (i) the impact of natural and man-made disasters afflicted communities; (ii) recognition that major disruptions can affect the whole economic landscape; (iii) the influence of other disciplines, such as ecology, where the main interest is on how ecosystems respond to shocks; and (iv) the effect at both local and regional levels of financial and economic crises and their consequences, due to the austerity policies pursued by many states. Against this backdrop, Carlson *et al*. (2012) recognise the concept of resilience as a multifaceted notion that can be managed differently according to different objectives. Based on this, Modica & Reggiani (2015) conclude that researchers interested in investigating the concept of resilience more deeply may be hindered by the range of definitions, classifications and uses of resilience. This could be attributed to the fact that the term resilience has been used across a wide range of academic disciplines and in many different contexts. For instance, in physics and mathematics (see Brown & Kulig, 1996; Bodin & Wiman, 2004). In psychology expanded to include community and social resilience (see Chenoweth & Stehlik, 2001; Adger, 2000). In ecology expanded to social resilience (see Adger *et al.*, 2005; Gunderson & Folke, 2005).

Similarly, within the context of disaster resilience; resilience has been described by a number of researchers, the most common definitions of resilience relates to the capacity of a society to "bounce back", cope, withstand, "resile from" or "spring back from" a shock (see Cutter *et al*., 2009; Béné *et al*., 2012). Further, Béné *et al*. (2012) and Cutter *et al*. (2008) assert that resilience has two major characteristics: (i) a capacity to recover from shocks, and (ii) a degree of preparedness. It is noteworthy to state the definition of resilience by UNISDR (2009), due to its comprehensiveness and acceptability in both industry and academia. Thus, UNISDR (2009) defines resilience as: "the ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions". Concerning community resilience UNISDR (2009) further reports that: "the resilience of a community in respect to potential hazard events is determined by the degree to which the community has the necessary resources and is capable of organising itself both prior to and during times of need". It can be deduced that community resilience is about the continued ability of a community to function during and following a disaster. Thus, there is a need for all stakeholders' contribution towards building community disaster resilience.

2.1 Disaster resilience dimensions

There are varieties of domains and indicators used for community disaster resilience. For instance, Twigg (2009) identifies 28 components of resilience, which are grouped into five major thematic areas: governance, risk assessment, knowledge and education, risk management and vulnerability reduction, and preparedness and response. Cutter *et al*. (2010) identify 36 baseline indicators used to measure and monitor the resilience of communities to disasters. Further, Cutter *et al*. (2010) assert that the resilience of a particular community is based on an aggregated resilience index, and therefore categorize community disaster resilience domains into five main categories including social resilience, economic resilience, institutional resilience, infrastructure resilience, and community capital. Burton (2012) identifies six dimensions of resilience, which are called variables. These include: social, economic, institutional, infrastructure, community capital, and environmental resilience. In the same vein, within the context of disaster knowledge factors (i.e. factors that enhance knowledge of managing disasters successfully) Pathirage *et al*. (2012) classify the knowledge factors into eight major categories including: technological, social, environmental, legal, economic, operational/managerial, institutional and political factors based on their characteristics. It is, therefore, evident that there are varieties of domains or dimensions used for community disaster resilience assessment. In this regard, this study would focus on five broad categories of dimensions or domains of resilience including: economic, environmental, institutional, social, and technological dimensions with their property five-stage life cycle to include preparation, design, pre-construction, construction, and use stage. This is illustrated in Figure 1 as follows:

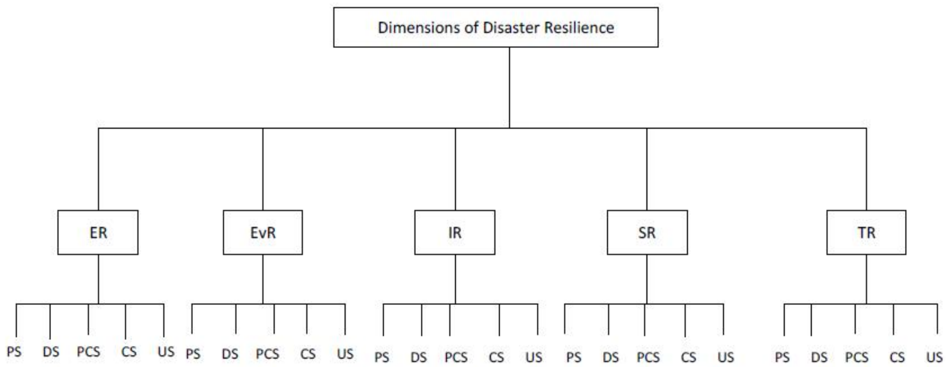

Figure 1: Dimensions of disaster resilience with their property lifecycle stages

Resilience Dimensions: ER-Economic Resilience; EvR-Environmental Resilience; IR-Institutional Resilience; SR-Social Resilience; TR- Technological Resilience

Property Lifecycle Stages: PS-Preparation Stage; DS-Design Stage; PCS-Pre-Construction Stage; CS-Construction Stage; US-Use Stage

It is believed that the aforementioned dimensions of resilience with their property lifecycle stages (see Figure1) covered all the dimensions of resilience identified by previous researchers.

3. Research methodology

The study area, which include the UK, Lithuania, Estonia, and Sri Lanka were selected in terms of disaster impacts like the flood in the UK, Lithuania & Estonia, and Tsunami in Sri Lanka. The study adopted literature review, brainstorming session, interviews, and expert group. The outcome of a comprehensive literature review produced the dimensions of disaster resilience with their property lifecycle (see Figure 1), which form the basis of inquiry for the data collection and analysis. Thus, the outcomes of literature review were subjected to internal brainstorming comprised four researchers and academia in the built environment, which have practical experience of communities affected by disasters with a view to developing and fine-tuning the interview questions. This is, therefore, addressing potential interpretation difficulties of some disaster resilience terminologies.

Semi-structured interviews were conducted on fifteen "community" stakeholder group purposively selected from the aforementioned countries. This approach is similar to the research work by Thayaparan *et al.* (2015) that conducted ten interviews with experts in the higher educations. Purposive sampling technique is adopted because this study involved only respondents that have either experienced disaster events as a member of an affected community or respondents that were deeply involved in the reconstruction and recovery of disaster affected communities. This is supported by a number of earlier researchers. For instance, Marshall (1996) asserted that purposively sampling technique enables the researcher to select the most productive participant. Blaxter *et al*. (2006) advocated for non-probability sampling when the researcher lacks a sampling frame of the target population for the study. The interviews were conducted face-to-face, and each interview lasted between 50 minutes and 60 minutes. During the interviews, the focus was on the needs of communities, and the skills required from construction industry professionals serving these communities. Thus, the interviews were more of a discourse structured around the stages of disaster management cycle. The interviews were recorded using a digital voice recorder and notes were taken during the interviews that were conducted in the second half of 2014. Detailed transcripts were prepared for each interview, resulting in fifteen full transcripts.

The fifteen full transcripts from respective interviews were analysed using thematic coding through Nvivo (version10). During the analysis using Nvivo, the themes were presented under two major headings: (i) Needs; and (ii) Skills. The "Needs" cover both the desires and expectations of interviewees during disaster experience, and what should be in place while professionals are working with them in enhancing community resilience. Similarly, some set of skills were identified comprising those displayed by professionals involved in the reconstruction and recovery of disaster affected communities, and those desired/or expected by interviewees. Therefore, all the identified "Needs" and "Skills" were further categorised into five dimensions of resilience (i.e. Economic, Environmental, Institutional, Social, & Technological) and each of the dimension of resilience is sub-headed with the five stages of property lifecycle to include: Preparation, Design, Pre-construction, Construction and Use stage (see Figure 1). In this regard, similar identified "Needs" and "Skills" were mapped to derive classifications encapsulate the "Needs" and "Skills" of communities related to professionals towards enhancing economic, environmental, institutional, social, & technological dimensions of disaster resilience of communities.

In addition, the derived classifications were presented to an expert group involved in CADRE (Collaborative Action towards Disaster Resilience Education) from five different countries in June 2015. These group of experts comprised thirteen professionals, researchers and academia in the built environment, which have vast experience in disaster management skills and knowledge among others. The thirteen groups of experts carefully checked and refined the derived classifications under respective dimensions of disaster resilience with their property lifecycle stages. This led to final classifications of "Needs" and "Skills" towards enhancing disaster resilience of communities. The expert group, therefore, suggested recommendations on how the aforementioned classifications can be used to update and upgrade the built environment professionals' competencies and other stakeholders at large.

4. Results and analysis

The outcome of semi-structured interviews using Nvivo (10 version) for the analysis produced a long list of 'Needs and Skills' expected of the construction industry professionals while serving communities in disaster-related situations under the respective dimensions of disaster resilience with their property lifecycle stages. Thus, due to the limitation of space, the sample portion of identified 'Needs and Skills' is presented in Figure 2 as follows:

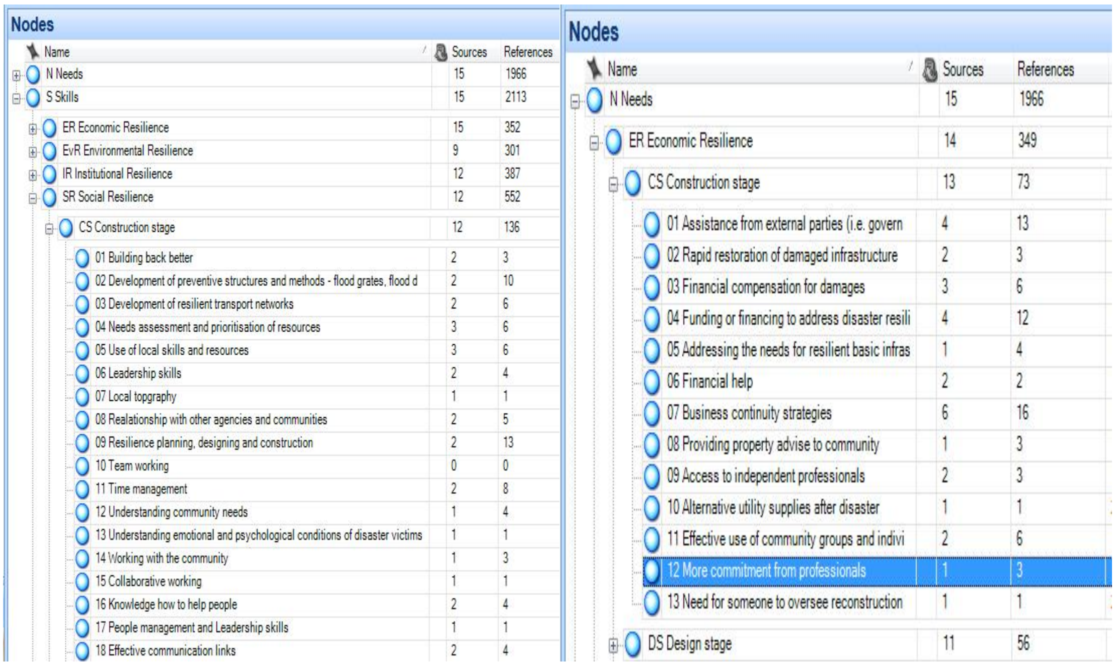

Figure 2: Sample portion of identified 'Needs and Skills' under the respective dimensions of disaster resilience with their property lifecycle stages

Table 1 indicates the twenty-nine final major classifications derived from the identified "Needs" and "Skills" (i.e. after combining similar "Needs" and "Skills" like-for-like) in each respective dimension of disaster resilience and their property lifecycle stages. Further, the final major classifications emanated in each dimension of disaster resilience with their respective stages of property lifecycle were numbered/or coded between 1 and 29 (see Table 1). For example, at Economic Resilience (ER) with its property lifecycle stages comprising Preparation Stage (PS), Design Stage (DS), Pre-Construction Stage (PCS), Construction Stage (CS), and Use Stage (US), the total major classifications emanated in each stage are 14,13,11,12,and 11 respectively (see Table 1 details).

Also, for more clarity Table 2 provides the descriptions of the twenty-nine major classifications derived with their sample portions of the identified 'Needs and Skills' under each major classification derived (see Table 2 for details).

Table 1: Coding of the twenty-nine classifications into the dimensions of disaster resilience and stages of property life cycle

Dimensions of resilience	*Stages of property life cycle*				
	PS	*DS*	*PCS*	*CS*	*US*
ER	*1,2,3,4,9,11,14, 15,16,17,19,20, 23,24*	*1,2,3,4,9,14,15,16, 17,23,24,25,26*	*1,2,3,4,5,11,14,17, 20, 23,24*	*1,2,3,4,9,11,14,16, 17,20,23,24*	*1,4,8,9,11,14,15, 17,23,24,26*
EvR	*6,8,9,12,15,16,25, 27*	*6,9,12,15,16,27,10*	*9,12,15,27*	*6,9,12,15,16,27*	*8,9,12,15,16,27*
IR	*4,6,7,8,9,10,11, 12,13,14,15,16, 17,18,19,20,21, 22,23*	*4,6,7,9,10,11,12, 13,14,15,16,18,19, 21,22,23,28*	*3,4,5,6,7,10,11,12, 13,17,18,19,21,22, 23*	*4,6,7,9,10,11,12, 13,14,15,16,18,19, 21,22,23,24,*	*4,6,7,9,10,11,12, 13,14,15,16,19,21, 22,23,24,26,27*
SR	*3,4,5,6,8,9,10,11, 12,14,15,16,17, 18,19,22,23,24,28*	*3,4,6,8,9,10,11,12, 15,16,18,19,22,23, 24,25,28*	*3,5,8,10,11,12,13, 14,15,18,19,22,23, 24,*	*3,4,6,8,9,10,11,12, 14,15,16,18,19,22,2 3,24,28*	*3,4,8,9,10,11,12, 15,16,19,22,23,24, 27,28*
TR	*3,4,6,8,9,12,15, 16,19,26,29*	*3,4,6,9,12,15,16,1 9, 24,26,29*	*3,4,6,9,12,15,19, 24,29*	*3,4,6,9,12,15,16,19, 24,29*	*4,6,8,9,15,16,19,26, 27,29*

Note: Dimensions of resilience: Economic Resilience – ER, Environmental Resilience – EvR, Institutional Resilience – IR, Social Resilience – SR, and Technological Resilience – TR.

Stages of property lifecycle: Preparation Stage – PS, Design Stage – DS, Pre-Construction Stage – PCS, Construction Stage – CS, and Use Stage – US

Table 2: Descriptions of the twenty-nine major classifications with their sample portion of the identified needs and skills

1. Budgeting & financial planning - Fund sourcing and financial management skills -Funding or financing to address disaster resilience -Financing flood adaptation strategies	**10. Quality leadership & people management** -Objective consideration of issues-Flexibility -Understanding the community needs -Leadership skills	**19. Communication & negotiation/Information systems** - Language (familiarity with local language) and communication skills - Effective communication links - Negotiation skills
2. Quantification & costing of construction works -Budgeting and estimating construction costs -Pricing and estimating-Construction works	**11. Team working** -Effective use of community groups & individuals -Engaging community - Relationship with other agencies and communities	**20. Project audit & reporting** - Knowledge of loss assessment and loss adjustment - Auditing skills
3. Supply chain management -Alternative utility supplies after disaster	**12. Governance** -Transparency and accountability in adopted processes - Minimising political interferences	**21. Management & dispute resolution procedures** - Knowledge of dispute resolution
4. Consultancy services -Assistance from external parties (i.e. government; NGOs; Private sector, etc.) -Providing property advice to community	**13. Stakeholder management** - Clarity on roles and responsibilities of different parties - Multi-stakeholder engagement	**22. Cross-cultural awareness in global resilience** - Familiarity with local language - Use of local skills and local knowledge
5. Procurement & contract administration/practice -Advice to community on selection of contractors and consultants -Selection of consultants and contractors - pre-qualifications	**14. Business planning** - Temporary business area - Business continuity strategies/plans - Business protection - Needs assessment and prioritisation of resources	**23. Project management** - Project management skills **24. Asset/Resource management** -Use of local skills and resources - Prioritisation of resources
6. Building regulation & planning -Resilience planning, designing and construction -Knowledge on land-use planning	**15. Environmental assessment** - Weather changes monitoring - Awareness of potential disaster threats - Forecasting and warnings	**25. Disaster management** - Management of disaster relief **26. Risk management** - Disaster risk assessments
7. Legal/Regulatory compliance -Knowledge of prevailing laws, need for the flexibility of laws and policies	**16. Management of the built environment** - Development of preventive structures and methods	**27. Continuing professional development** -Awareness & education on disaster resilience
8. Health & safety -Temporary housing provision -Availability and identification of suitable alternative place to relocate	**17. Insurance** - Financial compensation for damages - Knowledge and awareness on insurance - Property insurance - Adequacy of insurance cover	**28. Emergency management** - Rapid recovery after an onset of a disaster - Management of emergency shelters
9. Work progress & quality management -Rapid restoration of damaged infrastructure -Better infrastructure needs	**18. Time management** - Time management	**29. Construction technology & environmental services** - Knowledge on resilient construction practices

5. Discussion of findings

The study identified various needs and skills, which are matched like-for-like and filtered to produce twenty-nine major classifications of needs and skills expected of the construction industry professionals in enhancing disaster resilience of communities affected by natural disasters. The twenty-nine major classifications derived with their respective disaster resilience dimensions and property life cycle stages are briefly discussed as follows:

Economic resilience (ER): The study reveals a total of 18 (out of 29) major classifications emanated from the identified needs and skills requirements for enhancing economic resilience with their respective property lifecycle stage. Thus, the prevalent classifications include budgeting and financial planning, quantification and costing of construction works, insurance, supply chain management, consultancy services among others (see Table 1 & 2 for details).

Environmental resilience (EvR): In enhancing environmental resilience with their respective property lifecycle stage, the study indicates a total of 8 (out of 29) major classifications derived from the identified needs and skills under environmental resilience (see Table 1 & 2 for details). The common major classifications are work progress and quality management, governance, environmental assessment, management of the built environment, continuing professional development**.**

Institutional resilience (IR): The study shows the overall of 25 (out of 29) major classifications emanated from the identified needs and skills in enhancing institutional resilience with their respective property lifecycle stage. These include consultancy services, building regulation and planning, legal/regulatory compliance, quality leadership and people management, management and dispute resolution procedures, cross-cultural awareness in global resilience among others (see Table 1 & 2 for details)

Social resilience (SR): The study further reveals a total of 22 (out of 29) major classifications derived under social resilience with their respective property lifecycle stage. This includes supply chain management, health and safety, quality leadership and people management, team working, governance, stakeholder management (see Table 1 & 2 for details).

Technological resilience (TR): The study indicates the overall of 13 (out of 29) major classifications produced from the identified needs and skills in enhancing technological resilience with their respective property lifecycle stage (see Table 1 & 2 for details). The prevalent classifications are supply chain management, consultancy services, building regulation and planning, work progress and quality management, risk management, construction technology and environmental services.

6. Conclusions

Understanding and enhancing knowledge on disaster resilience among construction professionals continue to be a matter of significance and importance. Thus, identification of specific needs and skills requirement for the communities in enhancing disaster resilience becomes imperative. As communities are on the frontlines of both the immediate impact of a disaster and the initial emergency response; thus the receivers of all what other stakeholders in disaster resilience have to offer. Against this backdrop, this study identified different needs and skills requirement expected of the construction professionals across the dimensions of disaster resilience with their property lifecycle stages in enhancing disaster resilience of communities affected by natural disasters. The study, through a comprehensive desk review and selected expert group involved in CADRE (Collaborative Action towards Disaster Resilience Education) harmonised like-for-like the identified needs and skills across the dimensions of disaster resilience with their property lifecycle stages to produce a total of twenty-nine major classifications of skills and needs of communities in enhancing disaster resilience of societies. It is believed that this study would be beneficial to all construction professionals and other stakeholders in developing their competencies on the main classifications of needs and skills of communities identified in this study. These study findings would further be useful for professional bodies such as CIOB, RICS, ICE, and RIBA to review and upgrade their existing programmes.

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Resilience of Inner City Real Estate Development - Challenges For The Built Environment - An Austrian Case Study

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Abstract

Urbanism and future demographic changes are demanding new approaches for contemporary city development. Cities are growing and living space in inner cities is already a rare commodity. Therefore it is necessary to understand, what it takes to satisfy the needs of future cities. Even though these problems are well known, too little new living/housing space is available and the potentials of existing inner city housing stocks often remain unused.

The objective of this contribution is to show why the redevelopment in the built environment plays an increasingly important role in the construction industry in Austria. Redevelopment can be regarded as a necessity and accompaniment of new development. With the help of a SWOT-Analysis, criteria for the redevelopment of real estate in a built environment can be identified. The results can further be combined with costs for different improvement measures of the structures and equipment of buildings to calculate its economic performance. Further knowledge can be gained for each era if the whole life-cycle-costs of the building are also considered.

Statistical surveys show that there exists a large inner-city housing stock of different construction periods in Austria. These have different characteristics and enjoy different popularities among developers and investors. The existing buildings are clustered into typical periods of similar characteristics for further research. Those are the period of promoterism (1840-1920), the interwar years (1920-1945), the post-war period (1945-1960) and the period from 1961 to 1980. The buildings from the period of promoterism and the latest construction period have the best utilization possibilities; buildings from the interwar period and the post-war period are less popular. The evaluation of the SWOT-Analysis shows that the conservation of the built environment brings economic, environmental, as well as social benefits.

Keywords: Built environment, redevelopment, sustainability, SWOT-Analysis, Austrian case study

1. Introduction

Today's society shows a trend that the population wants to live in the inner-city increasingly because of demographic changes and urbanization. For this reason, in the future the available space and the existing buildings in cities must be better utilized in order to use their potential optimally. Only in this way, long-term sustainable coexistence can be enabled in cities and contemporary urban growth can be achieved. In addition, by the optimal, economical and sustainable use of existing buildings the environment can be protected cf. (Ollig 2016).

Future redevelopment projects must be technically realizable, economical and at the same time preserving the historic values of the townscape. The energy efficiency of renovations, the accessibility and the increasingly important multifunctionality of housing stocks will pose a challenge for planning and implementation (Riehle and Kilian 2012). By lower building activities of rehabilitation of existing buildings as opposed to a new construction of a project, the use of resources and the pressures on the environment can be considerably reduced. At the same time local residents are less affected by shorter construction periods and lower emissions..

Climate change is one of the main challenges we are facing in construction industry and city development. The building sector is responsible for 40% of the total energy consumption and 50% of resources in the European Union (BMUB 2014). Energy refurbishment of the building stock is a key component of climate action plans on European level (Directive 2012/27/EU, Directive 2010/31/EU) as well as in the national implementation. In Austria the implementation aims at improving energy efficiency up to 20% until 2020. Focusing on reaching the EU targeted goals cities have a significant impact on conservation of resources, environmental protection and economic strength. Thereby the environmental impact through the demolition of existing buildings, the site equipment, transportation, as well as the construction works is much worse than those of redevelopments. In this context the question arises, how the existing building stock can be adapted for future requirements. There is a need for analytical foundations and tools to support the decision-making process of public and private stakeholders (Lützkendorf, 2016). The current paper focuses on assessing refurbishment strategies for dealing with buildings form different construction periods.

To promote sustainable development, the consumption of space must be reduced and more economic ways of city planning have to be introduced. Therefore it is important to use the available space as economical as possible by redeveloping and converting existing buildings in order to meet future society's needs and to create sustainable spaces (Passer et al. 2012).

The advantages of refurbishment are accompanied by disadvantages, which should be identified with the help of a SWOT-analysis in the following contribution. The basis of this paper is a statistical survey conducted by experts from the construction industry. Furthermore, the results were compared with the literature.

2. Building stock

According to statistics there are about 2.191.280 buildings in Austria (2011). Compared to the previous statistical investigation in 2001, that means an increase of 7.1 percent. The number of residential buildings even increased about 12.1 percent. In addition, about 23.500 new buildings were approved for construction throughout Austria in 2014 (STATISTIK AUSTRIA 2015). In figure 1 the buildings divided into their construction periods are indicated.

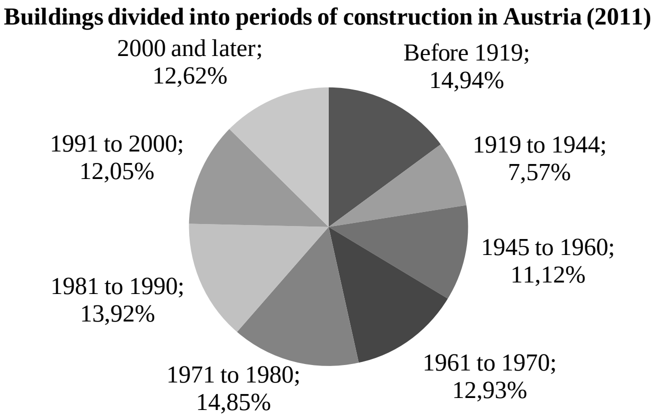


Figure 1: Buildings divided into periods of construction (STATISIK AUSTRIA 2015)

2.1 Utilization possibilities

User compliance of real estate represents itself as a decisive factor for the recovery of the building stock. For a successful project development it has to be considered what types of uses can be accommodated in the future. Especially the location and building fabrics are critical influences to verify the suitable use of properties and how they can be utilized through reorganization measures. The smaller the intervention in the building stock, the less investment costs of the construction work occur.

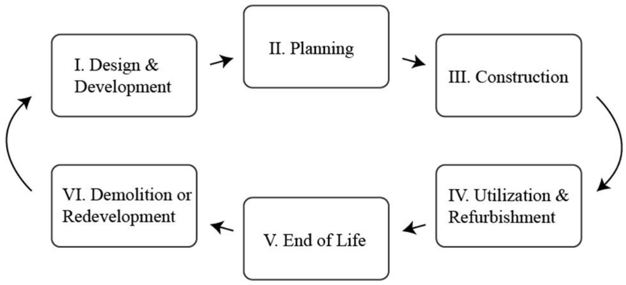
In addition to modernization, heightening, attic extensions, or annexes should be taken into consideration. Therewith coveted living and working spaces in popular areas can be created and the profitability of properties can be increased. In the progress any restrictions in construction law must be strictly observed in order to avoid unexpected complications in the planning effort (Stefan 2015, p.93).

By the mixing of functions, surface types and sizes, marketing risks can be minimized and with a flexible rental mix possible losses of rent can be countered in order to generate long-term profits with a property. Since user profiles frequently change over time, the real estate market always has to provide more flexible structures and adapt its offers for new uses through small interventions (Bielefeld and Wirths 2010, p.55).

2.2 Life Cycle Consideration

According to ISO 15686-5 the Life Cycle Costs are composed of construction, maintenance and end-of-life costs (German Association for Facility Management 2010, p.3). With including LCC (Life Cycle Costs) building measures can be holistically tested for their efficiency and the best long-term solutions can be identified.

Starting with the design and planning, the construction and the utilization with intermittent refurbishment measures towards to the end of the utilization, a building faces different stages of its life cycle as illustrated in figure 2. If a property has reached the end of the usage, it will be either demolished or rescheduled and reused.



Figrue 2: Stages in the life-cycle of a building

What is already established in the conceptions of new buildings must also be used at construction sites in the built environment in the future. Only by considering all costs over the life cycle of a property, it is possible to demonstrate the cost-effectiveness of constructional alternatives. During remedial actions, for example, also all aspects of the recycling of demolition material, which are among end-of-life-costs, must gain importance for a sustainable approach. The recent standardisation activities of the CEN TC 350 related to sustainability of construction works resulted in the development of building certification schemes. Various certification systems have evolved in Europe like BREEAM, LEED and DGNB. They are mainly covering new building developments but also refurbishment activities are going to be implemented in the systems (Sezer 2014). In Austria the main certification systems are Total Quality Building (TQB), the Austrian Sustainable Building Council (ÖGNI) and klimaaktiv as an initiative of the Federal Ministry of Agriculture, Forestry, Environment and Water Management

2.3 Building epochs in Austria

Since the supply and demand of the built environment is versatile, existing buildings are clustered into typical building periods of similar characteristics for further research. Those are the period of promoterism (1840-1920), the interwar years (1920-1945), the post-war period (1945-1960) and the period from 1961 to 1980 (as shown in figure 1). On average, every seventh building dates from the period of promoterism in Austria. Merely every thirteenth building was built during the interwar years and every ninth during the post-war period. Finally, every fourth building was built in the years from 1961 to 1980. This large range of existing buildings should arouse more interest among real estate developers and investors.

To judge the utilization potentials of the construction eras, a precise analysis of the building fabric is required. In practise, this often represents a major challenge for everyone involved, because often just inadequate plan material is available and it is difficult to asset the quality of the building stock in-site. Due to the different building materials and various architectural styles over time, there are specific cases of damage, which can be detected for each epoch (Stefan 2015, p.27-92).

3. Methodology

3.1 Definition

To point out the advantages, but also the negative aspects about retro fitting, a SWOT-Matrix was chosen to summarize the results. It represents a systematic situation analysis, whereat strengths, weaknesses, opportunities and threats are reviewed for positioning and strategy development of organizations. Another use of a SWOT-Analysis describes the comparison of competing methods. Hereby the external field of the method is reviewed and the compared methods are confronted to identify the main differences.

The SWOT-Matrix consists of two dimensions: The internal strengths and weaknesses of the company or the method, which is dealing with its resources (finance, human resources, organization, technologies) and the opportunities and risks, which result from the external environment (competitors, technology, customer expectations, policy) (Pelz 2004, p.5). Finally creative strategies should be developed, which are derived from the analyzed characteristics.

3.2 Tools

In this application, a SWOT-Analysis was not used for an organization but to draw attention to the advantages and disadvantages of the building sector of the built environment, compared to the new development of a construction. examine the redevelopment in the built environment for all stakeholders in more detail. So a survey was carried out to examine the redevelopment in the built environment for all stakeholders in more detail. Investors, private and public owners, designers, contractors, users and facility managers have been considered in the analysis.

Although the individual building periods differ in their characteristics concerning building constructions, damage cases as well as their utilization possibilities, existing buildings were generally analyzed in the following SWOT-analysis. In individual cases, the existing properties would need to be considered in more detail and the total costs of investment alternatives would have to be weighed out with a lifecycle costs calculation.

3.3 Empirical Analysis

The basis for the preparation of this research is a survey which was conducted with the help of the online portal “2ask” with a sample size of 63 standardized questionnaires in the professional field of design and construction in the built environment. The mail questionnaires were sent to the Federal Economic Chambers of Styria and Vienna, to the league of Life Cycle Building (IG Lebenszyklus Hochbau), to the Austrian Real Estate Association (OVI) and to the Austrian Society for Sustainable Real Estate (ÖGNI), which all redistributed the questionnaires among their members.

In the survey, the interest of experts for the utilization of housing-stocks was evaluated (Stefan 2015, p.113). The survey results, as well as a literature review, formed the input parameters for the SWOT analysis.

4. Results

4.1 Internal analysis

The competitor analysis was performed between the construction industries "new development" and "redevelopment" in the built environment (figure 3). Emphasis was placed on the inner-city construction and the factors profitability, complexity, sustainability, urban planning, mobility, disposability, technical and legal framework, were evaluated. Mobility describes the possibility of designing the buildings accessible for all residents in this context. Based on this analysis, the strengths and weaknesses of these sectors could be shown relatively to each other.

The evaluation of the parameters was carried out with the help of a points-based system from 1 to 9 (1 = very poor, 9 = very good). The higher the rating is, the more suitable the respective property of the method. The figure illustrates the result of the evaluation.

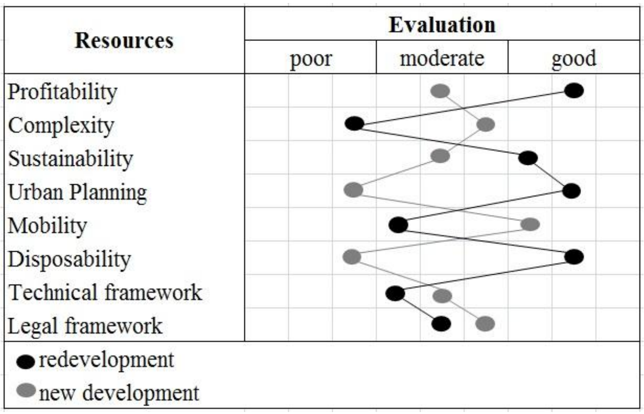


Figure 3: Competition analysis between redevelopment and new development

The analysis identifies the expected use of the building stock with the help of a strength-weakness analysis of the different eras: promoterism, the interwar years, the post-war years and the period from 1961-1980 (figure 4). In this analysis the factors requirements, demand, building fabric, expandability, architectural style, layout, disposability, and initial costs, were evaluated.

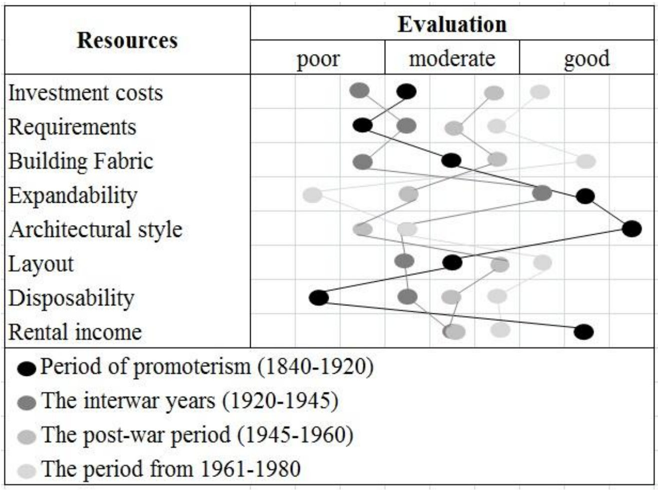


Figure 4: Competition analysis of the building eras

4.2 Illustration

The output of the analysis is presented by the SWOT-Matrix of redevelopment in the built environment (figure 5). Looking at the internal analysis, redevelopment scores with the following strengths: *Financial advantages*: Redevelopment has lower investment costs. Companies need less capital and can run multiple sites simultaneously. In addition you can achieve higher rental income and refurbishment is sponsored yearly with public subsidies. *Sustainability*: A holistic sustainable approach is possible by reducing environmental pollution as well as the use of resources. By manageable building activities and shorter construction periods there is less impact on the residents. Thus, economic, ecological and social aspects can be considered. *Urban-planning context*: With renovating ancient monuments; the typical townscape and historical buildings can be conserved. *Market position*: Due to the presence of a large inner-city building stock compared to limited new building sites, redevelopment in the built environment must play an important role for investors.

In contrast, the following weaknesses can be identified: *Complexity:* In redevelopment there are more insecurities and unpredictable events. Due to the many participants, time scheduling and the coordination are more complex. Redevelopment has increased requirements in planning and execution. Besides, by using the existing building structures the rental mix is harder to realize. *Political and legal frameworks:* There are many restrictions in building legislation. Listed buildings complicate the redevelopment process. *Technical framework:* The building quality of retention of old building structures is worse than new construction. There are lower potential savings achievable than in new development. The lack of information (Documentation, building plans, rate of abrasion) poses a further problem. *Structural mobility*: Structural measures that improve the quality of life and mobility of citizens are often costly and difficult to implement.

Derived from the external factors, opportunities can be seen in: *Supply and demand:* Because of demographic changes and urbanization, the demand of inner-city housing stock will increase. The built environment in rural zones may become more in demand. By heightening, additional residential units can be built in coveted areas. Also *Prospective use of housing-stocks:* Inner-city building sites are limited; many building-stocks are available. Historic buildings are on demand. Sustainable aspects will gain in importance. With the help of inner-city prestige, utilities companies can raise their reputation. As well as *financial benefits:* Through life cycle considerations, the cost-effectiveness of measures can be improved. By using certification models, attractiveness can be increased which leads to better utilization possibilities. Executive companies can use redevelopment complementary to new construction.

Possible threats can arise from: *Market changes*: The trend of the market may change and a weakening demand in historic buildings might be possible. New development is trend-setting. The inefficiency of energy refurbishment might not embrace the future requirements. Leading to *Rivalry in market*: Many business rivals are able to offer the same construction. The heavy competitive pressure can lead to price dumping. Companies wishing to enter the market might not have the necessary experience in refurbishment. Also *Political and legal framework*: Political decisions or new regulations may make the construction measure in redevelopment more difficult.

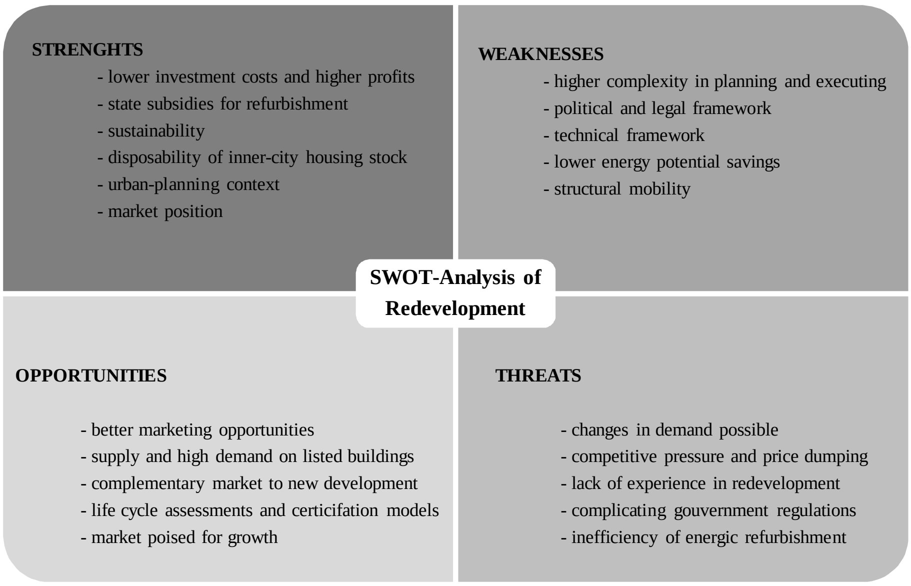


Figure 5: SWOT-Analysis of redevelopment in the built environment

5. Discussion

It can be said that the status quo of each building of the existing building stock must be closely examined before project launch. Only with an adequate analysis of the building fabric and an custom-tailored planning, the necessary redevelopment measures can be identified and thus the property can be successfully rehabilitated. The interfaces between all participants must be clearly defined. With forward-looking logistics and scheduling, the work of the various maintenance groups have to be managed. According to the author the decision-makers should consider the following practices:

- With a targeted selection of the property and an adaption to the particular benefit *investors* can optimize their rental income. Potential losses of rent can be intercepted by rental-mixes and by using sustainable certification models the LCC are minimized and marketing opportunities further increased.

- *Private/ public building owners* can renovate several existing properties due to the lower investment costs at the same time whereby higher profits are achievable due to good demand. In addition to the development of new projects, the renovation of existing buildings forms a lucrative complementary market.

- *Designers* must consider the political, legal, as well as the technical frameworks of redevelopments. Interfaces between planning and implementation have to be coordinated and well thought out accordingly in time to each other. Besides, attention must be paid to the accessibility of the property during the project development.

- *Executive companies* must observe all relevant building standards and have to manage the interfaces between all maintenance groups at the construction sites by planning the logistics and scheduling. The necessary know-how must be achieved by internal staff training.

- *Users* need to be aware of the circumstances of the advantages and disadvantages of the older housing stock and adjust their demands on the particular properties of redevelopment.

According to the experts, the use of existing buildings depends on the construction period. Although historical buildings are the most challenging buildings for renovation purposes, they are favoured by the experts due to user demand and the increased rental income. New buildings feature due to good planning documents, a short service life and modern designs also good recycling possibilities. Finally inter- and post-war buildings are less popular, but must also be recovered (Stefan 2015, p.113).

6. Conclusions

Considering the potential of the built environment, redevelopment has to become an important issue for the future development of cities/ urban settlement. Developing and providing flexible structures for different users will ensure the profitability of buildings. Furthermore applying a life-cycle-approach can create an additional incentive and help convincing building owners to rethinking their properties. With the help of the SWOT-Analysis, it became apparent that existing buildings have a different user demand and thus are not always equally interesting for investors. Especially existing buildings of the period of promoterism are in great demand due to the representative architectural style and yield higher rental income. Building constructions during the latest epoch can also be utilized well and show a very good building fabric due to the short working life. Buildings from the interim and post-war period are not in demand and difficult a remediation by their properties.

According to the current situation, the sustainability will be promoted by the paradigm shift in the construction industry and thus, the concomitant developments in redevelopment of the built environment will be further advanced. New ways will be found to run urban construction sites more efficiently and to reduce the adverse environmental impacts. At the same time new technologies will allow environmentally friendlier constructions. Even the recycling of demolition material must be made more effective and easier for construction companies and the accessibility of the living environment for families with small children, people with reduced mobility, but also for the increasingly aging society, will play an essential role. Here it is important that existing buildings will be adapted technically and economically as well as possible, without changing the representative appearance of the real estate.

By using certification systems, it is already possible to evaluate existing building on sustainability and to consider potential future remediation measures on their profitability. Further research is needed in the development of binding standards and guidelines. These will unify the construction measures in redevelopment and represent systematic work assistance to all participants of planning and executing.

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Green leasing in theory and practice: A study focusing on the drivers and barriers for owners and tenants of commercial offices

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Abstract

This paper investigates the drivers and barriers for green leasing associated with the relationship between building owners and tenants, whilst also considering the extent to which this should be considered during the life cycle phases of a building.

The procurement of appropriate rental property and its services is an important consideration for businesses. In terms of issues associated with this, few are more topical than factoring in sustainability. Emerging from this trend is a leasing product that deals with this directly. This product is a green lease. This not only impacts on the operations associated with a tenancy, but also requires a re-evaluation of the traditional owner, tenant and facilities management (FM) relationship.

Using a mixed methods approach, this paper evaluates how green leases and tenancies require a reconsideration and re-evaluation of the key drivers and barriers for the development, refit and occupancy of sustainable commercial office spaces. This is evaluated using a theoretical model that outlines the interrelation between the roles of owner, tenant and FM.

This research is based on existing literature and semi-structured interviews that studied qualitative and quantitative elements in the context of ownership and tenancy of sustainable buildings. The data collection and analysis is supported by literature research, with a focus on the provision of rental space and services in commercial office buildings with a ‘Building Research Establishment Environmental Assessment Methodology’ (BREEAM) certification.

This paper concludes that data gathered from practice contradicts some of the statements within existing literature, diminishing the importance of cost and the barrier of split incentive, but instead illuminate the importance of less tangible considerations such as company policy or a sustainability strategy. These findings have the potential to further develop theories, and provide an insight into how actors’ relationships need to be developed to ensure more proactive green leasing of sustainable

buildings, along with where strategic attention is required during the building design, construction, operational and use phases.

Keywords: Sustainable facilities management; sustainability strategy; sustainable buildings; sustainable facilities and services; green leasing

1. Introduction

The procurement of sustainable office space and its environmentally friendly, “green”, operation is an important consideration for businesses demands on improving the sustainability of their primary activities and supporting facilities and services. Emerging from this trend is a leasing product that deals with this directly. This product is ‘green leasing’. This not only impacts on the operations associated with a tenancy, but also requires a re-evaluation of the traditional owner, tenant and facilities management (FM) interaction. The industry, from both the perspective of building owners and tenants is facing a change both in terms of their relationship, and what they expect from their buildings in terms of quality, service provision and operating costs. With considerations for greener tenancies seemingly stemming not just from supply and demand, but also from an increased need for legislative compliance associated with sustainable development (Collins & Junghans, 2015, pp 131-133), demand for sustainable office buildings has the potential to increase. Considering the significance in the rise in demand of more sustainable building stock, services and greener leasing, there is also a call to better understand the drivers and barriers for their development and occupancy.

Referring to the overall objective on investigating the innovation needs for sustainable facilities management (SFM) this paper investigates the drivers and barriers of green leasing implementation associated with the relationship between building owners and tenants, whilst also considering the extent to which green leasing should be considered during the earlier lifecycle phases of new buildings’ development or the modernisation of existing buildings. With a selection of case studies on green leased offices in the UK and Norway, the aim is to better understand and analyse the following key issues:

1) The drivers and barriers for organisations (primary activities / core business) in demanding sustainability and energy efficiency in their building stock and associated services.

2) The roles that main stakeholders in the building-life-cycle can have in the way that they impact on the sustainability of building design and construction and operation and maintenance.

The following research questions will lead the investigation of these key issues:

- What are drivers and barriers for building owners to develop and provide sustainable office space in new or existing buildings?
- What are drivers and barriers for tenants to rent and occupy sustainable office space in new or existing buildings?

This paper will consider each research question by looking both at theories based on state of the art literature analyses, as well as empirical studies based on semi-structured interviews with owners and tenants. The reasoning behind the choice of stakeholders (owner and tenant) was due to the involvement they have in developing and occupying their respective buildings. A more detailed explanation as to this research choice will be outlined in the theoretical background.

2. Theoretical background

2.1 Definitions of green leasing and sustainable buildings

In moving forward, it is necessary to understand what is meant in this paper by green leasing. Whilst Bright et al. (2014) accept that it is difficult to define such leasing, they broadly define a green lease as standard lease that also "*purposively supports and facilitates the adoption of leasehold practices that enable the improvement of the environmental performance of buildings and their use*" (Bright & Dixie, 2014, p.6). Example clauses in a green lease could be to "*agree targets and strategies to improve the Environmental Performance of the Premises and/or the Building on a regular basis*", or "*reduction in or improved efficiency of water consumption*" (Bugden et al., 2013, pp. 14, 16 and 22). There is however no universally recognised definition, a conundrum that causes difficulties in both research and practice. In the context of tenancy, it is also important to note the context of the role of owners, tenants and FMs in an office building. This was described by Haugen (2008) who stated that owners adopt the perspective of "*value creation for the company throughout the life cycle of the building*", the FM or building manager viewing the building from the perspective of ensuring "*that the buildings' function optimally for their users, owners and surroundings over time*" and the user/ tenant operates from the perspective of a building that "*supports their own activity to the greatest possible degree*" and "*efficiency of the building according to how it meets their own requirements per cost unit*" (Haugen, 2008, pp.15-16).

Similarly to green leasing, defining a sustainable building offers challenges in terms of a definition. From an academic perspective, a definition was offered by Berardi (2013), who concluded that a sustainable building is "*a healthy facility designed and built in a cradle-to-grave resource-efficient manner, using ecological principles, social equity, and life-cycle quality value, and which promotes a sense of sustainable community*" (Berardi, 2013, p.76). From the perspective of practice, the US Environment Protection Agency define a sustainable building as: "*the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building's life-cycle from siting to design, construction, operation, maintenance, renovation and deconstruction. Green building is also known as a sustainable or high performance building*" ("Green Building - Basic Information," 2014). To this end, a so called 'green tenancy' can be considered to be a tenancy relationship where the activities of the users are as such that they are compatible with the sustainable credentials and infrastructure of the buildings that they possess a lease to occupy.

The definition of 'sustainable commercial office buildings' in this paper is referring to new and existing commercial offices with a BREEAM certification, as opposed to those directly with green leases. By new buildings we refer to them being BREEAM certified during the buildings initial development, whilst existing buildings refer to buildings with a retrofit certification. The choice of BREEAM certified buildings is due to definition concerns surrounding not just what constitutes a green lease, but also what even constitutes a sustainable building, regardless of whether it is new or existing. Using BREEAM certified buildings as a framework affords the opportunity to compare buildings through an internationally utilised and recognised certification framework that is already recognised as sustainable by many when considering its market share. Thus, using BREEAM would be an appropriate framing for the analysis of green tenancies. BREEAM has been the certification of choice in this paper due to BREEAM's 80% European market share (BREEAM, 2015). In the UK since 2008 alone, of the 6761 individual BREEAM certificates issued 1261 of these are for offices. Their largest single certified building type is the education sector, with 1472 total certifications. These figures include both interim and final certifications ("Certified BREEAM Assessments," 2016). In

Norway, which has only been using BREEAM (known as BREEAM-NOR) since 2011, the figures are equally as profound with offices representing the largest certified building type, amounting to 35 of the total of 54 interim and final BREEAM certificates issued at the time of writing in March 2016 ("Certified BREEAM Assessments Norway," 2016). The choice to focus on offices centres primary process similarity that is broadly pan European. Accounting for minor differences in office cultures and practices between Norway and the UK, most of their operations will be similar enough to offer comparisons.

2.2 Theories on what influences supply and demand of sustainable buildings and green leasing

The emerging and growing market for more sustainable office buildings that are available for rental are a part of a change that represents an increasing move toward a more sustainable approach to tenancies (Piper, 2014, p.4). The adoption of green leases and greener leasing options such as memorandums of understanding (MOU's), is limited in scope in the attention that it receives from academics at present. Whilst data on the growth of green leases specifically is not easily available, the Sydney chapter of the Better Buildings Partnership (BBP), a collaboration of property owners working together to improve the sustainability of existing building stock, have stated that 60% of leases signed in the financial years 2012/13 to 2013/14 included green clauses, compared to 15% in 2008/09 (Bright et al., 2015, p.3). According to Bright et al. (2014), the challenge of developing more environmentally friendly leasing options to improve the sustainable performance of commercial real estate is very much an international one (Bright & Dixie, 2014, p.18). From the perspective of building owners, Wiley et al. (2008) note that there is interest in answering as to "*whether the economics of "green" design will result in higher occupancy, rents or selling prices for their project*" (Wiley et al., 2008, p.229). Looking directly at coupling trends with those of tenants, Langley et al. (2008) write that a move to more sustainable real estate is stemming from corporate social responsibility (CSR), and is manifesting in better environmental management systems and policies in buildings, which in turn may result in tenants eventually becoming reluctant to sign leases for buildings that have poor energy performance (Langley et al., 2008, p.2). Hinnells et al. (2008) try to make clear to scholars and practitioners that there cannot simply be a development of green leases that adopt a format for everyone, as "*different classes of occupiers will have different attitudes to the greening of leases*" (Hinnells et al., 2008, p.549).

From a more theoretical perspective, academic literature does note drivers that may encourage the development of sustainable buildings stock. Steward Brand (1997) for example, took a less specific but more holistic approach to this definition by stating the kinds of elements drivers could contain. He notes what he calls "*driving forces*" that shape the future environment. In the case of business, he states that this comes in the form of changes to technology, regulation, the competitive environment and the demands of customers. In the buildings themselves, the drivers are slightly more technical in nature. They also contain the technological forces noted in business drivers, but also are impacted by the economy and the use by tenants (Brand, 1997, p.182). An example of a more specific identification of factors however can be found in the work of Bansal and Roth (2000). In their paper titled 'Preliminary Model of Corporate Ecological Responsiveness', they identified the drivers of 'Legislation', 'Stakeholder pressures', 'Economic Opportunities', and 'Leadership Corporate Values/ Ethical Motives' that in their eyes impact corporate ecological responsiveness (Bansal & Roth, 2000, p.718).

There is also a noticeable deficit in knowledge surrounding the development of sustainable buildings, green leases and associated tenancies, partially due to the relatively short amount of time this and periphery issues have caught the attention of academia and practice. Häkkinen and Belloni (2011) in their research on the barriers and drivers of sustainable buildings note in their Finnish case studies and interviews, that occupants and owners are increasing their demands and expectations for such buildings, which in turn requires a development of new products and services to support this (Häkkinen & Belloni, 2011, p.250). Whilst not naming BREEAM specifically, they note that assessment tools that offer support for designers in creating sustainable building solutions are one of these services (Häkkinen & Belloni, 2011, p.247). Oyedokun et al. (2015) note numerous unsolved issues in their research on the sustainable office market in the UK, with one being of particular importance in the context of this paper. They note that a recent property boom has resulted in an increase in the development of sustainable buildings, but are uncertain if this will reflect in a long term strategic change as the boom diminishes (Oyedokun et al., 2015, p.282). This poses an interesting point of consideration for this paper, in the case of understanding whether building owners are employing a sustainable/BREEAM approach to only the building being studied, a minority of their buildings, or a prospective portfolio wide strategy. Further to this, Wiley et al. (2008) concluded in that there is deficit in the 'behaviour' of sustainable office space in national commercial markets, as well as more research being needed in what added value exists in such offices beyond simply savings in operational costs (Wiley et al., 2008, p.240).

Bond (2010) claims in her research on the Australian experience, that perceived higher costs are putting off some developers from developing sustainable buildings (Bond, 2010, p.6), despite evidence by Kats (2003) that suggests premiums on such buildings average from only 1% to around 6.5% (Kats 2003, cited in Bond, 2010, p.6). There is however no mention in the research as to whether a reduction on operating costs for example, could be a driver that could overcome this barrier. In terms of other unanswered questions on this topic, Roper and Beard (2006) offer a broad list of research needs in the realms of sustainable office studies. They cite the cost implications of sustainable appraisal, data on lower vacancy rates and tenant lease-up along with return on investment information that they claim would be of considerable use to the real estate and FM sector that is aiming actively to push for sustainable real estate (Roper & Beard, 2006, p.101).

3. Methodology / Research approach

3.1 Interviews with owners and tenants of sustainable office buildings

For this research, interview participants from Norway and the UK were chosen. In the case of the tenants, they were chosen based on their occupancy of a BREEAM certified commercial office. In the case of building owners, they were chosen based on their role in commissioning the construction or refit of their BREEAM certified office, lease development and their instrumental role in procuring tenants for the property, along with being involved in the buildings management. This meant that their roles varied between being directly involved in leasing or the properties development; however their ultimate involvements in the buildings were the same. 46 potential participants were approached for study, and 15 interviewees agreed to take part over a course of 7 individual interviews and 4 group interviews with a total of 9 different buildings. The stakeholder make up consisted of 6 interviewees representing tenants, and 9 representing owners. The interviews were conducted between September 2015 and March 2016. Although the sample size is small and difficult to generalise, there is none the less scope for the preliminary results to 'shed light' on the issues addressed (Yin, 2014, p.40), as well provide scope to expand the study further.

Each of the interviewees were asked a multiple choice question regarding what factors of 'drivers' were important to them when choosing to develop, refit or occupy their building to BREEAM standard. The motivators reflected those most commonly found in the state of the art, both from academia and practice. They were asked to rank in order of '1-6' (1 being the highest priority) the categories of **A)'***Costs*', **B)'***A Green Certification*', **C)'***Legislative Compliance*', **D)**'*CSR*', **E)**'*Company Policy/ Culture*' and **F)'***Industry/ Customer Demand*'.

The above drivers were influenced and informed by an extensive examination of the literature, with the previously mentioned drivers by Bansal and Roth (2000) being of particular influence. The number of drivers was kept at six in order to concentrate the results and provide a workable scope within the timeframe of the interviews, and to follow up the quantitative answers with further and deeper qualitative questions. These drivers are described in more detail in table 1.

The quantitative questioning did not deal with barriers directly; however this was covered in qualitative follow up questioning with the interviewees. Qualitative discussions were semi structured in nature, but instigated by asking the interviews to explain the narrative behind their decision to develop or occupy their building, and by asking them about what challenges they faced during their development or occupancy. Some barriers were also illuminated when the interviewees explained their reasoning behind their choice of quantitative answer. The barriers raised as a result of these qualitative responses will be discussed later in the section on the discussion of the findings.

The key aim of the quantitative results is to demonstrate the difference in priorities between building owners and tenants regarding what they most value in their respective buildings. This is the reason for the data being displayed in a division of these roles. Within the analyses of the responses, those which were given highest priority (ranking 1-3) were considered as "high priority" drivers for implementing sustainability in building development (owner perspective) and operation and use (tenant perspective). Those categories with lowest ranking (4-6) were considered as "low priority" drivers.

The following overview outlines more directly the "High" and "Low" priority factors for each of the drivers presented to the interviewee (Table 1):

Table 1: 'High' and 'Low' priority factors for the drivers for owners and tenants

Categories	***Description***	***Owners response: "high priority" (1-3) or "low priority" (4-6) driver?***	***Tenants response: "high priority" (1-3) or "low priority" (4-6) driver?***
Costs	*In the context of owners, this referred the overall business case of the development of their building with a primary consideration of operating costs (if it is the responsibility of the owner), overall building development costs, and added financial value.* *For tenants, this referred to their outgoings in their tenancy related to rent, and utilities (if their lease makes this their responsibility).*	*Low Priority*	*High Priority*
Green certification	*In the context of owners, it was referring to the level of importance they placed the BREEAM certification in comparison to the other factors when developing their building.*	*High Priority*	*High Priority*

	The same considerations exist for the tenant, with the exception of them considering how important the BREEAM certification was as a factor in them choosing to rent this particular space.		
Legislative Compliance	*The meaning of this category is similar in both stakeholders' cases, in the sense that it asks the interviewee to gauge how important mandatory legislative obligations (national or international) were in their choice to develop or occupy their BREEAM certified building. This legislation could derive from the likes of local government, national buildings code, or international legislation (such as from the European Union).*	*Low Priority*	*Low Priority*
CSR	*Both stakeholders are asked to consider the importance of Corporate Social Responsibility (CSR) as an externally presented policy in their respective choices. CSR based decision making is also impactful on the reputation and brand image of the respective owner or tenant.*	*Low Priority*	*High Priority*
Company policy / culture	*This refers to the culture within the respective company or organisation of each stakeholder, and how important internal policy and cultural motivators impacted on their choices.*	*High Priority*	*High Priority*
Industry/ Customer Demand	*This category in case of owners refers to the degree to which demands from existing or prospective tenants influenced the development of their BREEAM building. Pressure from within their own industry is also a factor that they were asked to consider.* *This was reflected similarly in the case of tenants, however in the context of their decision to occupy their respective building.*	*High Priority*	*Low Priority*

The presented interview results demonstrate difference in the driver's priority levels depending on whether they were the owner a tenant (table 1).

There was near universal consensus amongst owners that their own *'company policy/ culture'* was the most important factor in the development of their respective building, with only one interviewee valuing their '*Green Certification*' over this and having '*Company policy/ culture*' at number 2. Another building owner placed '*Industry/ customer demand*' at number 1, with '*Company policy/ culture'* at number 2. Thus, '*Company policy/ culture*' can be considered as the most important driver from building owner perspective in the context of this study. Their lowest priority was split between five owners placing '*Costs*' at number 6, with only two interviewees placing '*Legislative Compliance*' at the same placing, with one interviewee valuing *'Costs'* much higher at number 2, and another at number 3. There was less consensuses on the other priorities, with three interviewees placing a '*Green Certification*' near the middle of the scale, and with two interviewees placing '*CSR*' at number 5.

With regards to tenants, there was less agreement as to what their priorities were when choosing to occupy their respective buildings. There was little consensus on the top priority, with the only commonality being two interviewees placing '*Green Certification*' at number 1. A similar lack of consensus was found at the bottom of the scale, with two tenants placing '*Legislative Compliance*' and another two placing '*Industry/ customer demand*' at number 6, representing the only commonality for the lowest priority factors. Two interviewees placed '*CSR*' at number 2 making it a "high priority" driver, and two interviewees placed '*Costs*' at number 3., and two of the tenants placed '*Legislative Compliance*' at number 5, which might be considered as a potential " low priority" driver.

The results show that '*Costs'* are mainly valued as a "high priority" driver amongst tenants, whilst in many cases the building owners consider it as "low priority" driver, (4-6). Whilst there was little commonality amongst tenants, the interviews point towards '*Company Policy/ culture*' as being a key "high priority" driver of the development of sustainable buildings amongst owners. Amongst almost all of the actors in the study, '*Legislative Compliance*' was considered as "low priority", and placed in the lower half of the rating scale (4-6).

4. Discussion of findings

4.1 The barriers and drivers for owners of BREEAM certified commercial offices in Norway and the UK

The literature notes numerous difficulties in the development of sustainable buildings. Bright et al. (2014) notes how there is little incentive for building owners to install energy efficient technologies in their buildings due to the upfront costs and expensive maintenance (Bright et al., 2014, p.17). Literature also claims that sustainable building management and FM is being increasingly driven by legislation, and less so by corporate image (Casals, 2006; Ayres et al., 2007; Shiers et al., 2007, cited in Elmualim et al. 2012, p.17) . The results of our study however, were indicative of the opposite. One of the British building owners for example, claimed that their investors were keen to have as many new and retrofitted high performance BREEAM buildings as possible, due to the long term financial benefits as well as those associated with CSR. This was despite the substantial upfront costs necessary to make this approach possible. Similar comments were echoed by other interviewees, all of whom cited a combination of company policy and long term financial benefits in terms of maintenance as being important factors in their investments. Despite some discussion on the contrary, an industry wide survey by law firm DLA Piper of more than 100 building developers did illustrate a consideration that was reflected in our study. DLA Piper claimed that only 3% of their respondents felt that existing or pending legislation influenced their decision to deliver sustainable real estate products (Piper, 2014,p. 17). This was reflected in our results, where less tangible considerations such as company policy were a higher priority than the likes of legislative compliance.

The key difficulties were technical and structural, with one of the Norwegian building owners, for example, being aware that their tenants were experiencing difficulties with their Building Management System (BMS). Many of the building owners also felt that the BREEAM process was overly difficult. One of the Norwegian building owners cited the frustrating lack of points received for building on an empty site and not demolishing an old property. The owners of existing buildings had experienced some construction difficulties when retrofitting their buildings, especially with regards to planning regulations. Of note was the planning restrictions experienced by one of the British building owners. Their building is a refitted Georgian building, and they were not permitted to replace the old sash windows with a modern equivalent. Although the building performs well, this they considered to be a frustrating barrier in the sustainable upgrade of existing building stock. Due to the BREEAM certification system not accounting for an issue such as this; it was a contributing factor in the building not receiving the level of BREEAM certification that was intended earlier in the buildings design phase. This is recognised by Dixon et al. (2008) referring to the point that cost effectiveness and the social acceptance of some refurbishment and retrofitting is an ongoing barrier to sustainability (Dixon et al., 2008, p.14).

4.2 The barriers and drivers for tenants occupying BREEAM certified commercial offices

Current research suggests that sustainable buildings are valued more by potential occupants due to their lower running costs, along with providing a more attractive working environment (Sayce et al., 2010, p.4), although some evidence suggest that their real world performance does not match the technical specifications (Turner and Frankel, 2008; Paul and Taylor, 2008, cited in Sayce et al., 2010, p.4) . The interviews conducted so far however place the likes of costs (both in the context of 'operational' and 'developmental') far closer to the middle and bottom of the priority scale, making it less of a consideration. The majority of buildings owners associated more closely with the development costs of the their building (for which they are more directly responsible) and tenants more with operational costs, which greater impact the day to day financial elements associated with their tenancy.

Wiley et al. (2008) suggests factors that could encourage tenants occupy a sustainable building. As well as helping enhance other aspect of the business, they note that a reduction in operating costs could offset some larger expenses (i.e. rent) that a high performance building may command (Wiley et al., 2008, pp.233-234). Whilst no tenants stated that a reduction in costs was a key factor in their decision to move to their respective buildings, they were none the less aware of the positive impact on their operational costs. One of the Norwegian tenants saw a 50% operational cost reduction, achieved through a combination of the building technology and the 50% reduction in space when moving from cell to open plan offices. Another Norwegian tenant also reflected on this, saying that whilst operational costs were not a key concern for them in choosing this building, they have always pursued operational cost reductions and even went as far as to attempt a green certification of their previous premises to act as a 'toolkit' to help reduce their energy.

When pursuing the occupancy of any building let alone a sustainable one, there are inherent barriers that risk the ease of both the buildings procurement and occupancy. The literature points mostly to financial and legal barriers to negotiating these tenancies, with the likes of split incentive causing a lack of trust and an growth in tensions (Wilson & Tagaza, 2006, p.2), with one scholar going as far as to say that split incentive is "*a notorious obstacle to improving the environmental performance of tenanted commercial space*" (Bright et al., 2014, p.17). Each of the tenants was asked specifically how the negotiations went with their landlord, and if any tensions or difficulties had arisen. None of the tenants claimed to have had any such problems, even, as is the case of one of the Norwegian tenants, appreciating the ability to be involved in the buildings design and even paying for the BREEAM certification themselves at the suggestion of the owner. This contradicts a potential barrier noted in literature, that states that often adversarial relationship between the landlord and tenant that can potentially stifle the development of sustainable buildings, and their associated greener tenancies (Hinnells et al., 2008, p.544). Whilst not necessarily a tension, one of the Norwegian tenants noted that their office building had experienced problems due to the tenant not engaging enough with the owners during the buildings initial development. Poor communication during the earlier design phases resulted in a building that was, according to the tenants "*not to the standard we had expected*" and a lack of progress meetings leaving numerous design problems that are not easily fixed now that the building is in operation. The tenant went on to say that "*we are also in the process of acquiring two new BREEAM buildings and we know the mistakes not to make again. One of them is now finished and we are very happy with it, mostly because the developers and we worked as a team this time*". The barrier of communication is one issue that the literature has recognised in these kinds of buildings (Hinnells et al., 2008, p.544), but also note that there is potential through the leasing structure to allow for "*effective channels of communication to promote green issues, and to promote day to day property use and management that takes account of environmental issues*" (Hinnells et al., 2008, p. 544), and thus go some way towards alleviating this barrier. In the literature studied for this paper however, there was no discussion on how this communication barrier could be addressed at an earlier life cycle stage. So far, all of the technical barriers relate exclusively to the buildings BMS systems, with this being a particular issue for one of the Norwegian tenants of a new BREEAM building. The integration of technology had been problematic for them to the extent that one of the tenants hired their own 'integrator' to help with the software implementation during the buildings development, which they felt averted larger problems. To quote the same tenant, "*developers are great at building buildings, but they need to work harder at understanding the technology they put in it and how to make it all work together*".

5. Conclusion

When looking more directly at what we know and do not know about the study of sustainable offices, there is a notable need for research to pursue what is driving not just the development of these buildings, but also what drives their tenants to sign leases for them. Whilst we know that there has been an increase in the uptake of the likes of BREEAM and other sustainable certification schemes, it is unsure at present as to if this is a temporary consideration by developers, or a long term commitment for their portfolios. In the context of BREEAM certifications, there is scope for the certification to consider the drivers and barriers presented by the development of sustainable building stock, both in terms of the context of its assessment criteria and how they make the scheme and methodology more attractive to prospective clients. This paper also demonstrates to some extent the business case of these buildings from the perspective of owners and tenants, and an understanding from both stakeholders as to the operational costs savings achievable in a sustainable office building with a BREEAM certification.

From the perspective of the delivery and development of green leases in theory and practice, the results in the paper have illuminated differences between both. The literature represents a need to understand 'value' from the perspective of both owners and tenants beyond what has been cited in the literature. The results have demonstrated that despite what is often in literature; less tangible drivers such as company policy and CSR are of significance. There is also scope to recognise some of the technical barriers associated with these buildings, and that the landlord\ tenant relationship may not be as adversarial as was previously believed in some literature. Overall, the results demonstrate that different needs, drivers and barriers exist depending on whether attention is placed on the owner or tenant, with a need to adjust priorities accordingly. Understanding these differences not just impacts on the development of sustainable office buildings as per the questions asked in the interviews, but also emphasises the consideration stakeholders need to be mindful of when developing an attractive and achievable green lease strategy for a sustainable office building. The development of sustainable buildings relate not just their development of their physical structure, but also how attractive their leasing and policy decisions are to the tenants who may occupy them. The results in this paper have also shown little demonstrable difference in the barriers and drivers of a building whether it is new or existing.

With these concluding thoughts in mind, this paper has scope to further existing research needs by providing a better understanding as to what drives key stakeholders in sustainable office buildings whilst also demonstrating a potential path for further research with larger samples, different focuses and the involvement of other stakeholders such as facilities managers and architects.

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The main objective of ZEB is to develop competitive products and solutions for existing and new buildings that will lead to market penetration of buildings that have zero emissions of greenhouse gases related to their production, operation and demolition. The Centre encompasses both residential and commercial buildings, as well as public buildings.

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The case of the AlpHouse Center in Belluno (Italy): promoting building culture and sharing know-how and experiences in an alpine territory

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Abstract

The Alps play a key role not only in the environmental and economic European scenario but also from a cultural point of view, as an example of long-term adaption to particular climatic and geographic conditions. The Alps can be historically considered a place in which the principles of economic, social and environmental sustainability were practiced before their official definition. Alpine territories and their traditional architecture can be considered a lesson from the past in terms of well tested construction techniques, careful uses of locally available resources, environmental balances and adaptation to local conditions. In the framework of the Alpine Space European Programme (2007-2013), many projects have focused on these aspects. Two in particular, AlpHouse and AlpBC, have analyzed regional building practices in the Alps in order to collect their traditional know-how, innovative content and to implement measures at different scales to preserve and advance alpine building culture. In the context of the AlpBC project, one of the activity promoted is the creation of a transnational network of AlpHouse Centers (AHC) across the Alps. The AHC are physical places, in which the results of the studies and pilot activities of Alpine Space projects are made available to stakeholders of the building sector and to the population. The goals of the AHC are those of sharing best practices in the territory and among the network Centers, promoting education regarding alpine building culture, doing interact the different figures which are involved in the territorial planning and building sectors in order to promote local identity and economic development. Considering the effort of the AHC network a significant example on the importance of sharing experiences, the paper will present the case of the AlpHouse Center of Belluno (AHCB), an initiative promoted by the Urban Planning Section of the Veneto regional authority and implemented by the Foundation "Architettura Belluno Dolomiti" (FABD). In order to analyze this experience as a best practice transferable to other contexts the paper will present the participatory work done by the regional government, Iuav University of Venice and FABD for the set-up of the Center and the start-up of its activities.

Keywords: Alpine Space Programme, building culture, best practice, involvement, sharing experiences

1. Introduction

After successfully distancing itself from the recurrent definition of less-favored area (75/273/EEC), the Alpine territory may be considered as a background to address and manage future environmental challenges and their social and economic effects. As declared by Fondazione Montagna Europa Arnaldo Colleselli (2012), "Mountain territories represent the ideal framework to test and establish a new model of economic development, marking the shift towards a resource-effective economy with lower carbon emissions and resilient to climate change. This will contribute to protecting and improving environmental quality while halting and reversing the loss of biodiversity" (page 2).

The Alps are ready to seize this opportunity. The organization of the territory and the settlements and the construction of traditional buildings have been historically characterized by the capacity to combine the requirements of the environment with human activities. This know-how has been handed down for centuries (Dematteis, 2011) and it can be re-interpreted and proposed today. Moreover, in the existing context of urban planning, requalification and building activities, the Alpine territories can therefore meet the EU directions on reducing emissions (COM (2011) 112 (2011), COM (2011) 885 (2011)) and resources consumption (COM (2014) 445 final (2014)), blending their traditional know-how with innovation in planning and building sector.

In 2000, the European Union launched the Alpine Space program for territorial cooperation dedicated to the development, innovation and sharing of experiences in the Alpine territories and the peri-Alpine belt. Within the 2007-2013 Alpine Space program, two projects specifically covered the above mentioned issues: the AlpHouse project (Alpine building culture and ecology, 2010-2012) and its continuation and capitalization ("Capitalising knowledge on Alpine Building Culture by performing regional smart planning and consultancy strategies for sustainable development and closed loop economies in the Alpine Space," 2013-2015). With reference to the priority axis of competitiveness and attractiveness, the objectives of these projects included the creation of a network of AlpHouse Centers in the Alps area (Germany, Austria, France, Italy and Slovenia) (Figure 1). These centers would become reference points for the dissemination of the building culture, sustainability and the exchange of knowledge and technologies, particularly those concerning the energetic and environmental requalification of buildings. Furthermore, their uniqueness would lie in their capacity to connect both with the local territory and with the network of AlpHouse Centers (Figure 2). The possibility of these centers of acting in the local areas and at the same time to belong to a wider network in the Alps meets the intent suggested by the Alpine Convention, in particular in its declaration "Population and Culture" (2006), which encourages community awareness and identity and, together, participation and cooperation.

The idea to establish an AlpHouse Center in Belluno (Veneto Region, Italy) for the promotion of the culture of living and building in the Alps arises from this context. The Veneto regional authority has been a partner of the Alpine Space programs on territorial and Alpine architecture sustainability for a decade. Through these same projects, the Belluno area - as a pilot area - participated in a series of territorial cooperation activities which saw the joint involvement of the academic world, public administrations, technical experts, enterprises, and members of the building sector. All the parties cooperated within a network of experiences involving other Alpine countries to share problems, solutions, policies and good practices. The Belluno province was chosen not only for historical, cultural and territorial reasons, but most importantly because it is the only Veneto province entirely located on mountain land and straddled over other Alpine regions, sharing the homogeneous features of the Dolomites area. This condition of physical and cultural belonging has helped the implementation of a number of studies, research activities and projects on common issues, whose consequences fall on a territory and a community committed to enhancing their identity resources, peculiarities and expertise.

In order to leave a tangible legacy of this remarkable activity, capable of taking over its aims, capitalizing the new heritage of knowledge and enhancing it, the professional organizations decided to create a "permanent center for the culture of living and building in the Alps" – the AlpHouse Center of Belluno. Part of a network of AlpHouse Centers already active in Europe which have already started to set their objectives in relation to their territorial, cultural and econimic peculiarities, the center would be in charge of spreading awareness among experts, operators, citizens and administrations around the issue of balancing natural resources and enhancing the local culture and economic systems.

Based at the already existing Fondazione Architettura Dolomiti Belluno (FABD), as the other AlpHouse Centers in the Alps, the AlpHouse Center of Belluno set a series of specific objectives that are relevant for its territory of reference, namely:

- protecting and developing the cultural heritage, composed of landscape, vernacular architecture, regional materials and local building techniques;
- developing knowledge of the territory and its different facets, peculiarities and constant evolution;
- enhancing and creating a network of building traditions and "consolidated expertise";
- promoting a short supply chain in the building sector;
- creating a platform to collect good practices, especially at the provincial and regional level, to be shared with public administrations, local bodies, individual citizens and, more in general, all the stakeholders in the field.

Seen as a physical space operating locally on the territory as well as part of a network of similar entities in the wider Alpine context, the experience of the AlpHouse Center of Belluno may set a standard for the sharing and enhancement of knowledge, training and territorial innovation, and the creation of opportunities, to be deployed in other contexts too. To encourage the transfer of experience which could be useful for other alpine territories, the following sections explain the methodologies and preliminary activities of the set-up of the AlpHouse Center of Belluno, the definition of the organization, and a summary of the early activities performed.

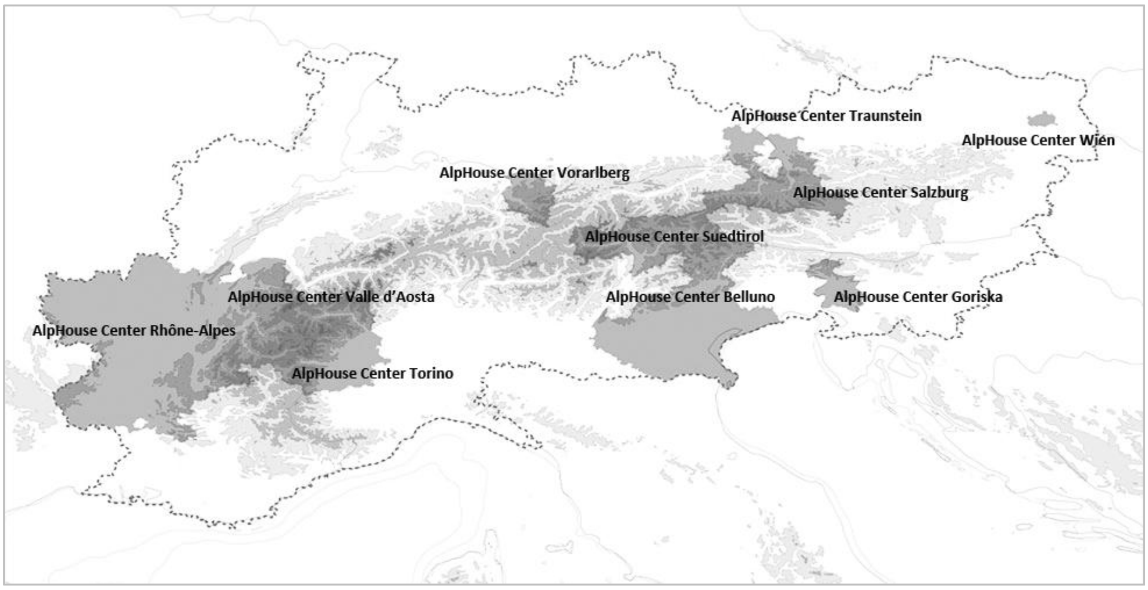

Figure 1- The AlpHouse Center network created in the Alps: together with the AlpHouse Center of Belluno, eight other AlpHouse Centers have been developed. Often they are hosted in research centers, regional offices, chamber of commerce, depending of their main objectives (www.alphousecenter.eu)

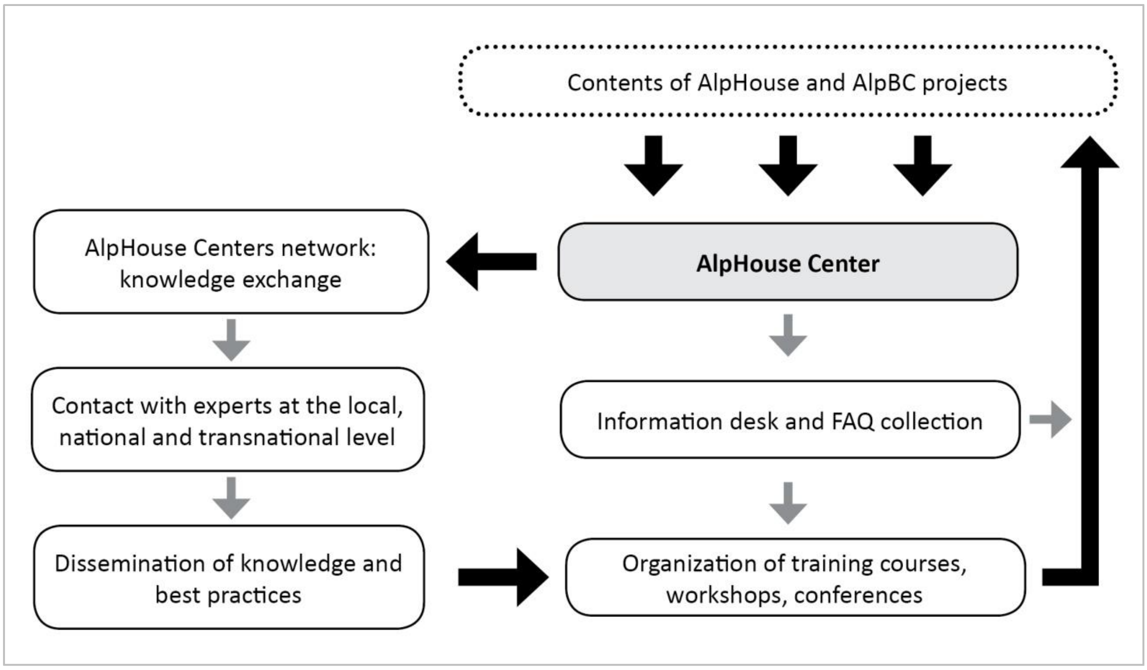

Figure 2- The operating structure of the AlpHouse Centers in the framework of the Alpine Space Programme. The AlpHouse Center network contributes on one side to act locally, with organization of training courses, workshops etc. and to share best practices; on the other side it supports research development in the Alpine context.

2. The set-up of the AlpHouse Center of Belluno

2.1 Preparatory activities

The preparatory phase of the set-up of the AlpHouse Center of Belluno, held between April and May 2015, began with the planning of three knowledge, discussion and investigation activities on some of the aims and priority areas among the objectives listed above. The first two activities were carried out in the form of focus groups, a technique often applied in social research work. A focus group consists in a guided discussion on a specific topic where a restricted group of participants is coordinated by a facilitator, whose task is to keep the conversation within the chosen subject. The topics of the two focus groups coordinated respectively by the Iuav University of Venice and Ambiente Italia, an environmental consulting firm, were the requalification of traditional Alpine buildings and the integration of energy-related issues in urban planning. The third preliminary activity was a study trip to another AlpHouse Center, with the participation of the subjects charged with the set-up of the Belluno center. These three experiences highlight the importance of exchanging information among different subjects, sharing good practices and adopting a participative approach, as suggested by the Alpine Convention, Declaration "Population and Culture" (2006).

For the first focus group, dedicated to the requalification of traditional Alpine buildings, thirteen participants were selected to take part in the guided discussion (Figure 3). They included planners (architects, engineers, renovators), building companies specialized in renovating existing buildings, plant engineering experts and public bodies representatives (municipalities and local action groups), all active in the Belluno area. The requalification of traditional Alpine architecture is one of the most recurrent themes in the Alpine Space European programs (as AlpCity, AlpHouse and AlpBC), as well as a relevant issue for the territory where the AlpHouse Center of Belluno is located: 44% of residential buildings in the province of Belluno have been built before 1945 (Istat, 2001) which means with traditional building techniques; to this number it should be necessary to add the rural buildings (e.g. barns and stables) which are not legally estimated yet. The involvement of different subject categories representing the various phases and aspects of the requalification process symbolized the willingness to adopt an integrated approach in handling the various issues surrounding the AlpHouse Centers. Furthermore, the collection of different perspectives among various subjects emerged as a real necessity. Indeed, requalification actions often require the harmonization of protection and conservation priorities with the existing legislative framework, the users' needs and the available technological innovations. The discussion held by the focus group led to the selection of a range of possible issues identified as priorities by the subjects operating in the sector and the territory. These may be dealt with during the next training and informative activities of the AlpHouse Center. They include statutory compliance, energy-related issues, the localization of materials and resources, the new relation between requalified traditional buildings and the mountain landscape, construction technologies, the integration of plant design, the importance of understanding the existing building, and redevelopment costs. In addition, participants expressed the need to receive training at different levels and specifically addressing the renovation of existing buildings, which confirms the purpose of the AlpHouse Center of Belluno as a training center. They also stressed the importance of creating a network to share knowledge and good practices on the requalification of traditional Alpine architecture, an idea which has been also planned for the AlpHouse Center.

The second focus group concentrated on the territorial scale and examined the integration of energy-related issues in urban planning. Due to the nature of the issue, the focus group involved some representatives of public administrations and urban planners of the Belluno province. In addition to energy, a topic unanimously considered as critical, the discussion highlighted the need for planning activities to start addressing sustainable mobility, the quality of settlements and limiting soil consumption. Indeed, these issues could be looked at within the wider scenario of the entire mountain territory regeneration towards the enhancement of the local economic system and culture. As in the first focus group, the second group also highlighted the need of applying good practices coming from other regions and form other AlpHouse Center, as e.g. the AlpHouse Center in Vorarlberg. Moreover, it identified information, training and consultancy as possible activities offered by the AlpHouse Center. Among the priority themes covered by these activities, the group selected sustainability, resilience and adaptation, the energy certification of buildings and settlements, the production of renewable energies and the implementation of energy planning tools.

Finally, in view of sharing good practices and experiences and creating a preliminary cooperation network, the third activity consisted in a study trip to the AlpHouse Center of the Aosta Valley (Italy). The AlpHouse Center in the Aosta valley, already in operation for some years, can be considered similar to the one being developed in Belluno. The two AlpHouse Centers share a similar alpine territory and building stock, a similar legislative backgroung and similar objectives for their activities. The study trip involved the participation of the people in charge of the creation of the AlpHouse Center of Belluno in some discussion boards for planners, companies and local administration of the Aosta Valley territory (Figure 4). The discussed themes included the restructuring of public buildings, the energy optimization of public lighting plants, the production of renewable energies, and the financing and enhancing of energy requalification projects, identified by the AlpHouse Center in the Aosta Valley as priorities for its territory of reference.

The three preparatory activities for the elaboration of the training program of the AlpHouse Center of Belluno had three main objectives. The first was to identify a preliminary list of building and planning-related issues perceived as relevant by those living and working in the Belluno area. The second was to test a number of modalities for a participative approach to activities (focus groups, discussion boards, etc.) and to set operating standards for the upcoming AlpHouse Center of Belluno. Finally they offered a chance to enter into contact with possible future interlocutors already active in the territory, and with other AlpHouse Centers, as e.g. the one in Valle d'Aosta.

Figure 3- The focus group in action during the first focus group related to the refurbishment of traditional buildings.

Figure 4- Different discussion boards during the study trip at the AlpHouse Center in the Aosta Valley.

2.2 The organization of the AlpHouse Center in Belluno

Based on the themes emerged from the preparatory activities, which have been combined with the specificities of the territory and the experience of the promoters of the AlpHouse Center initiative (Veneto regional authority and Fondazione Architettura Dolomiti Belluno) the main characteristics of the AlpHouse Center of Belluno - a permanent center for the culture of living and building in the Alps - have been defined (Figure 5). The priority themes, the target groups of the activity and the type of activities have been outlined as follows.

As regards the choice of the priority themes, the purpose has been to combine the specific needs of the territory (including the conspicuous presence of buildings to requalify and the specificity of a mountain area) with innovation and sustainability, in order to insert the activities of the Center in the context of a coordinated development at European level. The main themes defined by the AlpHouse Center of Belluno and the reasons of their choice are therefore:

- European-planning, especially related to the field of the culture of living and building in the mountains, in order to match the priorities set by Alpine Space Programme with the activities to develop in the Belluno area;
- Restoration and conservation of the architectural heritage, related to the specificity of the building stock in the Belluno area;
- Architecture and technology, as a theme which can combine tradition with innovation and involve the building sector;
- Sustainability, in order to fulfil national and European targets and to re-interpret traditional constructive know-how;
- Environment, landscape, urban planning and governance, in order to manage the development of the territory at different scales.

The first aim of the AlpHouse Center of Belluno is to appoint for each one of these issues a contact person with specific expertise with respect to the subject. The work of the contact person will then be supported by the development of a scientific committee made up of experts from different cultural and professional backgrounds. The scientific committee should identify any possible innovative content for every information and training activity in the territory.

As for the main recipients of the actions referring to the AlpHouse Center of Belluno, the preliminary activities have identified some categories of subjects to be preferred. These include firstly local governments, as the subjects that direct, regulate and put forward proposals in the field of construction activities and planning. A second target group is represented by the designers, both as entities that manage the design activities at different scales, and as entities that can collaborate in the program of the AlpHouse Center, through the expression of needs and innovative content. Another target group is then made up of enterprises and artisans, as entities operating in particular in the field of materials and construction techniques. Finally, the AlpHouse Center of Belluno intends to direct its activities towards two additional target groups, not specifically related to the field of building and planning: schools and citizen. The aim in this case, intending the word "culture" in a broader meaning, is to educate and raise awareness about the importance of the traditional built heritage of the area and, above all, of its sustainable development.

As already experienced in the preliminary activities, the purpose of the Center is to interact with the various target groups using a participative approach. Different ways of involving people, such as focus groups, action planning, brainstorming, etcetera, should be individuated from time to time and according to the training objectives of the activities.

Finally, the AlpHouse Center of Belluno aims to develop the following activities:

- the establishment and management of a "permanent information desk", a physical place and a reference point concerning the thematic areas listed above;
- the strengthening of networking with other AlpHouse Centers, in the framework of exchanging and sharing of best practices;
- the creation and implementation of a network of experts in the fields of interest of the AlpHouse Center at local, national and international level;
- the organization of training and information events related to the thematic areas;
- the structuring of a database of best practice related to design, construction, territorial planning, etcetera, available within a website.

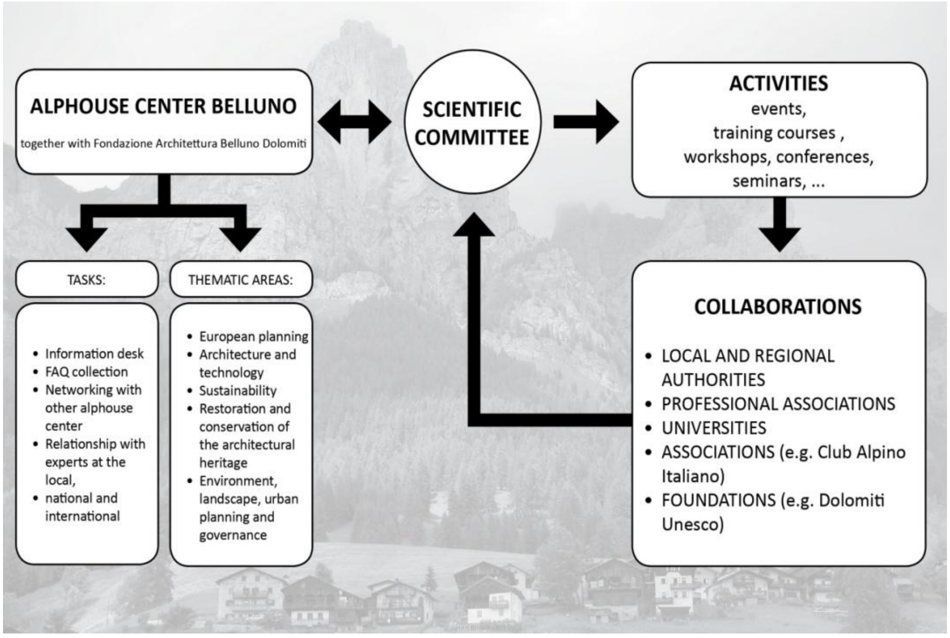

Figure 3- Summary of the organization, structure, objectives, activities and collaborations of the AlpHouse Center of Belluno.

2.3 Summary of the first activities

The AlpHouse Center of Belluno, based on the defined purpose and priority themes and in relation to the target groups that have been identified, has started its activities in May 2015. According to the preliminary activities and the organization foreseen for the AlpHouse Center of Belluno, some training and informative events and activities have been organized. As well as being an important opportunity of sharing knowledge and experience in the territory, these events and activities act as a check on the contents of the Center. Moreover they are an opportunity to gather feedbacks from the users, in order to enhance the future activities of the Center. The aims and thematic areas of the events and activities organized are reported below.

Table 1- Description of the first activity (21st May 2015)

	Title of the activity: "Culture of living and building in the Alps. Good practices between tradition and innovation in the province of Belluno"
	Type of activity: architectural trip
	Target groups: - professionals in the construction sector
	Objective of the activity: to visit and examine two best practices of new construction and refurbishment of traditional buildings in the alpine context

	Main thematic areas: - restoration and conservation of the architectural heritage - sustainability - architecture and technology

Table 2- Description of the second activity (22nd May 2015)

	Title of the activity: "Culture of living and building in the Alps. Conference to present the AlpHouse Center of Belluno"
	Type of activity: convention
	Target groups: - professionals in the construction sector - representatives of the construction industry - politicians - citizens
	Objective of the activity: to present the activity of the AlpHouse Center of Belluno and raise awareness on the integration of sustainability into the planning and construction sector
	Main thematic areas: - sustainability - environment, landscape, urban planning and governance.

Table 3- Description of the third activity (26th June 2015)

	Title of the activity: "Culture of living and building in the Alps. Good practices between tradition and innovation in the province of Belluno"
	Type of activity: conference and exhibition
	Target groups: - professionals in the construction sector - representatives of the construction industry - politicians - citizens
	Objective of the activity: to present the results of the international design competition for the reconstruction of the alpine hut "Fill. Fanton" in the Dolomites, with a focus on innovative building construction systems and materials in complex environments
	Main thematic areas:

	- sustainability - architecture and technology

Table 4- Description of the fourth activity (29th June 2015)

	Title of the activity: "Building refurbishment between tradition and innovation"
	Type of activity: convention
	Target groups: - professionals in the construction sector - representatives of the construction industry - citizens
	Objective of the activity: to inform and raise awareness on the issues of energy efficiency and conservation of traditional architecture
	Main thematic areas: - restoration and conservation of the architectural heritage - sustainability - architecture and technology

Examining the first activities carried out it is possible to underline their character of precursors of the future work of the AlpHouse Center: the activities are characterized by a general rather than specific approach. The most frequently encountered thematic areas have been the sustainability and architecture and technology. In particular sustainability can be considered a field which can involve a wider audience and not only the insiders and which is related to finding a way for the future development of the alpine territory. Moreover, the different thematic areas in most of the case have been treated during meetings open to the public (e.g. convention, exhibition, etc.) and often addressed to a non-specific audience, e.g. citizens. This can be considered a first attempt to create a connection between the AlpHouse Center of Belluno and its territory through participation and to spread a wider idea of the culture of living and building in the Alps. Another feature of some of the activities done regards the idea of knowing and sharing best practices, as claimed in the intents of European cooperation programme and of the AlpHouse Center network.

3. Conclusions

The paper have had the aim to present a best practice developed in an alpine area which can be an example to be developed in other areas, in the context of an exchange of experiences. To underline the most relevant findings, the work done in the set-up of the AlpHouse Center, in its organization and in its first activities has observed three main aspects.

First of all, the experience of the AlpHouse Center of Belluno - a permanent center for the culture of living and building in the Alps - reported in this paper, shows the importance of a participative approach and involvement of different target groups and communities in structuring a reference point on the themes of architecture and sustainable planning in the mountain area, in order to set appropriate strategies and solutions to identified needs. This participative approach, also suggested by the Declaration "Population and Culture" (2006), which has been used also in the preliminary organization of the Center and that aims to be pursued in the future activities, has led to the identification of two elements. Firstly, it identified different persons - governments, professionals, enterprises, schools and citizens - which can be interested in the AlpHouse Center activities and their fields of interest. This allows to structure the training offer and informative offer based on the specific needs that emerged. Secondly, this approach has allowed to identify, with a bottom-up approach, the most significant issues in the field of architecture and planning, as they are perceived from the people involved in the construction and planning sector within the territory of Belluno. The contents of the activities of the AlpHouse Center, in this sense, come from actually detected needs.

From a more general point of view, the creation of the AlpHouse Center of Belluno can be an opportunity for the exchange of experiences and expertise. On one side, this sharing opportunity can be possible between different subjects in the Belluno area in order to develop local awareness, capability and know-how. On the other side, the belonging of the AlpHouse Center to a network of other AlpHouse Centers gives to the Belluno area the possibility to interact with other alpine areas and with other people which live and work in the Alps. This aspects overcomes the idea of isolated mountain area and, on the contrary, supports the idea of the alpine areas as territories of experimentation, as recalled in the introduction of the paper. In this sense the AlpHouse Center of Belluno allows a continuous contact with various knowledge and innovation subjects and the inclusion of the territory of Belluno in the global Alpine context.

Finally, the activities of AlpHouse Center help to ensure that the teaching of a “ante-litteram sustainability” - which is a common aspect to the alpine areas and their traditional buildings and, as have been recalled, a part of an ancient knowledge - can be known, handed down, reinterpreted and then integrated with the new demands for innovation. By trying to combine the collection of this traditional background with the possibility of innovation, the AlpHouse Center can be a reference point for the future sustainable development of the building sector and of the planning activities in the Belluno area. In this sense thus the AlpHouse Center intends to align the experimentations done in an alpine territory with the global objectives of sustainable development suggested by the European Union.

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New potential indicators for energy matching at neighbourhood level

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Abstract

The key aspect of the energy matching in the districts is balancing the energy supply from local renewable sources with the energy demand of buildings and other urban infrastructures. The challenge is to simultaneously maximise energy efficiency and minimise peak power demand while maximising local renewable energy supply, including resolving energy storage issues. To avoid sub-optimisation it is important that the wider context is considered in the design and operation of neighbourhood's energy systems throughout its entire life cycle. The purpose of this study was to address this challenge by bringing new metrics to assess how well the local renewable supply meets the local demand in the neighbourhood level. A set of new key performance indicators (KPIs) is proposed for evaluating the energy positivity level of neighbourhoods. These KPIs include yearly on-site energy ratio (OER) and energy mismatch indicators for each energy type (heating, cooling and electricity). The mismatch indicators include annual mismatch ratio (AMRx), maximum hourly surplus (MHSx), maximum hourly deficit (MHDx) and monthly ratio of peak hourly demand to lowest hourly demand (RPLx), where x is replaced by an indicator for the different energy types respectively (h for heating, c for cooling, e for electricity). This is followed by presenting the first results from a number of energy simulations where the indicators are calculated. It can be observed that the threshold or target values for the indicators might be different for different countries. In a southern country it might be easier to meet the low AMR values by increasing local solar energy supply, if the local demand is predominantly caused by electricity driven cooling and domestic hot water. The indicators presented here proved useful in considering the probable configurations for the near future aiming at nearly zero-energy neighbourhoods. An interesting finding is that the on-site energy ratio also reveals the best energy efficiency level of buildings studied.

Keywords: Key performance indicators, energy matching, energy positive, neighbourhood

1. Introduction

In the near future, energy demand of buildings is expected to decrease. The Energy Performance of Buildings directive (EC, 2010/31) guides to adopting highly efficient nearly zero energy building performance requirements for both new and existing buildings, leading to so-called nearly zero-energy buildings. Lately the focus has been broadening towards zero energy neighbourhoods, or even energy positive neighbourhoods (e.g. Ala-Juusela et al. 2014 and Marigue et al. 2014).

In the longer term, zero energy and energy positive buildings are seen as an active part of cities' energy systems, contributing among others to increased share of renewable energy sources use and intelligent energy management (Kylili and Fokaides, 2015). Additionally, for example a report from a European Large Scale bridging Action (ELSA) Thematic Working Group on ICT for energy efficiency concluded that (Davis, 2009): "*Energy-positive buildings and neighbourhoods are those that generate more power than their needs. They include the management of local energy sources (mainly renewable, e.g. solar, fuel cells, micro-turbines) and the connection to the power grid in order to sell energy if there is excess or, conversely, to buy energy when their own is not sufficient*". The traditional role of buildings is transforming from energy consumers to small scale energy producers, or so-called prosumers (Picciariello et al. 2015; Rathnayaka et al. 2015). Matching of energy supply and demand on the neighbourhood level is one step in this long term development.

Energy matching aims to balance the energy supply from local renewable sources with the energy demand of a neighbourhood (Pina et al. 2012; Sunliang et al. 2013). This will include maximising energy efficiency and minimising peak power demand, while maximising the local renewable energy supply and the management of energy storage. The energy demand and its potential flexibility (shifting of times of use etc.) can be utilised for energy matching with the available local renewable energy sources, and/or with the energy tariff levels from energy markets (Heimonen et al. 2012). To avoid sub–optimisation it is important that the wider context is considered in the design and energy operation of neighbourhood throughout its entire life cycle. The appropriate time scales and energy components for studying the matching of energy demand and renewable supply can vary.

The research question was to study what are the new energy matching indicator values for different kinds of neighbourhoods located in Helsinki, Finland and Madrid, Spain, and how they can be used to compare the studied neighbourhoods. In this work, neighbourhoods have been defined as a group of buildings, which have a common geographical location and are served by common energy networks. The more detailed boundaries for the concept of neighbourhood depend on the studied case. Energy demand of a neighbourhood includes in this study the energy demand of buildings, but in general, the scope could also include the energy demand of transportation and other urban infrastructures (such as waste and water management, parks, open spaces and public lighting).

2. Methodology

2.1 KPIs for matching the neighbourhood energy supply and demand

Ala-Juusela et al. (2014 and 2015) have developed a set of key performance indicators (KPIs) for assessing the matching of energy demand and supply of a neighbourhood. In addition to meeting the overall annual energy balance, it is important that different types of energy are taken into account and the timing of the supply and demand of these different types of energy is matched as well as possible.

The KPIs developed to measure the energy positivity level of a neighbourhood (Ala-Juusela et al. 2014 and 2015) include yearly on-site energy ratio (OER) and energy mismatch indicators for each energy type (heating, cooling and electricity). The mismatch indicators include annual mismatch ratio (AMRx), maximum hourly surplus (MHSx), maximum hourly deficit (MHDx) and monthly ratio of peak hourly demand to lowest hourly demand (RPLx), where x is replaced by an indicator for the different energy types respectively (h for heating, c for cooling, e for electricity).

The <u>overall balance</u> between annual energy demand and local renewable supply is indicated with the **On-site Energy Ratio (OER)**, which is the ratio of these two:

- Annual energy supply from local renewable sources (all energy types together)
- Annual energy demand (all energy types together).

The <u>short term imbalances</u> are indicated with:

- **Annual Mismatch Ratio (AMR)**, which indicates how much energy needs to be imported into the area for each energy type on average. It is the annual average ratio of these two, for those hours when the local demand exceeds the local renewable supply:
    - hourly difference between demand and local renewable supply (by energy type)
    - hourly demand (by energy type) during that same hour
- **Maximum Hourly Surplus (MHS)**, which is the maximum yearly value of how much the hourly local renewable supply overrides the demand during one single hour (by energy type)
- **Maximum Hourly Deficit (MHD)**, which is the maximum yearly value of how much the hourly local demand overrides the local renewable supply during one single hour (by energy type)
- **Monthly Ratio of Peak hourly demand to Lowest hourly demand (RPL)** indicates the magnitude of the peak power demand, and it is calculated as the ratio of these two (by energy type):
    - The highest value for hourly demand over the month
    - The lowest value of hourly demand over the month (0-values are ignored)

It is worth noticing that OER=1 means zero energy building or neighbourhood and OER>1 means energy positive building or neighbourhood. OER<1 indicates that a building or a neighbourhood requires imported energy, i.e. it represents a typical situation today.

AMR indicator can have values between 0 (meaning perfect match) and 1 (no match at all), i.e. the smaller value AMR has, the better the local renewable supply matches with the demand.

2.2 Energy simulations

Altogether, 60 energy simulations were carried out for different combinations of building categories, their technical systems and usage profiles. These will be described in the following sections. Dynamic simulation software IDA-ICE (Equa 2013) was used.

2.3 Simulated scenarios

Hourly simulations for demand and renewable supply over one year were conducted. All the different cases were simulated in two different climates: Helsinki, Finland, representing Northern climate (60°10′10″ N; 24°56′07″ E) and Madrid, Spain, representing Southern climate (40°24′59″ N; 3°42′09″ W).

2.3.1 Buildings

Two broad types of buildings were simulated: a residential single-family building and an office building, both with variable construction technology, users and renewable energy supply (see Table 1 and Table 2).

Table 1: A summary of the simulated variables for the residential buildings.

(18) Detached houses in Helsinki / Madrid	**1**	**2**	**3**
Energy class	Normal wooden house	LowE wooden house	Old massive HighE house
User class	4 persons, wake-up late	4 persons, wake-up early	Retired couple
Orientation class	Facing South	Facing East	-

For the residential building, three different types of construction technology were simulated: a wooden house complying with current requirements from the building code, a low-energy wooden house and an old massive house with high energy use. For the simulation of residential buildings, also three types of user profiles were used: a family of four, waking up relatively late, another family of four, but with a habit to wake up early, and a retired couple (Figure 1). These all have different behaviour patterns, affecting the timing of the energy use, and therefore also the possibilities to match the renewable supply with the demand on the right time. The third variable parameter was the orientation of the house, either to South or to East. All different building technologies, user types and orientations were combined, resulting in total of 18 different configurations (3 construction types x 3 user types x 2 orientations).

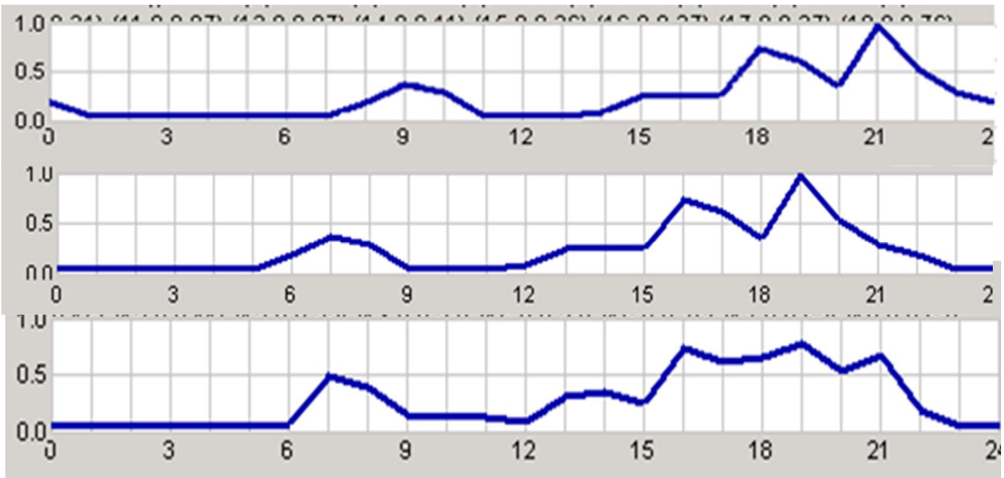


Figure 1: Different daily schedules for electricity use for the three user types.

For the office building, three different types of construction and building technology were simulated: A building with normal insulation level and heat recovery, a low energy office building and an old house with high energy use and no ventilation heat recovery. The second variable parameter was the orientation of the building, either to South or to East. For the simulation of office buildings, also two types of window shading options were used: no shading, or external shading, lights and schedule control. All different building technologies, orientations and window shading options were combined, resulting in total of 12 different configurations for the office building (3 construction types x 2 orientations x 2 window shading options).

Table 2: A summary of the simulated variables for the office buildings.

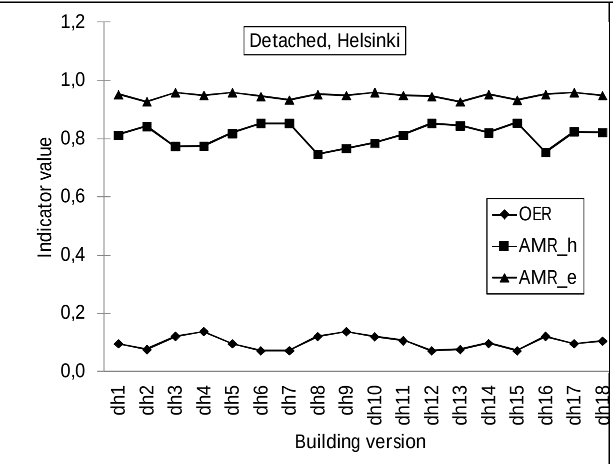
(12) Offices in Helsinki / Madrid	**1**	**2**	**3**
Energy class	Normal insulation and heat recovery	LowE building	Old High Energy building, no ventilation heat recovery
Orientation class	Facing South	Facing East	-
Window shading	No shading	External shading, lights and schedule control	-

2.3.2 Renewable production

Three types of renewable production were simulated: photovoltaic panels, solar thermal collectors and wind power. Three orientations and two tilt angles were simulated for the solar panels and collectors: South 45°; South-East 60° and South-West 60°. The nominal power of the wind turbine was 5300 W. The simulations for solar yield were conducted for 1 m^2 of panel or collector area, so the size of the solar installation can be varied in the scenarios.

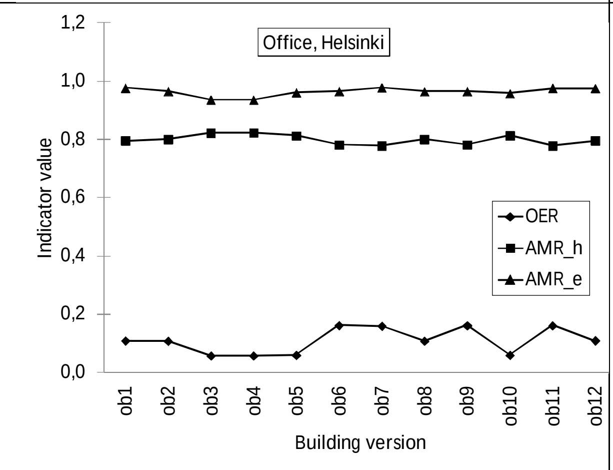
2.3.3 New indicators at building level

As a first approach all possible building variations were considered and the new indicators were calculated for each case in two climatic zones: Northern represented by Helsinki and Southern represented by Madrid. In both climates the renewable energy generation was assumed to be solar collectors and PV panels (4 and 2 m^2 respectively for detached houses and 120 and 80 m^2 respectively for office buildings) tilted 45° and facing south. The results are summarised in Figure 2 for Helsinki and in Figure 3 for Madrid.



Detached, Helsinki	1	2	3
Energy class	Normal wooden house	LowE wooden house	*Old massive HighE house*
User class	4 persons, wake-up late	*4 person, wake-up early*	Retired coupl
Orientation class	Facing South	*Facing East*	

Best (dh4): OER = 0.14
Worst (dh6): OER = 0.07



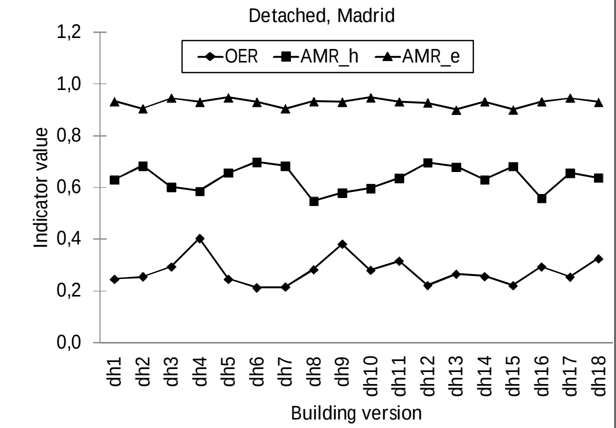
Office, Helsinki	1	2	3
Energy class	Normal insulation and heat recovery	LowE building	*Old High Energy building, no ventilation heat recovery*
Orientation class	*Facing South*	Facing East	
Window shading	*No shading*	External shading, lights and schedule control	

Best (ob6): OER = 0.16
Worst (ob4): OER = 0.06

Figure 2: New KPI-indicators for all possible building versions (left) and best and worst building versions (right) in Northern climate (Helsinki).

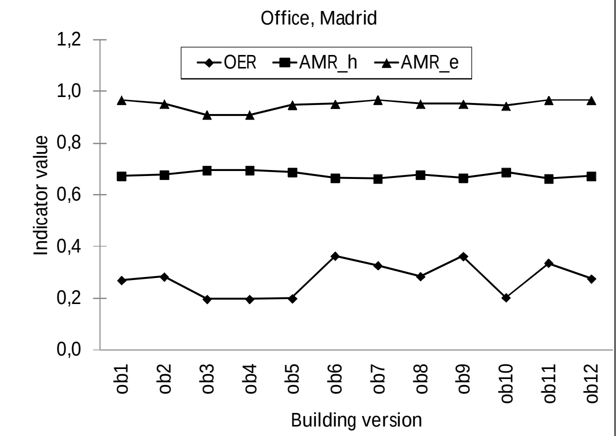
From the energy consumption point of view, the most energy-efficient detached building version (dh4 in Figure 2) is the one with also the highest OER-indicator, i.e. the low energy wooden house, facing south and occupied by a retired couple. This result is marked with bolded font in the table up-right in Figure 2. The other extreme, the worst solution from energy point of view (dh6 in Figure 2) is the one with also the lowest OER-indicator, i.e. old massive high energy house, facing east and occupied by 4 people rising early in the morning. This result is marked with italic font in the table up-right in Figure 2. The range between extreme values of OER indicators imply that the worst solution will use double the amount of energy compared with the best solution.

Respective analysis for office building solutions show that the most energy efficient office building version (ob6 in Figure 2) is the one with also the highest OER-indicator, i.e. the low energy building, facing east and equipped with external shading and having lighting with schedule control. This result is marked with bolded font in the table low-right in Figure 2. The other extreme, the worst solution from energy point of view (ob4 in Figure 2) is the one with also the lowest OER-indicator, i.e. old high energy building without ventilation heat recovery, facing south and having no shading. This result is marked with italic font in the table low-right in Figure 2. The range between extreme values of OER indicators imply that the worst solution will use approx. 2.5 the amount of energy compared with the best solution.



Detached, Madrid	1	2	3
Energy class	Normal wooden house	LowE wooden house	*Old massive HighE house*
User class	4 persons, wake-up late	*4 person, wake-up early*	Retired couple
Orientation class	Facing South	*Facing East*	

Best (dh4): OER = 0.40
Worst (dh6): OER = 0.21



Office, Madrid	1	2	3
Energy class	Normal insulation and heat recovery	LowE building	*Old High Energy building, no ventilation heat recovery*
Orientation class	*Facing South*	Facing East	
Window shading	*No shading*	External shading, lights and schedule control	

Best (ob6): OER = 0.36
Worst (ob4): OER = 0.20

Figure 3: New KPI-indicators for all possible building versions (left) and best and worst building versions (right) in southern climate (Madrid).

An analysis of the exactly respective building versions simulated in Southern climate is summarized in Figure 3. It is easy to notice that it allows for similar conclusions as above. The same building versions were identified as the best and the worst solutions, both for detached houses and offices, respectively. However, it is worth noticing that the values of OER indicator in Southern climate are considerably higher compared with the values in Northern climate. This is obviously telling that buildings with identical construction located in mild climate will consume less energy, and considerably more renewable energy is available for use there, compared with Northern climate, see Figure 3.

3. Simulated energy matching indicators at neighbourhood level

The simulated buildings and renewable production elements can be combined into different neighbourhoods to study which combinations would lead to energy positivity on the neighbourhood level. The buildings selected for the following analysis include: ob6 (the most effective office), ob12 (standard office), dh4 (the most effective detached house), dh14 (standard detached house), and a few other detached houses with different energy classes, user classes and orientations (dh9, dh10, dh11). These buildings were preselected from among all carried simulations described in previous section. All of the preselected buildings are identified in Table 3.

Table 3: Definition of the detached houses and the office buildings used in the neighbourhood analysis. (For numbering of different classes, see Table 1 and Table 2)

Detached house	**dh4**	**dh9**	**dh10**	**dh11**	**dh14**	Office	**ob6**	**ob12**
Energy class	2	2	2	1	1	Energy class	2	1
User class	3	3	2	3	1	Orientation class	2	1
Orientation class	1	2	2	2	1	Shading type	2	1

It was assumed that the neighbourhood would be located in Southern climate (Madrid) and would consist of 10 buildings, including at least 1 office. The amount of other buildings could vary.

The following exercise was carried out to study how to arrive from a solution that would be a standard today to an energy positive neighbourhood. The steps are represented by the following cases: (1) standard today, (2) low energy, (3) balanced mixture, (4) enhanced mixture and (5) energy positive neighbourhood. The cases are defined with further detail in Table 4.

This means that the neighbourhood in Case 1 consists of 8 detached houses (each type dh4, with 4 m^2 of solar collectors and 2 m^2 of PV panels on each building) and 2 offices (each type ob12, with 120 m^2 of solar collectors and 80 m^2 of PV panels on each building). Neighbourhood in Case 2 consists of 9 detached houses (type dh4 each) and one office building (type ob6), etc.

For each case, the energy consumptions, renewable generations and corresponding KPIs were calculated not only for each individual building but also for the group of buildings and for the entire neighbourhood level. The results are summarized in Table 5.

Table 4: Cases 1 – 5 in Madrid climate.

Case 1	dh4	dh9	dh10	dh11	**dh14**	ob6	**ob12**
Amount of buildings					8		2
Solar thermal, m^2					4		120
Photovoltaic, m^2					2		80
Case 2	**dh4**	dh9	dh10	dh11	dh14	**ob6**	ob12
Amount of buildings	9					1	
Solar thermal, m^2	4					120	
Photovoltaic, m^2	2					80	
Case 3	**dh4**	**dh9**	**dh10**	**dh11**	**dh14**	**ob6**	**ob12**
Amount of buildings	2	2	1	1	2	1	1
Solar thermal, m^2	4	4	4	4	4	120	120
Photovoltaic, m^2	2	2	2	2	2	80	80
Case 4	**dh4**	**dh9**	**dh10**	**dh11**	**dh14**	**ob6**	**ob12**
Amount of buildings	2	2	1	1	2	1	1
Solar thermal, m^2	8	8	8	8	8	120	120
Photovoltaic, m^2	8	8	8	8	8	240	240
Case 5	**dh4**	dh9	**dh10**	dh11	**dh14**	**ob6**	ob12
Amount of buildings	7		1		1	1	
Solar thermal, m^2	12		12		12	240	
Photovoltaic, m^2	12		12		12	320	

The target of the exercise was to obtain the energy positive neighbourhood (OER>1). Therefore the change from Case 4 to Case 5 essentially meant to sufficiently increase the local generation, i.e. the area of solar panels.

The Case 5 was also calculated in Northern climate and the results are included in the last column in Table 5. The comparison with Case 5 in Madrid climate shows that the neighbourhood that is clearly energy positive in Southern climate is far from being positive in Northern climate (compare OER values 1.13 vs 0.42). To achieve this position, considerably more renewable generation would be required for heating function.

Table 5: Results of analysis for Cases 1-5 in Madrid climate, including Case 5 also in Helsinki climate.

	Case 1	**Case 2**	**Case 3**	**Case 4**	**Case 5**	**Case 5 (Helsinki)**
Detached houses						
Amount of buildings	8	9	8	8	9	9
Heating, kWh/m2	40.6	24.5	31.6	31.6	27.2	69.1
Electricity, kWh/m2	41.4	27.6	33.5	33.5	30.9	27.1
Total, kWh/m2	82.1	52.2	65.0	65.0	58.0	96.2
OER	0.26	0.40	0.32	0.71	1.19	0.43
AMR_h	0.63	0.59	0.60	0.58	0.56	0.75
AMR_e	0.93	0.93	0.93	0.78	0.73	0.81
Offices						
Amount of buildings	2	1	2	2	1	1
Heating, kWh/m2	28.7	12.6	20.7	20.7	12.6	63.1
Electricity, kWh/m2	103.6	87.6	95.6	95.6	87.6	71.1
Total, kWh/m2	132.4	100.3	116.3	116.3	100.3	134.2
OER	0.28	0.36	0.31	0.39	0.82	0.36
AMR_h	0.67	0.67	0.67	0.67	0.66	0.78
AMR_e	0.97	0.95	0.96	0.89	0.84	0.89
Neighbourhood						
Amount of buildings	10	10	10	10	10	10
OER	0.26	0.40	0.32	0.61	**1.13**	0.42
AMR_h	0.64	0.59	0.62	0.60	0.57	0.75
AMR_e	0.94	0.93	0.94	0.80	0.74	0.82

4. Discussion and conclusions

The exercise presented in this paper was aimed to imitate the work architects presumably do today in their daily practice without having easy tools to assist them in considering energy aspects of their designs. While tools to simulate energy consumption of single buildings are available, they also usually require a considerable degree of expertise not only to set up and run them but also to interpret the results. The new KPIs for energy matching of buildings and neighbourhoods are aimed to help in this context. The studied KPIs help to assess the energy positivity level of neighbourhoods, meaning that how well the local renewable supply meets the local demand at the neighbourhood level. The KPIs include yearly on-site energy ratio (OER) and energy mismatch indicators for each energy type (heating, cooling and electricity). The mismatch indicators include annual mismatch ratio (AMRx), maximum hourly surplus (MHSx), maximum hourly deficit

(MHDx) and monthly ratio of peak hourly demand to lowest hourly demand (RPLx), where x is replaced by an indicator for the different energy types respectively.

The simulation results indicate that it is relatively easy to draw conclusions based on simple values of OERs and AMRs to guide architect in making educated choices in an early design stage that would be difficult or impossible to change in a later stage of the process. Achieving zero energy building or neighbourhood requires that OER=1, or higher for energy positive buildings and neighbourhoods. AMR indicator shows the level of energy matching (how well energy demand and supply are corresponding), with AMR values ranging from 0 for a perfect energy match to 1 for no match at all. This information could also be used already in the land use planning when aiming to energy efficient, zero energy or energy positive neighbourhoods.

Because the proposed KPIs are new, further experimentation is needed to gain confidence before it will be safe to propose any target values for these new KPIs to be used as reference for architects in making designs. Experiment presented in this paper showed that such target values will certainly have to be different in different climates.

From the methodological point of view, it is advisable to run large number of simulations varying a number of design parameters and draw conclusions using KPIs. Already today using KPIs in a manual manner, as presented in this paper, will improve the design of neighbourhoods. In the future the process could be further developed including optimisation function. Thereafter, it could be made even easier and faster by making the whole process automatic.

In the development of the indicators presented here only the probable configurations for the near future were considered, which will be nearly zero-energy neighbourhoods with relatively modest excess energy supply. Further ahead into the future, there might exist neighbourhoods that aim to make a financial profit by producing much more energy than the local demand, and storing some of the energy to be sold when the demand on national market is high and the price for the energy is at its peak. These kinds of future scenarios will require a rethinking of the indicators.

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Integrating sustainability into real estate and construction business development.

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Abstract

Ramboll Green Market study (GMS) on 2014 was the fourth survey since 2008. The purpose of the study was to find out how sustainability is integrated into real estate and construction business in the Nordic countries. The GMS contains questions about management, operation and development for tenants, property managers, owners, developers, construction industry, designers and municipalities. It provides a view of the drivers, emerging topics, challenges and opportunities towards sustainability.

Assumptions were made before the GMS study based on the market situation and previous studies: the role of the user as the customer has been enhanced, tighter economic situation has reflected to the need to find cost savings, new technical systems are emerging and "green building is becoming the standard." It was assumed that new technologies and accounting sustainability requires more communication.

Based on GMS study the development has resulted in more efficient use of resources, increased significance of green buildings and co-operation between stakeholders. 71% of respondents saw the environmental values as a part of the corporate responsibility strategy. The respondents clearly indicated that green premises will become considerably more common in 5 years. Tenants seemed to be well aware of the green premises positive impacts and are willing to pay slightly (< 3 %) more of the green premises.

According to the study, the industry in Nordic countries has strong trust in integrated solar energy production. In area planning global warming, scarcity of natural resources and primary energy consumption were ranked as the most important sustainability topics. Great majority (93 %) do believe life cycle contract projects to become more common in the near future. There is also need for whole building life cycle consideration that require holistic data collection and sharing with building information modelling (BIM). The greatest possibilities to influence sustainability integration were seen in participation in EU decision-making and through education.

85% of the GMS respondents were aware of environmental impacts monitoring. Monitored indicators are most commonly communicated to the stakeholders within the annual report.

Annual report may not be active and engaging communication for integrating sustainability, but a place to show what is done.

Keywords: sustainability, real-estate, construction, communication, measurement

1. Introduction

In 2014 spring it seemed that the Nordic countries real-estate industry had found the key environmental aspects. Heads were turned towards actions in measurement, communication and constant improvement operations. The economic situation had tightened the monitoring of building efficiency and environmental certification helped to find the customers in the tight competition of tenants. The environmental monitoring tools nationally and globally such as LEED (Leadership in Energy and Environmental Design) and BREEAM (BRE Environmental Assessment Method) for real estate industry had revealed the front runners that wanted to show their superiority. Independent bodies showed their environmental aspects with public administrated example buildings. These were assumptions and the aim was to find out what was actually happening. This paper was written to find out if the Green Market Study 2014 (GMS) and statistics show the same results as assumed.

2. Ramboll Green Market study (GMS) 2014 background

2.1 Purpose of the study

The purpose of the study was to find out how sustainability is integrated into real estate and construction business in the Nordic countries. New sustainable innovations were sourced. It was believed that new business models needed to be developed to support sustainability and data management will be needed. It was assumed that because of the economic situation, the increased competition of tenants will emphasise the user wishes and find new cost savings from e.g. new technical systems. Also, it was believed that “green building is becoming the standard.” All stakeholders need to adjust to the new situation and communicate with each other’s. The study was done to find out what is now developing fastest in the markets.

2.2 GMS Survey questions and respondents

GMS 2014 is the fourth insight of real estate business trends and development related to sustainability and green building in Nordic countries since 2008. Themes included real estate and construction industry trends yesterday and today, real estate data monitoring and utilization and green values. Also respondents’ views on the future of the real estate and construction industry were inquired. GMS 2014 aimed to focus more on the views of tenants. The topics of GMS 2014 were selected in co-operation with Ramboll specialists.

The trends contained questions about important aspects and reasons influencing to environmental awareness and possible barriers for not doing so. To found out the trends, same questions are asked in every time GMS since 2008 and also future aspects are included. Data monitoring questions were detailed to found out what exactly is measured, how it is communicated and what influences measurement has. Additionally survey contained questions about tools that are used for real estate sustainability performance evaluation. Many questions were related to sustainable values and new innovations on the field were discussed.

The data for GMS 2014 was collected with an on-line survey within real estate and building industry professionals, tenants and industry peers. Link was available on the web page and send to real estate operators. The survey was conducted in August 2014. The survey had a total of 177 respondents. Approximately 45% of respondents work in the public sector and 55% in the private sector. Respondents gave also answer for their respondent group based on their position in organisation with company management (19%), operative management (33%), expert or consultant (47%) and other (1%) groups.

Most of the answers gained (98 %) were from Finnish company operators. The answers were divided based on real estate sector operator groups. Answers divided quite evenly for all the groups shown below.

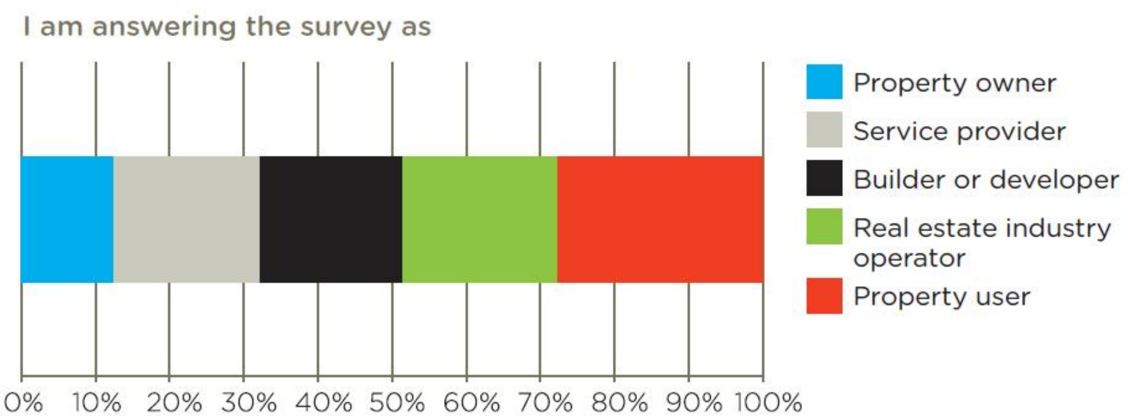

Figure 1: Green Market Study respondent groups in Ramboll Green Market Study 2014

2.3 The accuracy of the background assumptions

As pointed out earlier, it was assumed that because of the economic situation, the increased competition of tenants will emphasise the user wishes and find new cost savings from e.g. new technical systems. Also, it was believed that "green building is becoming the standard."

The number of certified buildings is increasing in the Nordic countries. According to article by Ryan Zizzo (2013) "the popularity of green building rating systems in general and LEED in particular has grown quickly over the past decade" (pp.1). FIGBC (Green building council Finland) that keeps combined records on the certifications with LEED and BREEAM announces that in in November 2015 the amount has reached more than 120 LEED and BREEAM certified buildings in Finland (Finnish green building council, 2015). According to Swedish Green building council there are **632** Swedish buildings certified with Swedish certifying system "Miljöbyggnad" and **266** buildings certified with GreenBuilding (Swedish BREEAM) (Swedish green building council, 2015). The amount of certified buildings is hence bigger in Sweden currently.

Both Sweden and Norway have integrated the BREEAM for their own countries. According to Norway Green building council the amount of BREEAM certified or registered buildings in Norway is 40 (Norwegian green building council, 2015). Green Building Council Denmark has established a Danish certification within sustainability: DGNB Denmark. According to the page there are currently 17 certified buildings (Denmark green building council, 2015).

On 2012 the GMS survey results showed that people are more familiar with the tools to improve sustainability than 2010. This can be seen from the number of "I do not know" - answers that were greatly diminished especially for BREEAM, ISO standards, Green Office (tool from WWF), Green Lease (contract for green buildings) and carbon footprint calculations (Pöyryn Kaupunki ja liikenne liiketoimintaryhmän julkaisu, 2010). Above written is the background for the assumption "green building is becoming the standard."

Good economic indicators are the share prices. According to Nordic Statistical Yearbook 2014 (Klaus Munch Haagensen, 2014) *from 2003 to the spring of 2007, share prices increased markedly in all Nordic countries – and definitely more than in the remaining West European countries. The increase happened after a considerable decrease in especially technological shares from 2000 to 2003. From the end of 2007, Nordic shares have decreased drastically as a result of the general crisis in the world economy. Despite a turning point in 2009 the share prices have not yet fully recovered.* The above mentioned and graph below illustrates well how the assumption for increased competition of tenants in the more competitive markets.

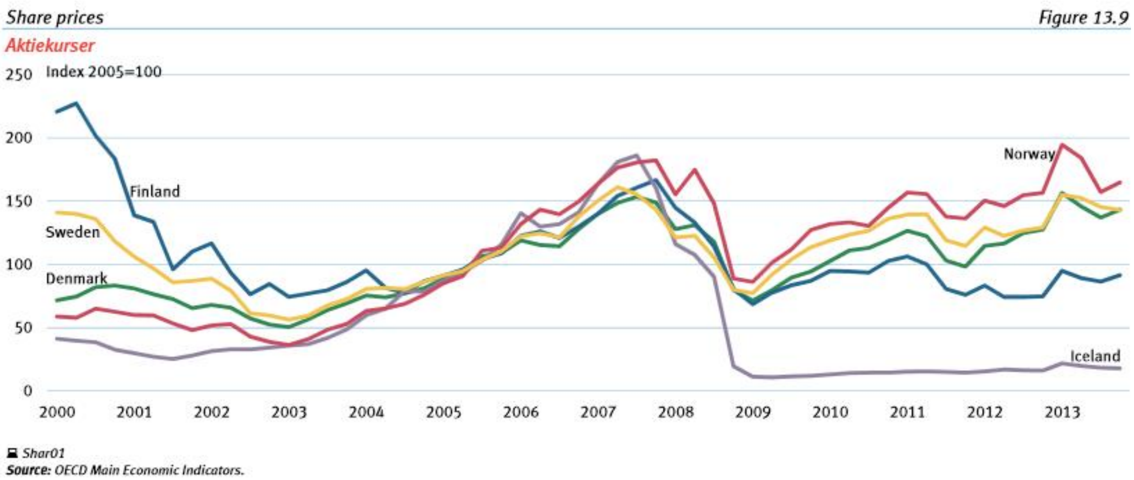

Figure 2: Nordic Statistical Yearbook 2014, OECD main economic indicators, Share prices 2014(Klaus Munch Haagensen, 2014)

3. Ramboll Green Market Study (GMS) driving forces towards sustainability 2008, 2010, 2012 and 2014

In 2008 the GMS results showed that respondents expected environmental issues to be dealt out of responsibility (Pöyry building services Oy:n julkaisu, 2008). In 2010 GMS results showed that respondents expected market opportunities and business development from Sustainability consideration. The front runners of the industry were clearly in the construction field (Pöyryn Kaupunki ja liikenne liiketoimintaryhmän julkaisu, 2010). Since then the will of the organisation key players and legislation have increased on the similar level as these earlier more recognized drivers which indicates that the market is changing. Sustainability is now driven from all the reasons mentioned above (Pöyry urban business group, Real estate consulting and design, 2012).

On 2014 the influence of regulation and legislation as an environmental driver in the business has become more evident. Regulation and legislation has become considerably stricter after 2010. At the same time, environmental values are not seen any more as a strong opportunity for strengthening company brand and image. Therefore the forecast of GMS 2010 has realized in part as regulation and legislation guide the environmental decisions in the real estate and construction industry. However, this far energy costs increase has not impacted as significantly as it was believed and seen in the figure below.

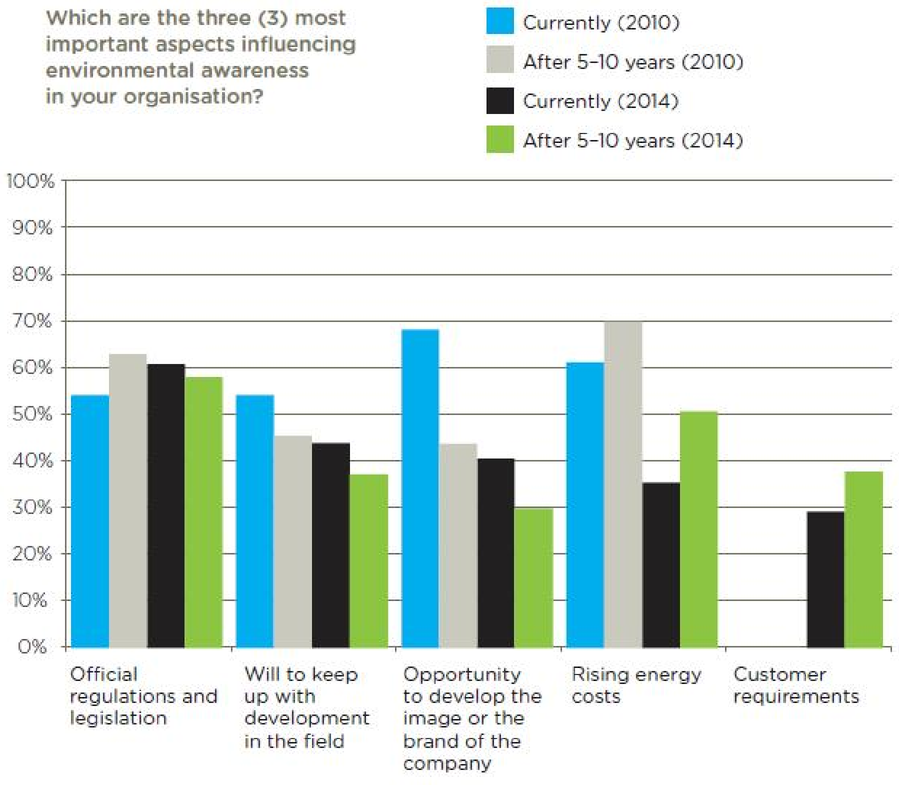

Figure 3: Green Market Study environmental aspect drivers according to Ramboll Green Market Study 2014

According to GMS 2014, half of the respondents believe that in the future the cost of energy will become one of the most significant factors in coming 5–10 years with the legislation. New driver was added to the survey 2014 “customer requirement”. It is shown that it is believed to become more important in future with the factor “keep up with the development”. This indicates that the “green is becoming the new standard level” and new innovations are needed for the emerging front runners.

4. Results

According to GMS 2014 premises are selected based on the location, cost, modification potential and access to public transportation network. Premises are built based on location, energy and water use efficiency, cost, modification potential and access to public transport network. According to GMS 2014 real estate environmental certification has clearly no influence in premise selection decision (3 %), but 30 % of the owners and construction professionals answered that environmental certification effects to the decision making (Ramboll Finland publications, 2014). However, tenants seem to be very well aware of the green premises positive impacts and are willing to pay slightly (less than 3 %) more of the green premises.

85% of the respondents are aware of environmental impacts monitoring. 18% of respondents say that they do not know if monitoring key environmental indicators influences decision-making in the company. The figure below illustrates the environmental indicators according to GMS 2014 that are monitored, should be monitored and are estimated to be monitored in coming 5 – 10 years.

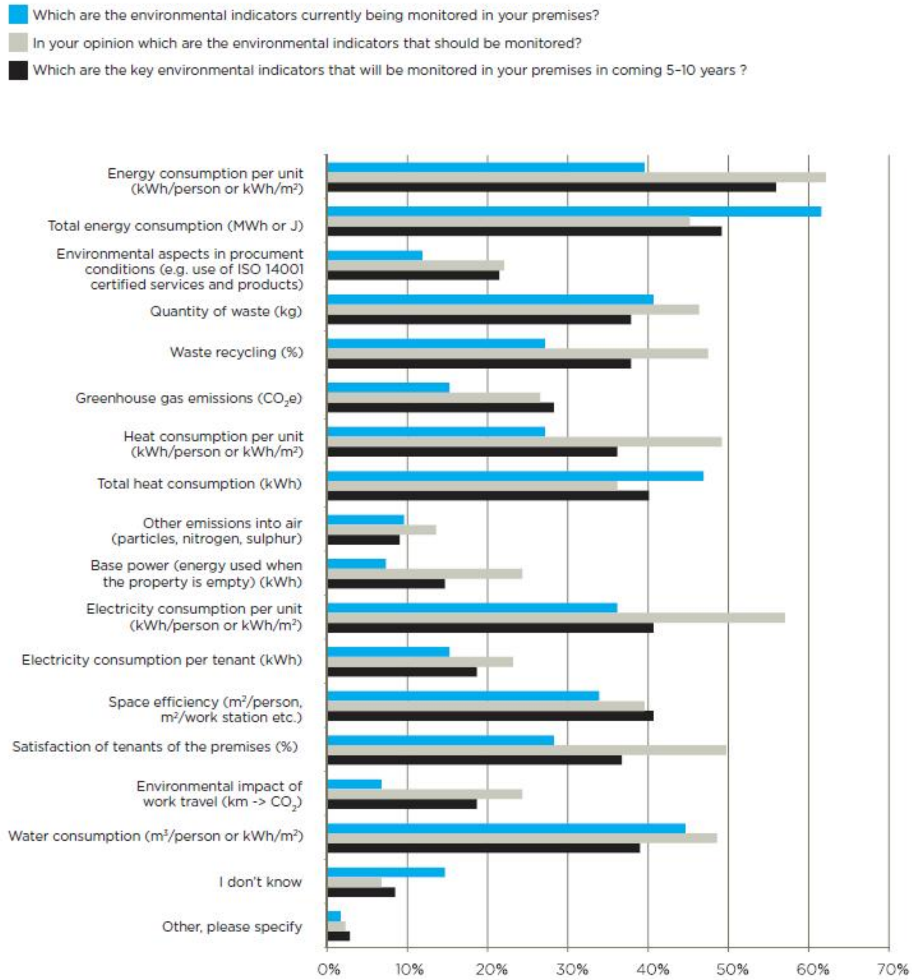

Figure 4: Green Market Study environmental indicator monitoring according to Ramboll Green Market Study 2014

When it was asked what environmental indicators are followed, companies are extensively monitoring energy and water consumption in total and also at tenant level. Fourth monitored key variable is the amount of waste, but recycling rate is left ninth in order of priority. Respondents believe that the trend proceeds towards unit-based monitoring (kWh/m2/person/product) in energy consumption, which would improve the use of data in facility and operations management. When asked what should be monitored, tenant satisfaction and waste recycling rate are also stated alongside the traditional indicators. (Ramboll Finland publications, 2014)

71% of respondents saw the environmental values as a part of the corporate responsibility strategy. The reason for adding values to strategy is because of legislation, keeping up with the development and company image. 30% of the respondents are members of national Green Building Councils and can therefore be considered part of the front runners. Environmental indicators are most commonly communicated to the stakeholders within the annual report, but issues are also considered strongly in procurement documents, in training and tenant instructions, that indicate true commitment to the strategic values. The next figure illustrates the different stakeholder's communication methods. (Ramboll Finland publications, 2014)

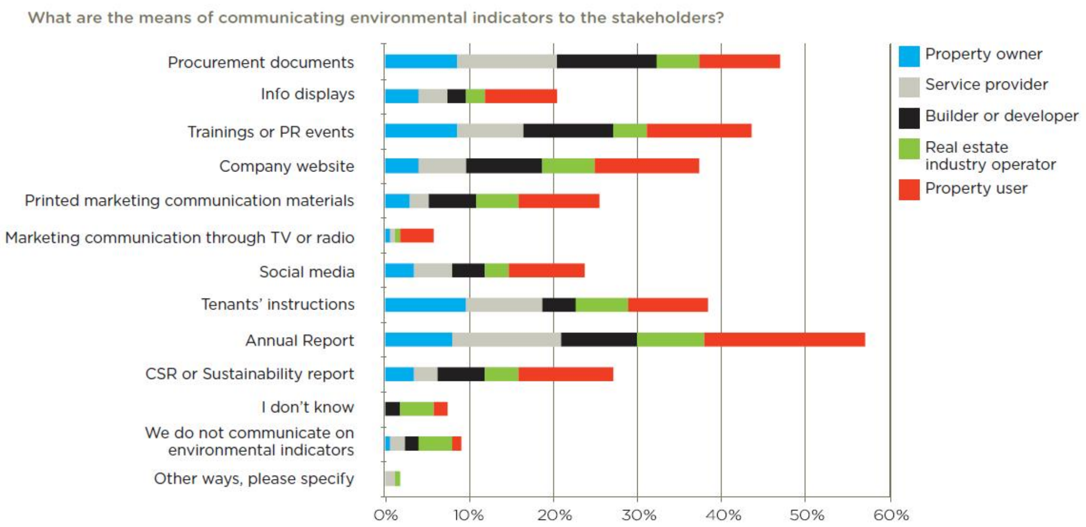

Figure 5: Green Market Study environmental indicator communication according to Ramboll Green Market Study 2014

According to GMS 2014 communication of environmental key indicators is integrated to the instructions of space use. Most commonly instructed are waste recycling and efficient use of energy and water. Tenants are environmentally aware and need more information. The environmental certification systems, standards and tools are well known (LEED and BREEAM among 70 %). The best known and most used green tools are the Nordic Ecolabel, passive house standard, carbon footprint calculations and ISO 14000 environmental management series standards. All respondent groups clearly indicated that green premises will become considerably more common in 5 years. User group estimation can be seen from figure below. (Ramboll Finland publications, 2014)

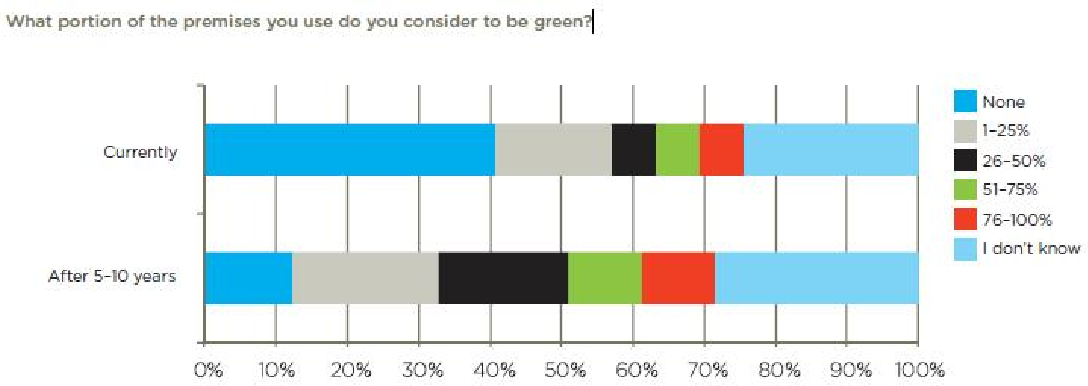

Figure 6: Green Market Study portion of green premises according to Ramboll Green Market Study 2014

Great majority of the respondents (80%) believed that Nordic countries will use more integrated solar energy applications in windows, walls and other building materials. Also it was believed that building information modelling (BIM) (60 %), the zero net energy technologies (57%) and versatility and adaptability of premises e.g. possibility for separate daytime and evening uses will increase (53%). There is also need for whole building life cycle calculation consideration (47 %) and spatial data use (48 %) that accelerates the need for more holistic data collection and sharing with building information modelling (BIM). In project planning global warming, scarcity of natural resources and primary energy consumption were ranked as the most important topics. Great majority (93 %) do believe life cycle contract projects to become more common in the near future. The greatest possibilities to influence were seen in participation (64%) in EU decision-making and through education (64%). (Ramboll Finland publications, 2014)

5. Discussion

Before the study it was assumed that the role of the user as the customer has been enhanced, tighter economic situation has reflected to the need to find cost savings, new technical systems are emerging and “green building is becoming the standard.”

According to results the premises are selected based on the location, cost, modification potential and access to public transportation network and environmental certification has no influence in premise selection decision. However, tenants seem to be very well aware of the green premises positive impacts and are willing to pay slightly (less than 3 %) more of the green premises.

One of the most important environmental indicator is energy efficiency (as shown in Figure 4). Regulation and legislation has tightened especially to control building energy efficiency which has resulted in less variation in the energy efficiency of new buildings. On the contrary the energy price has not reached such a level that it would increase the attractiveness of especially energy efficient building that has the environmental certification. At the same time, environmental values are not seen any more as a strong opportunity for strengthening company brand and image. This is perhaps, because more companies are considered to be green?

According to GRESB (global real estate Sustainability benchmark) the overall GRESB scores demonstrate a clear and upward trend in the sustainability performance of property companies and funds since 2013. On 2014 over 93 % have a long-term vision (up from 85 % in 2012) with nearly as many (80 %) also communicating more detailed short-term objectives. Importantly, on 2014 over 80 % involve their senior management board in the reviewing and monitoring of sustainability processes, as compared to 70 % in 2012. On 2015 over 94% of GRESB participants have a senior decision-maker dedicated to sustainability, most commonly a member of the senior management team (49% in 2015 from 42% in 2014). (GRESB, 2014) (GRESB, 2015)

In GMS 2014 environmental indicators are most commonly communicated to the stakeholders within the annual report, but issues are also considered strongly in procurement documents, in training and tenant instructions, that indicate true commitment to the strategic values. Formal annual report is perhaps not sufficiently active and engaging communication for integrating sustainability, but there the sustainability benchmark numbers are shown comprehensively for the year and compared to the historic data. Social media (24 %) and screens or displays on wall (20 %) are not very actively used although people seem to be spending more and more time with displays. Maybe this is why tenants seem to be lacking information especially on energy efficiency (73 %). It should be kept in mind that 94% of all respondents estimate that their own actions can influence on the energy consumption and costs of their premises. Efficient communication tools for real estate sector might be a true success story for someone as the study was partly set up to develop a business model to support sustainability and data management.

6. Conclusions

The purpose of the study was to find out how sustainability is integrated into real estate and construction business in the Nordic countries. It was revealed that the real estate industry sustainability in Nordic countries is driven mainly by legislation and green buildings are becoming standard buildings. As stated in the paper, the number of certified green buildings has increased and people are more aware of the green building benefits. Cost, location and modification potential increase most the real estate attractiveness. Tenants are very well aware of the green premises positive impacts and are willing to pay slightly more (< 3%) of recognized green premises.

As it was stated in the paper, the green building is becoming the new standard. Front runners have to show their commitment with new ways such as using the new clean technology solutions. It was revealed in the GMS that the great majority of the respondents (80%) believed that Nordic countries will use more integrated solar energy applications in windows, walls and other building materials. Also it was believed that building information modelling (BIM) (60 %) and the zero net energy technologies (57%) will increase in future.

The most important environmental indicator of the premise sustainability is energy efficiency. The energy efficiency level in Nordic countries new buildings is high and driven by tight legislation. Energy price has not reached such a level that it would increase the attractively of especially energy efficient building. However, sustainability performance of property companies and funds is increasing. That is seen also from GRESB (global real estate Sustainability benchmark) results recently. The GMS respondents believe that the trend proceeds towards unit-based monitoring (kWh/m2/person/product) in energy consumption, which would improve the use of data in facility and operations management. Sustainability performance should be shown to the customers with better communication and new innovations will be needed.

The role of the tenant as a property user and customer will most certainly emphasize. According to the GMS study better communication about the sustainability aspects is needed to the stakeholders. As an example tenants see that their own actions can influence on the energy costs of their premises and need up to date information on their environmental impacts in the building. Tenants would like to share information more about their satisfaction for premises and know actual waste recycling rate. Waste recycling is the most commonly instructed as key indicator alongside efficient water and energy consumption.

New communication ways are needed to improve the messaging. As an example social media or displays on the premises are still used less than expected. New economic situation is also driving the versatility and adaptability of premises e.g. for separate daytime and evening uses (53 % expects to increase) that will need better communication especially between the space users.

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A Strategic Tri-Level Relational Model for Building Capabilities and Effective Governance of Complex Adaptive Systems: The English Housing Perspective

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Abstract

This paper presents a conceptual strategic engagement model which underpins multi-level interventions required for decision-making – especially those governing sustainable transformations. Using the case study of the English housing system, it highlights the importance of integrating complex adaptive systems along with the socio-technical systems theoretical underpinnings, and analyses the strategic interventions needed for populating emerging strategic capabilities (with associated multi-level emerging strategic component-elements). In this context, the discussion includes a conceptual model: Strategic tri-level relational interventions for delivering energy efficiency and sustainability (STRIDES) which makes an innovative contribution to the evidence base for securing successful sustainable transformations.

This research engages the research lens of transdisciplinarity using an explicit mixed methods design to maximise engagement and participation approaches. This includes an online survey, Delphi study and focus group (to embrace multi-dimensional sustainability). The online survey was used to identify latent constructs based on correlated commonly agreed perspectives, which helped to provide multi-framing representations of the domains of housing providers, occupiers and regulators. The Delphi study focused on securing strategic interventions in the existing English housing system, in terms of both the strategic capabilities required for effective governance of these interventions and the strategic outcomes of these interventions. The focus group was used to secure in-depth understanding of the STRIDES model, cognisant of it being 'fit for purpose' within the tri-level arrangement.

Research findings highlight the need to strengthen strategic capabilities that draws on systems-thinking – especially for the implications of specificity (within multi-dimensional complex contexts); and the alignment of decision-making strategies which embrace multi-dimensional perspectives and multi-level governance – as these can often constrain systemic responses to

change. The STRIDES model presents a series of sustainable transformational activities in a cogent form through which strategies for energy efficiency and sustainability in societal systems can be effectively leveraged.

Keywords: sustainability, transformation, capabilities, systems, governance

1. Introduction

Sustainable transformation is rapidly gaining concerns in both academic and organisational domains. It arose from the notion that current decision-making and governance arrangements for transformation do not support those seeking broader and systemic change (O'Brien, 2012). Having recognised the significance of decision-making, a number of studies have provided several insights informing what comprehends in sustainable transformation. Accordingly effective decision-making and governance of sustainable transformation require systemic transformations in fundamentals drawing on transformations in values and beliefs, behaviour patterns, and governing practices. Further, multi-dimensional [demographic, technological, economic, social, cultural, institutional, informational and ideological] sustainability is also needed to be interlinked in order to incorporate coevolution of core concepts of sustainable development in the transformation process (see Patterson *et al.,* 2015).

Despite these advances in the academic domain, holistic understanding of dynamic relationships, mechanisms, processes and conditions essential for sustainable transformations are not clearly established, including its ability to link to decision-making (Willows and Connell, 2003). A major issue is that the existing evidence on decision-making for sustainable transformations is heavily biased towards increasing mitigating capacities to decarbonise including rationalist and linear approach in order to address the "specific risks" identified as a possible solution (Bassett and Fogelman, 2013). As a result, several mitigating interventions have been promoted and implemented by energy-intensive sectors, but it remains unclear how to invest in adaptive capacities that are essential to manage the "generic, complex risks" and building specific capacities[1] identified as crucial to deal with the challenges of decision-making for sustainable transformation (Karpouzoglou *et al.,* 2016).

Within the field of sustainable transformations, adopting systemic approaches and better integrating framing in order to advance collaborative response has recently been identified as a key challenge (Gaziulusoy and Brezet, 2015). However, greater consideration is also needs to be paid to the complexity and integration of dynamic relationships of different perspectives and levels of the whole system (Gaziulusoy, 2015; Spangenberg *et al.*, 2010). This is because the real-world transformation cannot follow a rationalist and linear approach evolved from the science of

[1] According to Eakin *et al.* (2014), two types of capacities exist. Generic capacities enable decision-making and actions for general development pathways and specific capacities enable decision-making and actions for specific change such as the one required for implementing energy efficiency and sustainability. These specific capacities are often not evident within the existing demographic and socioeconomic characteristics of a population.

sustainability, but instead takes place within a broader adaptation pathway with an expanded, dynamic and non-linear decision-making space (Kläy *et al.*, 2015). Notably, decision-making and governance issues are beginning to be considered in sustainable transformations, but multi-level governance issues especially for effective systemic outcomes linking multi-dimensional sustainability have not been addressed to date (Nalau *et al.*, 2015).

Drawing on the sustainable transformations literature, this paper interprets sustainable transformation as "long-term and restructuring processes – through intervention techniques – required to articulate multi-dimensional energy efficiency and sustainability objectives– in order to effectively overcome challenges of development pathways and direct alternative development pathways towards multi-dimensional sustainability opportunities". This is in relation to the change required in the energy and resource consumption patterns, reduction of carbon emissions, and delivery of multi-dimensional sustainable development pathways. When calling for such a transformation, emphases are made on developing capabilities and reforming practices of decision-making to leverage sustainable transformations (Poli, 2015).

This paper proffers that sustainable transformations will be most effective by: (1) populating emerging strategic capabilities within an integrated complex adaptive and socio-technical governing framework and (2) drawing on correlated commonly agreed perspective and multi-framing representations of both experts and non-experts from transdisciplinarity research to be more apprehensive of the contextual specific reality in which transformations ultimately take place. This paper focuses primarily on the existing English housing system because here, transformations are particularly dominated by data collected for technological solutions (Killip, 2013). The following sections identify challenges posed by most evidence pertaining to sustainable transformations and highlight how these challenges could be overcome by explicitly populating emerging strategic interventions. These also encompass relationships of strategic component-elements as well as multi-framing representations. In this context, the discussion includes a conceptual model: Strategic tri-level relational interventions for delivering energy efficiency and sustainability (STRIDES) which makes an innovative contribution to the evidence base for delivering effective sustainable transformations.

2. Sustainable transformations – key challenges

Synopses of sustainable transformations in general address the topic of evaluation – whether potential system transformations actually further sustainable development with respect to their starting points. These involve assessments of effectiveness and decision-making (Kates *et al.*, 2001; Pope *et al.*, 2004). Normally, assessments are based on the 'triple-bottom-line' approach. These assessments are not carried out in an 'integrated' fashion and raise concerns for their legitimacy, especially when their interpretations are considered in decision-making. Alternatively, assessment based on principles-based approach encourages positive steps or proactive actions while avoiding any adverse effects during the process of transformations (Gibson *et al.*, 2013). Therefore, principles-based approach signifies interactions between interventions and relevant prime multi-dimensional sustainability objectives and supports decision-making for sustainable transformations.

One of the criticisms of the established principles-based approach has been that these lack the capacity of offering alternatives to existing problems (Hajer and Wagernaar, 2003). Particularly in sustainable transformations, there can be a risk that alternative interventions are being governed by principles underpinning specific needs and interests of disparate domains of the systems (Walker *et al.,* 2006). In addition, the best alternative at hand may be challenged by internal as well external behavioural and institutional and organisational governance structures (Block and Paredis, 2013). Given this, the mismatch can be bridged if decision-making for implementing strategic interventions for sustainable transformations is explicitly considered in the context of overarching governing-rules and theoretical transformations including transformations in values and purposes, as well as considering the complexities of the current governance arrangements.

Implementing and integrating strategic interventions demands robust assessments of these interventions guided by a comprehensive analytical approach. These include assessments of actual outcomes, impacts on multi-dimensional sustainability and comprehension of learning for governing such interventions for future challenges of sustainable development. Thus, these assessments are not only important to know strategic outcomes, but also how these strategic interventions contribute to active participation of diverse system-agents, collaborative actions and institutional capacity building (Holden, 2010; Polk, 2011; Smedby and Neij, 2013). Embedding evidence on strategic interventions within overarching governing-rules of sustainable development have potential of contributing to a more holistic and integrated sustainable development perspective, recognising interconnectedness, collaboration and consensus-based processes facilitating alternative development pathways (EGM Report, United Nations).

While strategic interventions [as highlighted above] focus on principles-based approach for sustainable transformations, it is challenging because of societal systems have inherently multi-level, multi-organisational, and multi-stakeholder nature of governance arrangements (Wise *et al.,* 2014). Moreover, societal processes underpin unsustainable values, cultures and institutions, which do not fully allow consideration of wider values, cultures, and institutions that are required in governing rules underpinning decision-making for sustainable transformations (see Pahl-Wostl *et al.,* 2013). Therefore, the principles-based approach may not be desirable for multiple and deep uncertainties, dynamic interdependencies of wider values, cultures and institutions, cross-scale global and inter-generational problems, and decision-making in a governance structure having absolutely top-down or bottom-up governance (Voß *et al.,* 2007).

A number of studies have argued that approaches for sustainable transformations need paradigmatic shifts in framing and decision-making [individuals and collectives] to deliver effective sustainable transformations. These studies also signify viewing local societal systems as complex adaptive system in relation to wider complex global processes (see Bale *et al.,* 2015). In addition, there is a widespread recognition that sustainable transformations are required to underpin science and practice discourses (Gorddard *et al.,* 2016). Such advances are required to provide opportunities for a new aggregation of theories and practices, including modelling that can support effective decision-making in sustainable transformations of a complex adaptive system (Holtz *et al.,* 2015).

In addition to above, the approaches for sustainable transformations are required to overcome the limitation of previous assessment techniques that range from inability to change human behaviour through failures of governance arrangements and institutional disorganisation to inability to drive the change to leverage sustainable transformations (Amundsen *et al.,* 2010; Hammill and Tanner, 2011). Therefore, these approaches must have capacities of dealing with uncertainties, devolved decision-making and disputed values (Weaver *et al.,* 2013). In addition, these approaches must employ technological advances for management and the concept of 'pathways' to visualise transformations processes and be able to consider interdependencies of many variables of internal and external environment. These approaches need to be flexible, allow iterative management and accommodation of strategic future requirements (Haasnoot *et al.,* 2013).

In this context, broader conceptualisation of sustainable transformations presented by Wise *et al.* (2014) interface a number of factors including (a) various contexts [economic, environmental, social, political, institutional, cultural etc.]; (b) coordination of changes [outcomes] and responses [decision-making] across spatial scales; (c) processes, interactions and feedback within the temporal scales to facilitate the change overcoming the 'lock-in' characteristics; (d) evaluating mechanism to understand if the emergent properties are leading to desired outcome; and (e) recognising and understanding interdependencies of all these four factors and enabling sustainable transformations, particularly in consideration to core values, governing-rules and institutional capacities in which these processes occur. Given the importance of these factors, further sections investigate these issues to identify systemic interdependencies between local performances and national and global targets, dynamic networks within organisations and inter-organisational field and emergent decision-making processes that underpin emergent governing-rules for effective sustainable transformations.

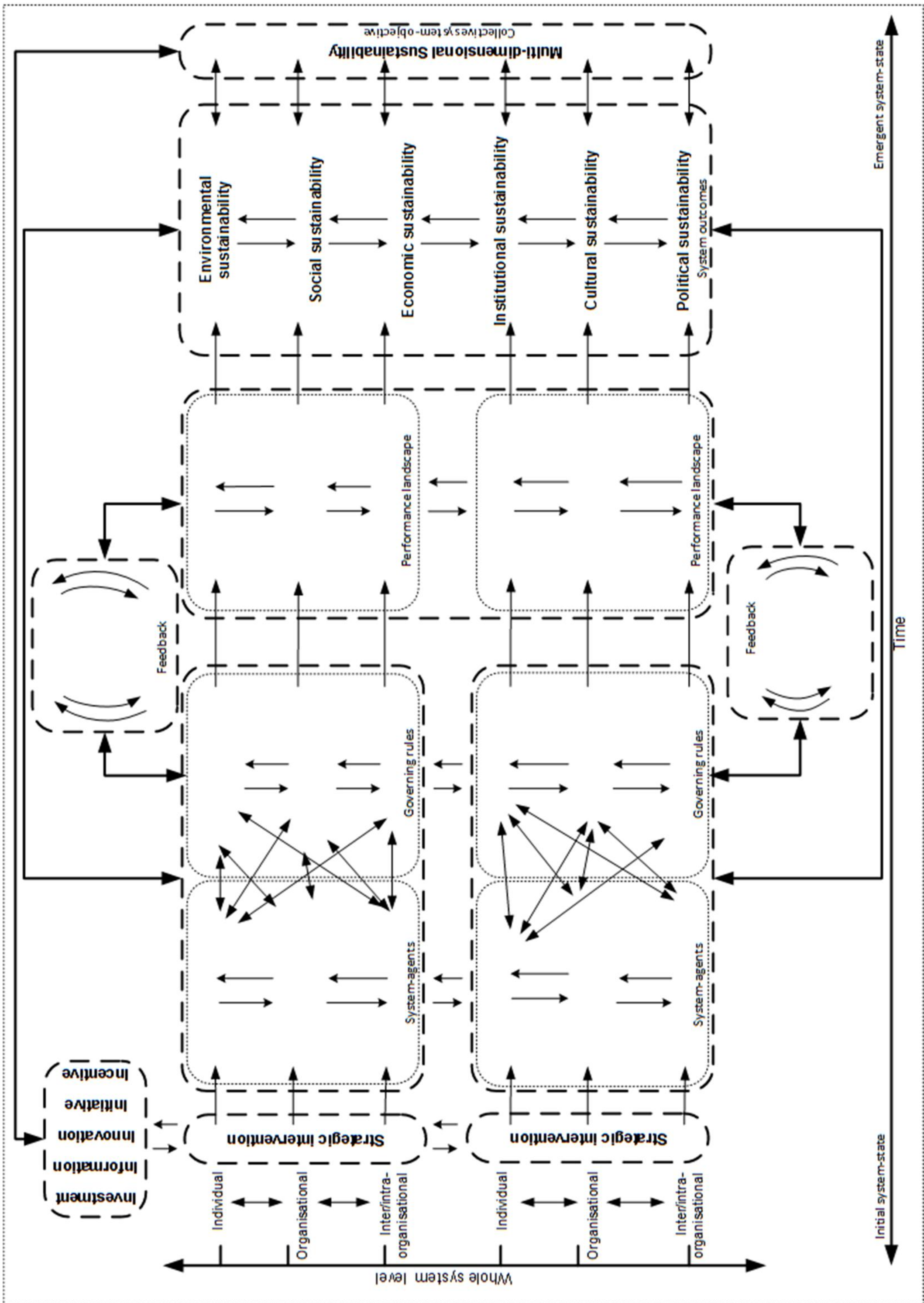
3. Research Methodology

An effective response to sustainable transformations, therefore, requires engaging the research lens of transdisciplinarity (Nicolescu, 2008) adopting an integrated constructivist/interpretivism paradigm (Burrell and Morgan, 1979; Gray, 2014) and using an explicit mixed methods design. Following the identification of a list of critical barriers and of immediate relevance to the English housing sector (including its stakeholders and sustainable transformation), the priorities of the essential conditions was formally determined through an online questionnaire which contributed to systems-knowledge development. Two Delphi questionnaires, further, allowed for critical evaluation of strategies aligned with energy efficiency objectives and support sustainable transformations generating target-knowledge. A conceptual strategic engagement model for delivering energy efficiency initiatives within the English housing system incorporating evidence gathered from both system-knowledge and target-knowledge was developed through the focus-group discussion generating transformative-knowledge.

4. Research Findings

Figure 1: Tri-level relational governance structure

In practice, sustainable transformations would be substantially effective if they took more careful



account of the inherently multi-level, multi-organisational, and multi-stakeholder nature of governance arrangements – in many instances, integrating complex adaptive and socio-technical governing arrangements will be just as important in shaping the success of an energy-efficiency initiative as the sustainability science, system innovation and system-transformation underpinning the broader conceptualisation of sustainable transformations. Therefore, the research findings provided suggestions for how building strategic capabilities with tri-level decision-making framework can address critical challenges in accounting for the wider complex governance context in multi-dimensional sustainable transformations.

In terms of challenges, first, the initiatives should underpin multi-dimensional sustainability principles drawing on a broad consensus backing by major stakeholders having capability for decision-making and delivering effective sustainable transformations not only at individual level but also contribute to full implementation as well as enforcement for sustainability deliverables at global, European or national level. Second, the governance and planning of transformation should be embedded within tri-level relational governance structure (Figure 1). Doing so implies that decisions will be informed by correlated commonly agreed perspectives, multi-framing representations of multi-level, multi-organisational, and multi-stakeholder nature of existing governance arrangements.

To meet these challenges, the first step, according to the proposed tri-level relational governance structure, is to implement strategic interventions in the context of individual, organisational, and inter/intra-organisational energy-efficiency and multi-dimensional sustainability targets/objectives. The multiple perspectives of the system-agents and their association with multi-dimensional sustainability that embodies economic, environmental, social, political, regulatory, cultural, technical and institutional dimensions are required to be reconsidered over and over and refined to ensure building of strategic capabilities for decision-making and sustainable transformations.

The second step will be to ensure that experts and non-experts stakeholders contribute in understanding the complexity of the English housing system going beyond the subsequent challenges posed by the transformation process. From the outset, each decision-maker should consider interdependence of the governing-rules of the system and relate to the system-objective that is valued in common. Therefore, sustainable transformations cannot take place in the existing governance structure but instead by understanding inter-relationships and building strategic capabilities that are critical for sustainable development of the whole housing sector. These strategic capabilities are those that encompass unified relationships of very important interventions and barriers identified by a number of disparate housing system-agents. As a consequence, there is a strong need to develop tri-level relational effective interventions.

5. Conclusions

Sustainable transformations can be substantially more effective if they embrace the inherently multi-level, multi-organisational, and multi-stakeholder nature of governance arrangements. While individual transformations can be informed by solid empirical outcomes; this, on its own is typically insufficient in informing the strategic capabilities required for decision-making and learning as well as in delivering effective governance of sustainable transformation for the entire sector. Given these issues, this paper highlighted the critical challenges in engaging the wider complex governance context for multi-dimensional sustainable transformations and provided suggestions for addressing these challenges.

The research lens of transdisciplinarity using an explicit mixed methods design maximises engagement and participation, providing multi-framing representations of the domains of housing providers, occupiers and regulators and in-depth understanding of the cognisant that are 'fit for purpose' and apprehensive of the contextual specific reality for sustainable transformations. In contrast to work by Gaziulusoy *et al.* 2015, who focus on integrating framing, this work fully acknowledges the conceptual modelling for explicitly and directly illustrating theoretical underpinnings. In addition, this research suggest that the use of integrating framing and systems-thinking might have benefits if they are used for the implications of emerging properties within multi-dimensional complex contexts. It thus can affect strategies for energy efficiency and sustainability in societal systems and leverage sustainable transformations.

While this paper provides a number of implications of the conceptual engagement model, for e.g. for explicitly and directly illustrating theoretical underpinnings and generating learning for the system-stakeholders, it just begins to establish a model of how emerging properties are identify through engagement and participatory processes. It therefore describes an initial state of the system, a starting point of research. Thus, the suggested conceptual model can be applied to multi-level governance structure and building capabilities for shared and correlated objectives. Future work can also focus on analysing in depth understanding of each emerging strategic process to relate tri-level governance structure to what participants know already.

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Sustainable Food Environments

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Abstract

The relationship between food, the built environment and sustainability has not been widely researched. However, food consumption patterns can have a significantly negative impact on the environment, as well as beneficial impacts on human health and well-being. For instance, locally grown food has much lower carbon emissions associated with it compared to imported, highly processed, foods. Similarly, a balanced and nutritious diet ensures health and wellbeing while a poor diet leads to increased susceptibility to ill-health and disease. Achieving sustainability will therefore require food that both promotes health and has low negative environmental impacts (sustainable foods). Built environments can hinder, or support, access to these foods.

This paper draws on the Ecological Footprint measure to define preferred, or more sustainable, food and diets. In turn, this is analysed to determine built environment configurations and characteristics that enable these diets and promote access to sustainable foods. This analysis is distilled into simple 'sustainable food environment criteria' which can be used to assess built environments. These criteria are investigated by applying these to a neighbourhood in Pretoria, South Africa. The paper finds that the sustainable food environment criteria developed provide a useful measure of the extent to which built environments promote sustainable diets and recommends that further research is undertaken in this field.

Keywords: Food, Built Environments, Ecological Footprint, Neighbourhoods

Sustainable Food Environments

1. Introduction

The problem with many definitions of sustainability is that they are not specific and do not provide clear quantified targets. Without a specific ‘end’ to be aimed at, it is very difficult to define the ‘means’ by which this will be achieved (Costanza and Patten, 1995). Therefore in order to make progress in achieving sustainability, an effective definition is required (Robèrt et al, 2002)

In this paper, a definition of sustainability developed by the World Life Fund (WWF) is adopted. This sets specific Human Development Index and Ecological Footprint targets that must be attained in order for sustainability to be achieved (World Wild Life Fund, 2006). This paper analyses this definition in order to understand the implications of this for food and for the built environment.

A Household Ecological Footprint Calculator is used to understand the nature and characteristics of a low ecological footprint diet (Redefining Progress 2003). Once determined, low ecological footprint diets are analysed to extrapolate the implications for households and for the local built environment. In turn this forms the basis for the development of a simple set of ‘sustainable food environment’ assessment criteria. These criteria are investigated by applying them to a household and neighbourhood in Pretoria, South Africa. The results of this assessment, and a review of the methodology and criteria, are discussed in order to evaluate the value of the approach. Finally, the paper draws conclusions and makes recommendations for further study.

2. Defining sustainability

The Human Development Index (HDI) was developed by the United Nations and is extensively applied as a measure of quality of life (United Nations Development Programme, 2007). The HDI is based on:

- A long healthy life, measured by life expectancy at birth
- Knowledge, measured by the adult literacy rate and combined primary, secondary, and tertiary gross enrolment ratio
- A decent standard of living, as measure by the GDP per capital in purchasing power parity (PPP) in terms of US dollars

The WWF definition of sustainability indicates that the achievement of an HDI of 0.8, or above, should be regarded as evidence that minimum acceptable standards of quality of life have been achieved (World Wild Life Fund, 2006).

An ecological footprint is the amount of land and sea required to provide the resources that a human population consumes and to absorb the corresponding waste. Consumption of resources and production of waste and emissions used in the Footprint are drawn from the following areas:

- Food, measured in type and amount of food consumed
- Shelter, measured in size, utilization and energy consumption
- Mobility, measured in type of transport used and distances travelled
- Goods, measured in type and quantity consumed
- Services, measured in type and quantity consumed
- Waste, measured in type and quantity produced

The area of land and sea required for each of these areas is calculated in global hectares (gha) and added together to provide an overall ecological footprint per person (Wackernagel and Yount, 2000). The Earth's surface area is used to define limits for personal ecological footprints and this is calculated by dividing the Earth's carrying capacity by the size of the human population. In 2006, this calculation resulted in a limitation of 1.8 global hectares (gha) per person (World Wild Life Fund, 2006).

This definition provides clear criteria and targets that can analysed to understand the relationship between food, the built environment and sustainability. This analysis is used to contribute towards the development of indicators of 'built environment capacity' to support the achievement of reduced ecological footprints for food consumption (Kitzes et al, 2009)

3. Food

Food can be defined as 'any nutritious substance that people …. eat or drink …in order to maintain life and growth' (Oxford Dictionaries, 2015). Aspects of food consumption which are measured for ecological footprint calculations are identified in a Household Ecological Footprint Calculator (Redefining Progress, 2003). These are listed in table 1.

Table 1. Household Ecological Footprint Calculator food types

Vegetables, potatoes & fruit
Bread and bakery products
Flour, rice, noodles, cereal products (exc maize)
Maize
Beans and other dried pulses
Milk, cream, yogurt, sour cream
Ice cream, other frozen dairy
Cheese, butter
Eggs [assumed to be 50 g each]
Meat
- *Pork*
- *Chicken, turkey*
- *Beef*

Fish
Sugar
Vegetable oil (seed or olive oil)
Margarine
Coffee & tea
Juice & wine
Beer
Garden [area used for food]
Eating out

3.1 The ecological footprint of food

Entering data into the Household Ecological Footprint Calculator can be used to understand existing patterns of food consumption within households and to calculate their ecological footprint (Redefining Progress, 2003). This assessment was carried out for a household of 5 people in Muckleneuk, Pretoria, South Africa, in October 2015. Muckleneuk is indicated in figure 1, later in the paper. The calculation indicates that the household has an overall ecological footprint of 6.7 gha/person, with food consisting of 1.5 gha/person, of this total. Food, in this instance, is responsible for about 20% of the ecological footprint of the household. The overall footprint of 6.7gha/person far exceeds the 1.8gha/person target required for sustainability and represents overconsumption (Rice J, 2008; Princen, 2002).

A review of the food criteria within the Household Ecological Footprint calculator can be used to determine measures which could be used to reduce the ecological footprint of food used within households, and ideally, ensure that these contribute to achieving the overall sustainability target of 1.8gha/ person.

3.2 Measures to promote sustainable diets

The following measures can be used to reduce the ecological footprint of food within households.

1. Locally produced, fresh vegetables and fruit are purchased in preference to other foodstuffs (Andersson and Lindroth, 2001)

2. Vegetarian sources of protein such as beans and pulses are purchased in preference to meat and fish.
3. Locally produced milk, cheese and eggs are purchased in preference to processed food products.
4. Margarine, oil, tea, coffee, beers, juice and wine, meat, fish and processed food items are only purchased once 1-3 items have been purchased and then purchased in limited quantities.
5. Food items 1 to 3 are available within 2km (Rundle et al, 2009; Gibberd 2015).
6. Food items 1 to 3 are affordable to local population.
7. Cultivated areas within the neighbourhood are used to produce fresh vegetables and fruit.
8. Eating out at restaurants is limited. Where this exists, restaurants with menus based on food types 1 to 3, are given preference.

Adopting these measures and recalculating the ecological footprint of the Muckleneuk household using the Ecological Footprint Calculator indicates that an ecological footprint for food of 0.3 to 0.4 gha can be achieved. This represents about 20% of the total household ecological footprint. Along with measures in the other areas (such as goods and services, shelter and transport) these actions would enable the achievement of the target 1.8gha, required for sustainability (World Wild Life Fund, 2006). Therefore these 'sustainable food' measures provide a set of requirements that built environments must meet.

4. Implications for the built environment

Local availability has been shown to be a key influence on household food consumption patterns (Rundle et al, 2009; Gordon-larsen, 2014; Frank et al, 2007). However, it is also important to note that the availability of particular types of food do not necessarily mean that occupants of households will consume these foods (Gordon-larsen, 2014). So while built environments may not be able to *ensure* that sustainable diets are achieved, they can support this directly by enabling local access to sustainable food. It is likely that other measures, coupled with local availability, such as 'promotion, education and incentives' will also be required for sustainable diets (Gordon-larsen, 2014).

4.1 Built environment requirements for sustainable diets

The 'Measures to promote sustainable diets' outlined above can be used to define built environment and neighbourhood requirements. These are listed below.

1. Neighbourhoods should include a retailer of, or access to, fresh vegetables, fruit, beans and pulses, bakery products and milk, cheese and eggs. The cost of these products should be affordable for the local population.
2. Highly processed, non-local food products, oil, tea, coffee, beers, juice and wine, meat and fish should be more difficult to access than the food types in 1.

3. A proportion of household gardens and open space within the neighbourhood should be allocated to vegetable and fruit production.
4. Restaurants with menus based on locally produced fruit, vegetables and include vegetarian, diary and egg-based dishes, should be given preference over restaurants which have menu based on high ecological footprint items such as meat and imported items.

5. Sustainable food environment criteria

Built environment and neighbourhood requirements to promote access to low ecological footprint food can be translated into a simple assessment framework, as illustrated in table 2. In this framework, 'locally produced' and 'local', means that the item is produced within the country and is not imported from another country. This aspect could be refined in future frameworks to refer to a specific distance, such as 100km from the retailer, but this will considerably increase the complexity of the assessment. The term 'neighbourhood' in the framework refers to the area surrounding a household.

Table 2. Sustainable food environment criteria

	Criteria
FO1	*There is access to / a retailer of locally produced fresh vegetables and fruit within 2 km. The cost of these products is affordable for the local population.*
FO2	*There is access to / a retailer of locally produced beans and pulses within 2 km. The cost of these products is affordable for the local population.*
FO3	*There is access to / a retailer of bakery products within the 2km. The cost of these products is affordable for the local population.*
FO4	*There is access to / a retailer of locally produced milk, cheese and eggs within the 2 km. The cost of these products is affordable for the local population.*
FO5	*Access to products such as highly processed and non-local foods as well as oil, tea, coffee, beers, juice and wine, meat and fish are more difficult to access than food types in FO 1-4.*
FO6	*Fifty per cent of the cultivated area within the neighbourhood is used to produce fresh vegetables and fruit.*
FO 7	*Restaurants with menus based on locally produced fruit, vegetables and include vegetarian and diary and egg-based dishes, should be given preferential locations over restaurants which have menu based on high ecological footprint items such as meat and imported items.*

5.1 Mapping criteria on to a neighbourhood

The criteria in table 2 can be investigated by applying these to the neighbourhood identified earlier in the paper. The selected neighbourhood is Muckleneuk in Pretoria, South Africa (latitude -25.76329, longitude 28.20816) and is represented by the shaded area indicated in figure 1.

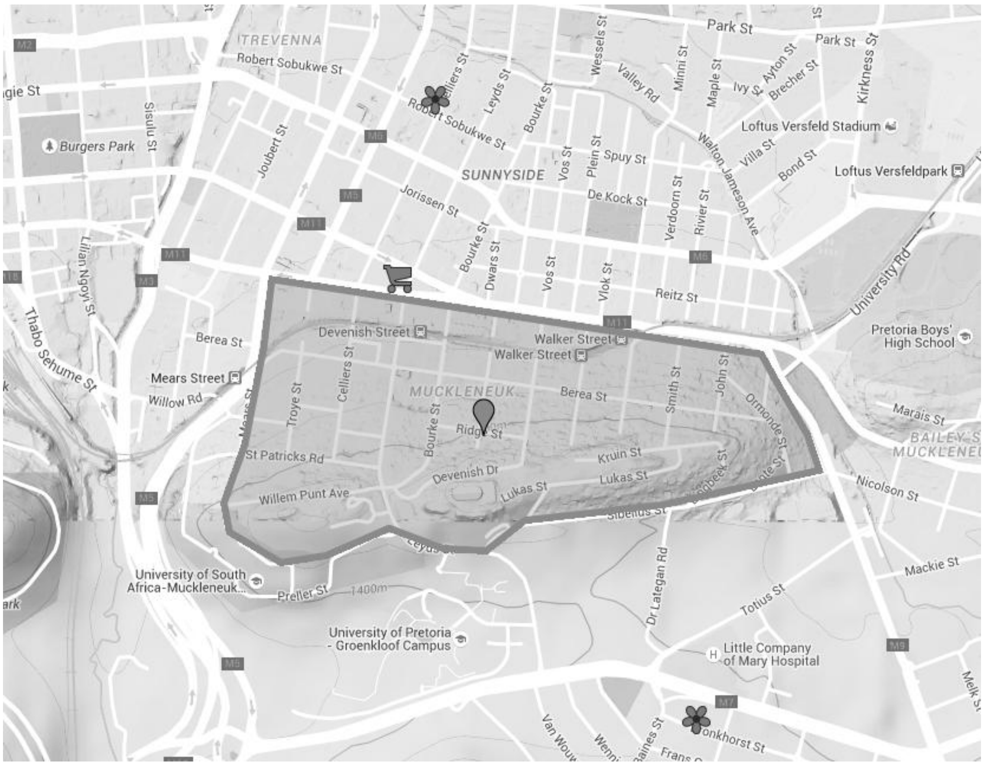

Figure 1. Map of neighbourhood indicating food retailers

A location in the centre of the neighbourhood is identified (pointer). Facilities required for a low ecological food footprint such as local retailer(s) of low ecological food are then identified and marked on the map. Facilities that are within the neighbourhood, or nearby, are marked on the map in figure 1 using icons. Icons used are a daisy for a green grocer and a shopping trolley for super market. The distance of these facilities to the centre of the neighbourhood is also measured and recorded in the assessment and captured in table 3 below. The first column of table 3 indicates the assessment criteria for built environment aspects of food. The second column indicates the assessment. This includes the distance of the facilities from the centre of the neighbourhood in metres and provides a key to the symbols on the map in brackets (ie daisy). The third column indicates whether the criterion was achieved for the Muckleneuk neighbourhood.

Table 3: Sustainable food assessment

Criteria		*Assessment*	*Criterion achieved?*
FO1	*There is access to / a retailer of locally produced fresh vegetables and fruit within 2 km. The cost of these products is affordable for the local population.*	*The nearest retailer of fresh vegetables and fruit is 1720 m away. (daisy symbol)*	*Yes*

FO2	*There is access to / a retailer of locally produced beans and pulses within 2 km. The cost of these products is affordable for the local population.*	*The nearest retailer of beans and pulses is 930 m away. (shopping trolley symbol)*	*Yes*
FO3	*There is access to / a retailer of bakery products within the 2km. The cost of these products is affordable for the local population.*	*The retailer of bakery products is 930 m away. (shopping trolley symbol)*	*Yes*
FO4	*There is access to / a retailer of locally produced milk, cheese and eggs within the 2 km. The cost of these products is affordable for the local population.*	*The retailer of milk, cheese and eggs is 930 m away. (shopping trolley symbol)*	*Yes*
FO5	*Access to products such as highly processed and non-local foods as well as oil, tea, coffee, beers, juice and wine, meat and fish are more difficult to access than food types in FO 1-4.*	*The retailer of oil, tea, coffee, beers, juice and wine, meat and fish is 930 m away. This retailer is easier to access than some the retailers in FO1-4. (shopping trolley symbol)*	*No*
FO6	*Fifty per cent of the cultivated area within the neighbourhood is used to produce fresh vegetables and fruit.*	*The area used to produce fresh vegetables and fruit is less than 10% of the cultivated area which consists of lawns, shrubs and non-fruit bearing trees.*	*No*
FO 7	*Restaurants with menus based on locally produced fruit, vegetables and include vegetarian and diary and egg-based dishes, should be given preferential locations over restaurants which have menu based on high ecological footprint items such as meat and imported items.*	*No local restaurants have menus based on locally produced fruit, vegetables and include vegetarian and diary and egg-based dishes.*	*No*

6. Discussion

A number of interesting findings emerge from the use of the proposed methodology and the assessment framework. These can be discussed with a view to improving the approach.

While it is important that the ecological footprint of food is reduced, it is also important to ensure that diets have the correct nutritional content. This aspect is addressed to some extent in the Household Ecological Footprint Calculator which records the protein and calorie content of food consumed and compares this to recommended daily allowances (RDA) (Redefining Progress, 2003). This aspect of the calculator is helpful and could be developed further to include other essential elements of a diet such as vitamins.

Affordability in the assessment criteria has not been sufficiently defined. This should be developed and could be addressed in the following way. Affordability could be defined in terms of the monthly cost of a food item relative to the monthly income of the household. For instance, the affordability of fresh local vegetables could be determined by establishing the proportion of monthly household income that would be required to buy a month's supply of vegetables for the household.

Criterion FO6 raises a number of questions in relation to efficiency. For instance, it may be argued that household and neighbourhood gardens are inefficient and that food production is more efficient on large commercial farms. There are a number of counter arguments to this. Firstly, inputs such as water, fertiliser and labour, are likely to be consumed in household gardens and neighbourhood parks anyway to create lawns, flower beds and ornamental shrubberies. Using a proportion of these inputs for productive food production would therefore reduce overall ecological footprints. In addition, at a household and neighbourhood scale, cultivation is likely to be carried out largely by hand which will have a lower ecological footprint than mechanised approaches used in commercial farms.

Criteria in the framework refer to retailers being 'within 2km'. While this distance may be acceptable in some situations, this may not be the case for others (Gibberd, 2013). In particular, this distance may be regarded as too great in cold or hot climates and where households include children, infirm and elderly people. In these cases, the use of a shorter distance, such as 400m, which is used in some green building rating tools, may be more suitable (United States Green Building Council, 2015). It is interesting to note that if 400m is used, the Muckleneuk neighbourhood would not meet any of the sustainable food criteria indicated in table 3.

Finally, the methodology assumes that inhabitants will use the lowest ecological footprint food options. In reality this is not true; as people may consume higher ecological footprint food because this is cheaper, is seen to be more 'fashionable', or is easier to access. Therefore, in addition, to making low ecological footprint easy to access, it is also important to ensure that this is affordable and seen to be desirable (Gordon-larsen, 2014).

7. Conclusion and recommendations

The study provides useful insight into how built environments may support the reduction of ecological footprints associated with food. While a number of criticisms can be levelled at the approach, it provides a simple way of assessing the extent to which the built environment may be configured to reduce food-related ecological footprints. It accepts that other factors, such as affordability and personal preference, may result in the capability of the local built environment to reduce ecological footprints not being used. These issues are important and should be addressed if the methodology is developed further.

7.1 Recommendations

From a review of the study the following recommendations are made:

a. Household ecological footprint calculators should be developed to include defined minimum nutritional requirements for diets. This will help avoid the situation where locally available food may meet ecological footprint requirements but not be sufficient to maintain human health.
b. The affordability aspect of the criteria needs to be designed. Affordability could be defined in terms of the monthly cost of specified food items as a proportion of household income. For instance, locally available fruit and vegetables could be classified as affordable where the cost of purchasing a month's supply for a household was less than, say, X% of the household income.
c. The criteria related to the cultivation of vegetables and fruit within household gardens and within the neighbourhood requires further investigation. For instance, the proportion of cultivated area required for vegetable and fruit production may vary depending on local population densities, local climate, availability of water for irrigation and the productivity of soils (Andersson and Lindroth, 2001)
d. The social capital value of local food retail facilities identified in this study should also be researched further. This should draw on work that links improved environmental efficiency in communities with higher social capital (Knight and Rosa, 2011).
e. Sustainable food environment criteria from this study, particularly if further developed through recommendations (a to d) should be incorporated into built environment sustainability assessments tools, such as the Built Environment Sustainability Tool (BEST) and the Sustainable Building Assessment Tool (SBAT) (Gibberd, 2015).

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Kampung Development for a Resilient City

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Abstract

Kampung is self-developed settlements inhabited by low income class in Indonesia. In Surabaya, the second largest city of Indonesia, kampungs are retained and developed as a decent place to live with all of its uniqueness. Kampung Improvement Program (KIP) in Surabaya, for example, is purposed to raise awareness of the inhabitants, to empower and to improve their quality of life and their living environment independently. Physical improvements are conducted based on community awareness which in turn grow the community's sense of belonging. The improvement is sustainable and has significant result in improving the quality of life of the inhabitants as well as the quality of the settlement. In addition, awareness and self-reliance of the community can maintain the originality of neighbourhoods, and together they create a unique atmosphere in the city scale. Surabaya is growing as a metropolitan city, but also humanist by creating a decent living environment for all residents.

This research develops the concept of resilience that seeds from the kampung of Surabaya in dealing with problems and changes occur in urban areas. Vulnerable state is addressed by action in the form of prevention, adaptation and improvement to survive and, at the same time, to change without losing its identity, such as through Kampung Improvement Program.

Using qualitative descriptive method, this study examines the aspects of resilience found in the kampung which include preparedness, mitigation measures and response capabilities of the urban kampung. They are analyzed in the context of creating/improving the level of city resilience. This study shows that kampung as urban informal settlement is not a burden but a great value deserved to be improved to be able to contribute in creating resilient city. Surabaya can be an example for other cities that are building their resilience and have the same context with the city of Surabaya.

Keywords: low income settlement, kampung, city, resilience

1. Introduction

It is projected in 2025 that around 68% of the world population will live in urban areas. The carrying capacities of the city are decreased and triggered. Every city dweller makes efforts to survive. Residents of middle to high economic level might have no difficulty making an effort to earn a decent living. However the poor community might be forced to survive with all the limitations and the rigors of life in the city competition; to live in dense environments, inadequate dwelling and lacks of basic infrastructure.

Kampung is a form of indigenous settlement which developed without planning process mostly inhabited by lower middle income group. In many urban area of Indonesia, kampung is more dominant in comparison to formal settlement. Although mass housing development policy for low income group has been started and succeeded in Indonesia since 1974, self-help housing still has a great contribution in the provision of housing; contributes about 85% of housing delivery (Struyk, 1990). In comparison to village in rural area, kampung is far more compact and influenced by the city activity as the centre of trading and services.

Physically, kampung represents the concept of urban as the compact area in terms of population density and efficiency of land. Its high-density built-up area with minimal infrastructure is the main characteristics of the kampongs which at the beginning will lead to the impression of slum areas. However kampungs are rich with non-physical aspects, such as their culture and social bound. Kampungs provide a positive value to the city of diverse community i.e. origin, income, education, occupation, ethnicity, political affiliation, etc. This diversity allows the community to create and develop the principles of diversity, tolerance and solidarity.

Various studies indicate kampung are able to provide a positive contribution for development of Surabaya (Colombijn, 2010, Dick, 2003). Nowadays, approximately 70% of total population (3 million) is living in the kampongs Surabaya (City Government of Surabaya, 2012, Surabaya in Numbers, Statistic Bureau, 2015). A sustain kampung development program have been able to create viable and self-supporting settlements in Surabaya. The program is done to create a viable living environment with regard to the uniqueness of each kampung which includes physical aspects (house and surroundings) and non-physical ones (economics, management capability of the community, the quality of human resources, etc) (Silas, 2010, Building and Social Housing Foundation, 1993).

The kampung improvement program is carried out by improving the community capacity to improve the kampung physical condition. This program fosters their fighting spirits which sustains the program and improve their sense of belonging of the environment. Kampung Surabaya receives various national and international recognitions for providing a decent living environment for the lower income group in the pace of urbanisation and modernisation movement such as Aga Khan Award in 1986 for Kampung Kebalen (Silas, 2012).

2. Urban Resilience

Resilience is the capacity of a system (infrastructure, government, businesses, communities and individuals)to absorb disturbance, to undergo change arising from the disruption and to maintain the function, structure, identity and provide appropriate feedback (Longstaff et al,2010).The concept of urban resilience (resilience city) has been developed from a social perspective. There are many aspects or variables to measure resilience. According to the Infrastructure Survey Tool (IST) developed by Argonne National Laboratory resilience within a community or region consists of five (5) aspects. They are 1) Economy, 2) Civil society, 3) The main Infrastructure, 4) Supply chains (dependencies) and 5) Government (related to emergency response services). Meanwhile to measure the resistance of an individual more accurately, there are four (4) main variables namely1) Preparedness, 2) mitigation, 3) response capabilities and 4) recovery mechanisms.

Urban is defined as multi-dimensional dynamic activities, in which there are aspects of change, vulnerability, or even potential crisis. In rapidly urban development, kampungs need to survive as a decent living space for the inhabitants. It means they have to deal with rapid physical changes as well as the changing needs of the dwellers in line with the social, economic changes in many aspects of life. There are several key elements which related one another in building resilience, namely i) disaster preparedness, ii) the capacity to adapt, iii) empowerment and iv) the diversity of choice and security. Resilience can be established as the result of dynamic and holistic integration of those key elements.

3. Method

This study focus on how informal settlements build resilience in a neighbourhood level that contribute to the city level of resilience. The concept of urban resilience can help to understand the changes in complex systems and that a change is not just something urban necessity somewhat forced, but should also be adapted and managed. In building the resilience of the kampung this study will look at several key elements, namely, i) disaster preparedness, ii) the capacity to adapt, iii) empowerment and iv) the diversity of choice and security.

This study applies qualitative descriptive method. Variables of this study are the ability to manage threats, to adapt the changes, and to secure the adequacies. There are four kampung chosen as a case study which is expected to represent the character of the kampong in Surabaya (densely populated, minimum open space, its location, etc), its role for Surabaya, and the status of the community, namely:

1. Kampung Kaliasin at the centre of Surabaya, the old kampung sandwiched with the Central Business District Tunjungan.

2. Kampung Peneleh, located on the riverbank of Kalimas River, experienced the first kampung improvement program by the Dutch government. It is now developed into one of heritage kampung related to several historical events occurred in this area.

3. Kampung Ampel is an old kampung of Arab developed since the early period of Surabaya Kingdom. It is now as a pilgrim and tourist destination.

4. Kampung Gundih located on the bank of railroad, has a strategic location near wholesale trade centre and train station. Originally inhabited by criminals yet has been change into a green and clean kampung.

Figure 1 shows the settlement area in Surabaya. Kampung/self-help housing area is marked with the light colour while real estate is marked with a darker colour.

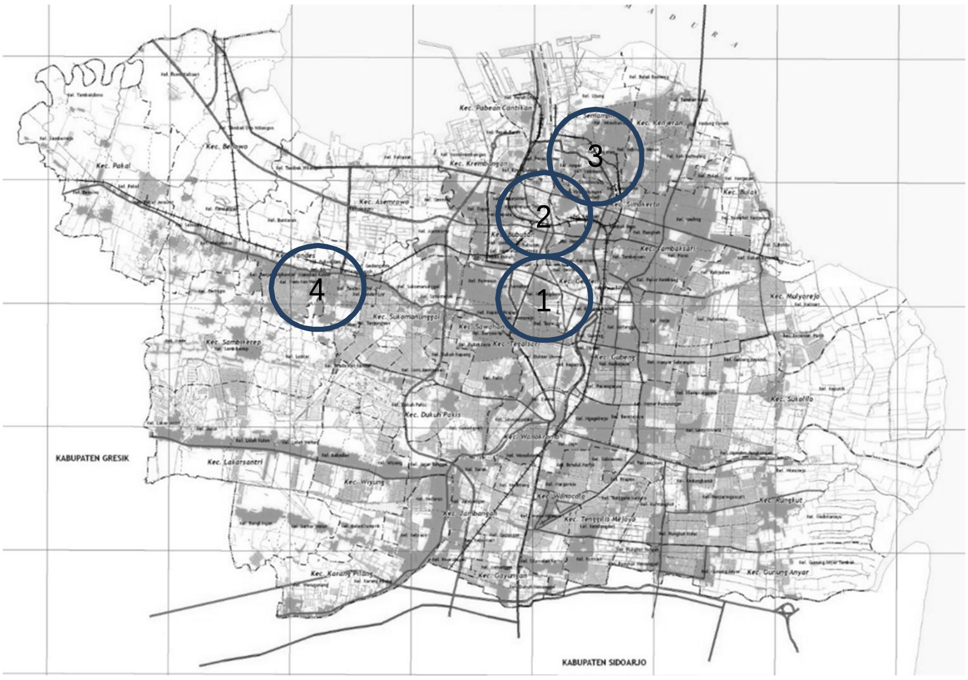

Figure 1: Surabaya map and the research location

Research location:

1. Kampung Kaliasin
2. Kampung Peneleh
3. Kampung Ampel
4. Kampung Gundih

4. Kampungs of Surabaya

Surabaya covers an area of 326.37 km^2, administratively is divided into 31 districts and 163 sub-districts. Most of the city area (80.72%) lies on lowland area (3-6 meters above sea level) and the rest is on hilly area of 20-50 m asl. The slope of the land ranges from 0-2% in the low-lying areas and 2-15% in the gently sloping hills. In 2015 the city' population is 3.269.931 with the average growth is 0.6%. The projection of the next five years (2020) the population of Surabaya will reach 3.5million inhabitants and in 2030 will exceed 4 million people (Surabaya in Numbers, Statistic Bureau, 2015)

The high number of population with all their activities directly affects the capacity of regional development, increases the living competition, more expensive land, limits employment opportunities, declines environmental quality, as well as the fulfilment of infrastructure and facilities urbanity that must be met by the municipality. In term of housing policy, it appears that the government of Surabaya has a strong commitment to protect the kampongs as part of the city built environment to keep the city history and to provide living space for the lower-middle income group, in addition to develop new settlement area in accordance with the growing population.

It should be recognized that the kampung Surabaya has not only a passive role as the city heritage but also still an active one as the urban living space, shown by many awards received by the city of Surabaya for the role of the kampungs and its residents in the city development. As heritage, Kampung Surabaya has a unique characteristic showing the peculiarities of the city history, and the ability, effort, struggle and independent community spirit. Every kampung has its own uniqueness by geography, economic, social and cultural diverse. Awareness of the importance of environment makes the kampung clean and green, not just to ward off the negative impression. Surabaya has proved that the kampung is not slum areas. They are densely populated but look beautiful, complemented by a variety of basic amenities and well maintained by the residents.

As informal settlements, kampungs has a number of physical problems associated with the quality of the environment and poverty causes a lot of kampungs fall into categories of inadequate settlement. However, kampungs in Surabaya able to prove that the physical condition of the kampung can be upgraded through various kampung development and establishes an integrated urban infrastructure and facilities to serve the kampungs (Silas, 2012). The following is a short description of the kampungs chosen for this study.

4.1. Kampung Kaliasin

Kampung Kaliasinin sub-district Tegalsari is one of the old kampung Surabaya characterized by Sholeh Mosque which is the second oldest Muhammadiyah mosque in Surabaya after Peneleh Mosque. The kampung is strategically located right behind commercial district of Jl. Tunjungan and serve as a residential area for blue collar workers, especially those of shopping centres and five stars hotels in Tunjungan. Kampung Kaliasin has several problems with poor public spaces and services, prone to flooding, environmental degradation, crime and commercialization of land. Figure 2 shows new houses are built adjacent to the old houses since there is limited space. The inhabitants use alley as a common place.

4.2. Kampung Peneleh

Kampung Peneleh in sub-district Peneleh has been developed since the period of Surabaya kingdom in the 15^{th} century. A prince (Pinilih-Peneleh) was given a rank and a territory of the area between Pegirian River and Kalimas River. Kampung Peneleh was Sunan Ampel (a prominent Muslim preacher in Java) stopover before settling in kampungAmpel(Silas, 2012). It is also the settlement of several nationalist prominent, such as young Soekarno, the Indonesian first president.

Kampung Peneleh location is close to the city hall, commercial area, and revitalised waterfront area. Some buildings in the kampung have been enlisted as heritage buildings and in adjacent to an old Dutch cemetery which has a distinct forms. The kampung is relatively in good order with majority of the buildings in good condition. This kampung has several challenges, mainly the housing's land status and its very dense population. Figure 3 shows the Dutch old graveyard located next to the kampung and the example condition of old and new houses in Kampung Peneleh.

Figure 3. Kampung Peneleh

4.3. Kampung Ampel

Similar to Kampung Peneleh, Kampung Ampel in sub-district Ampel is also in the old part of Surabaya. While Dutch took place on the western part of Kalimas Riverbank (previously place of the Surabaya palace), the Arab, Chinese, Malay and other ethnics were living on the eastern riverbank. Kampung Ampel was the settlement of Arab community and the centre of the early spread of Islam in Java.

Nowadays the kampung has been developed as a tourist area particularly for the pilgrim and from this activity residents can improve the quality of settlements, physical and non-physical. However there are several challenges such as susceptible to crime, not well organized vendors, loading dock activities which cause congestion. Figure 4 shows an alley to/from Ampel Mosque with small vendors in comparison to a quieter alley, both located in Kampung Ampel.

Figure 4. Kampung Ampel

4.4. Kampung Gundih

Kampung Gundih in sub-district Gundih has been transformed from a 'criminal' kampung in 1990's into one of the winners of 'best of the best kampung Surabaya' in 2010 (Silas, 2012). The kampung is surrounded by various region-scale facilities trade areas such as Surabaya Wholesale Center and Pasar Turi Train Station. Their works on environmental management such as greening, domestic waste management and domestic waste water treatment become one of their prominent works. The kampung has also various social activities which social awareness and strengthen the community bound. However because of its location kampung Gundih attracts many investors to develop the area to be a commercial area.

Figure 5. The Kampung Gundih

5. Discussion

Surabaya as one of the metropolitan cities in Indonesian faces severe challenges as the rapid globalization and modernisation. *Kampung* which is home to the majority of the city residents face the vulnerability of the environmental, economic, and social and culture dimensions. Vulnerability in the environmental dimension is the focus of this study with consideration to strong linkages with the built environment (residential area).

Kampung is a form of settlement that developed organically by the community, so that the buildings pattern tends to be irregular. It is home to people with diverse cultural backgrounds, economic, education and customs. The diversity of the community creates the kampung uniqueness if managed properly but lead to vulnerability if no tolerance among the fellow inhabitants. Identification of *kampong* vulnerabilities is based on the results of field observations and the synthesis of interviews with community leaders on the kampung current condition and the challenges potentially experienced by the inhabitants within the next decade period. In each *kampung* identified vulnerabilities caused by 3 (three) aspects of location of the kampung, economic, and social structure and cultural characteristics of the community.

5.1. Kampung Kaliasin Resilience

Behind buildings of a strategic area called Tunjungan with numerous malls and shopping centres, five-star hotels and apartments, and high-rise office buildings there are several kampungs. One of them is Kampung Kaliasin. The kampung is densely populated because most of the houses are also boarding houses for blue collar workers of Tunjungan business district. The area of Kampung Kaliasin can mainly be divided into two types; (1) The region with small building, normally accessible by foot and motorcycles, (2) the region with bigger buildings usually can be accessed by car (one way). The density level of this kampung is very high; makes majority of houses has neither yard, nor space between buildings. This condition makes the kampung vulnerable to fire and flood, low occupancy comfort level and may cause the emergence of slums.

Table 1: Forms of Resilience in Kampung Kaliasin

Vulnerability	Form of Resilience
Environmental	There is no environment communal activity particularly greening in Kampung Kaliasin because of land limitation which means that additional fund is needed to provide media for the plants. Thus domestic waste management is conducted on household basis. *Gotong royong*, a traditional communal work especially to clean their living environment is periodically conducted.
Social	Kampung Kaliasin housed a large number of blue collar worker of the Tunjungan CBD. The kampung leaders (formal and informal) have a mutual understanding with the managements of the surrounding buildings, in the

	forms of supporting community social events. Permanent inhabitants have kampung rules to guide the temporary occupants living in harmony in the kampung, such as the boarding owner has to report the neighbourhood leader everytime he accept a new person at the latest in 2X24 hours a long with the ID copy of the guess, no motorbike allowed to pass in the alley after 10.00 pm, in certain alleys there are no motorbike allowed at all (mostly those of very narrow or place to play for the children), etc.Theclose social ties between the two groups of inhabitant not only build a living harmony but also reduce the criminal rate in the kampung because in the very limited space they are known each other.
Economy	There are numbers and variations of small house based enterprises that providegroceries, food and services not only for the temporary inhabitants but also for the CBD blue collar workers in general.

5.2. Kampung Peneleh Resilience

Kampung Peneleh has a very strategic geographic position. The kampung is easily reached from the City Hall, Tunjungan central business district and various city facilities such as shopping (Atum shopping centre and Pasar Turi Wholesale marker), recreation (Tugu Pahlawan museum), art and entertainment (Centre for culture and arts Surabaya, the Youth Park and the Surabaya Amusement Park). In addition to those facilities, Kampung Peneleh is located close to the revitalisation area of Kalimas River which is also planned as a cultural tourist destination.

Table 2: Forms of Resilience in Kampung Peneleh

Vulnerability	Form of Resilience
Environmental	Similar to Kampung Kaliasin, there is communal works on environmental management in Kampung Peneleh, but people awareness on greening and waste management is quite high. The community also aware on heritage protection by maintaining their environment. On an occation the community refused a program (alley pavementation) that will change the level of the alleys which lead to reducing the height of the buildings and covering the works of the first KIP in Surabaya.
Social	The peculiarities of the kampung should be emphasized not on what is seen through any material object, but on the cultural activities undertaken by its citizens. Various activities of Kampung Peneleh community are conducted either in a private physical space (home, meeting rooms, etc.) as well as in public spaces such as roads, mosque, etc.

	Many typical Peneleh community activities could be seeded to be developed as tourist activities. Uniqueness formed hereditary with cultural elements from many ethnics (Java, Madura, Arabic, Chinese, etc.) are one of the cultural distinctiveness of Kampung Peneleh.
Economy	In an effort to meet the needs of everyday life, the inhabitants establish small-medium home-based businesses which can be grouped as follows: A. Manufacturing Enterprises, processing of raw products into finished products, such as sewing clothes, veils and pillowcases, leather and plastic bags for children, food processing such as bread, fish crackers, traditional chips and cakes, traditional herbal drink, etc. B. Selling, providing products and services such as production of silk screening, plaques, pennant and business cards, printing, furniture, upholstery sofa or car seat making, various courses, beauty salon, computer rentals, photocopy, etc.

5.3. Kampung Ampel Resilience

Kampung Ampel is a residential area of Arab community. The kampung gains its name from a famous Islam priest in Java –Sunan Ampel- who stayed in the Kampung. In the middle of the kampung is located an old Ampel Mosque and Graveyard, a significant pilgrim destination in Java particularly in the fasting month and the death anniversary of Sunan Ampel.

Kampung Ampel community still bond to Islamic culture, thus the settlement layout and housing plan are influenced by Islamic values. Similar to the previous described kampung, Kampung Ampel has a high level of building density, but the community is relatively more inclusive in comparison to the other chosen kampungs.

Table 3: Forms of Resilience in Kampung Ampel

Vulnerability	Form of Resilience
Environmental	There is communal movement for greening and waste management in Kampung Ampel. Awareness on waste management makes the community to delegate it to other parties who clean the kampung and conduct 3R. Thus the kampung is clean and tidy. Circulation pattern of the settlement is like a labyrinth, is still used as a main access to the Ampel Mosque and Graveyard which in the central of the settlement. Architectural distinctiveness of Kampung Ampel is still well

	maintained. Unique architecture is an inseparable element in the development of the kampung as a tourist destination.
Social	Kampung Ampel is a complex area, serves residential, trading and tourism purposes. All the functions create a unique atmostphere of the kampung with an interesting blended cultures of Arab and Java. To keep the harmony within the community, they make a commitment to limit new residents to settlement.
Economy	Since 1972, Sunan Ampel Mosque has been developed as a religious tourist destination by the Surabaya City Government. Along with its development more trading and services activities have been also flourished around mosque area, ranging from muslim clothes, prayer appliances, accessories- mostly produced by locals, and traditional Middle East foods.

5.4. Kampung Gundih

Kampung Gundih location is next to a train station that connects main cities in Java, and a large-scale trade area that serves as far as Kalimantan dan Papua, the eastern part of Indonesia. The kampung is passed by a primary arterial road leading out of the city highway access. Additionally, Kampung Gundih is adjacent to railroad tracks which most probably make it the living area of criminals (pickpockets, drug dealers, etc) in the 1990's. Only later an informal leader started to make changes, the kampung becomes prominent with their works on environmental management.

Kampung Gundih community is dominated by Javanese and Madurese ethnic with diverse cultural, economic, educational and customs backgrounds. The diversity can potentially lead to vulnerability of social conflic in the absence of a mutual understanding among fellow inhabitants. Moreover as the location is very strategic makes the house not only serves for a place to live but also for business which need more control.

Table 4: Forms of Resilience in Kampung Gundih

Vulnerability	Form of Resilience
Environmental	To improve environment quality in Kampung Gundih, environmental management is carried out not only in aspects of greening the kampung, but also in the management of household solid and water waste. Solid waste management in Kampung Gundih is conducted through the 3R (reduce, reuse, and recycle) practice, meanwhile domestic grey water management is implemented by a simple grey water treatment equipment, which so far16 units has been installed serving about 1200 houses.

Social	At the lower level, each neighbourhood has at least one organization with regular activities for the inhabitants. All community in Kampung Gundih, despite of gender and age, have a fairly high level of participation in various communal activities such as communal work to clean the kampung, Sunday morning exercise, baby/toddler and elderly health group, etc. This makes the kampung development planning and program can be easily disseminated, discussed and implemented. There are also a variety of community organizations to facilitate the channelling aspirations related to the kampung development.
Economy	The strategic location of Kampung Gundih provides employment and home-based business opportunities. Moreover the success of environmental management in Kampung Gundih has attracted other local governments and community organisation as well as foreigners (mostly students and researchers) to come to the kampung. This provides business opportunities for the inhabitants such as home stay, souvenir, culinary etc. On the other hand, the city government also involves. Empowerment of women is intensified through education and training activities, micro credit as capital support is provided so that the results of training can be developed into new businesses, etc.

6. Conclusions

This study formulates the factors that cause the emergence of resistance (resilience) of the kampung communities that can be deployed in urban scale to support and create the city resilience to keep a decent living environment, livability and competitiveness both regionally and globally.

The research shows that each aspect of kampung resilience contributes to the city resilience. Environmental management in Kampung contributes to the improvement of residential comfort, to anticipate floods and fires. Another benefit of the environmental management is to increase the beauty of the kampung. Waste management conducted through the 3R (reduce, reuse, and recycle) program is able to reduce the volume of waste dumped in landfill area up to 83.34%. It is a great contribution to the resilience of the city in anticipation of potential disasters (flooding, outbreaks of disease, slum, etc.). Waste water management is beneficial to maintain cleanliness and health of the environment, anticipation of potential flooding, and reduce the use of water taps.

Social resilience contributes to the public awareness of the kampung condition and situation, and in turn to the city. It is not only building a good sense of place of their kampungs and the city but in general social resilience will keep the identity of the city as a place for various ethnics. Meanwhile economic resilience not only can be seen as a way of reducing unemployment rate but it is a way of low income community contributing to the city economic development.

The problems in kampungs as an urban settlement such as sub-standard housing, poor environmental condition, flooding, and poor sanitation influence the carrying capacity of the city. On the other hand the research shows that the resilience appears in the kampungs of Surabaya are supporting the creation of a viable, livable and competitive city. It shows that kampungs have capabilities to overcome problems and changes occurred in urban areas without losing its identity and is able to survive in the midst of urban development even improving its condition.

Table 5: Kampung Resilence Contribution

Vulnerability	Kampung Resilience	Contribution to the City Resilience
Environment	Greening, domestic waste and grey water management	Improvement of community health level and living comfort, free from flood, fire and slums, forming a positive image of the kampunng, reducing quantity of waste processed in the city level.
Social	Social security by high level of public participation, various forms of social organization and communal activities	Avoiding conflicts among communities and ethnict, increased security, reducing criminal rate
Economic	Economic security by small business, productive housing, and environmental economics	Reducing economic uncertainty, the utilization of local resources, economic community empowerment

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Sustainability by improving energy efficiency in traditional housing in Kosovo

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Abstract

The objective of this paper is to identify and evaluate aspects of sustainability by improving the energy efficiency of traditional housing in Kosovo. The refurbishment of traditional houses is looked from different sustainable perspectives, like sustainable occupancy, sustainable environmental protection, sustainable tourism, and as learning case for urban planners, architects and real estate experts l.

It is acknowledged that master artisans of traditional architecture in Kosovo were conscious of the sustainability parameters in designing and constructing traditional houses in villages and rural areas. Efficiency in the use of space, building location and orientation, design of the buildings, functionality of inner spaces, the layout of windows and use of materials have been important from the traditional old buildings. Traditional housing today, does not fulfil the needs and requirements regarding energy efficiency and comfort, as there is not sufficient insulation and heating. Rational use of space in neighbourhood creation, density within a city, connectivity with other neighbourhoods and the rest of the city, accessibility, a careful approach to environment, proper orientation of buildings to enable wind flow through the city, should also be identified as part of the sustainable urban development.

Keywords: sustainability**,** energy efficiency, traditional housing refurbishment, passive design, inner city rehabilitation,

1. Introduction

This paper is prepared within in the framework of joint cooperation project “SEEB – Sustainable Energy Efficient Buildings” between Kosovo and Norway, where have looked at case studies of existing traditional houses to find relevant and suitable measures to improve the energy efficiency and indoor comfort in the traditional houses. Through the energy analysis of refurbishment, we have found recommendations for solutions for energy improvements through passive design. The needs for refurbishment have to take into account the historic values and sustainable qualities of the buildings and historic urban areas. The majority of energy in Kosovo is used for residential needs. The absolute majority of houses in Kosovo, including old and new buildings, are not energy efficient. Furthermore, a large part of the houses and apartments in Kosovo use electrical energy for heating, causing energy efficiency to be at an alarmingly low level. Kosovo authorities have begun planning and drafting public policies related to efficiency based more on the requests made by the European Union rather than on the basic need for efficiency.

Prizren city in Kosovo, is an ancient city and have in its core or central district, the historic nutshell (downtown of the city),compoof cultural heritage buildings, mainly of traditional houses as well as public buildings. Houses are poorly inhabited (mainly empty), with the tendency to either be demolished and newly reconstructed or being left uninhabited, because of poor living conditions, poor living conditions.

The main objective of this study is to analyze possible measures in traditional houses in Prizren /Kosovo and compare them vs sustainability indicators, socio-economic and physical/environmental indicators. Improvements in energy efficiency in traditional houses in Prizren , are seen as appropriate measures, towards reaching other different sustainable goals than of only comfort. This is seen as an initial step, important and useful with big outcome results for the city, region, culture, economy etc.

From most recent data from the Conservation Plan of the City of Prizren, 2007 it is found that many of traditional houses in the city district core were have been demolished or left un-inhabited, from the main reason – to be newly rebuilt. The main driver of these actions are due to higher economic income benefits to the owners of the houses, when renting a new house. New designed houses in downtown of the city, (previosly with traditional design), do not obey on the traditional design and architecture, what is a threat as perceived by the owner-interviewe of this study: “there is a loss of the cultural heritage, loss of the city spirit” (Int. #7, 2015). The refurbishment of existing buildings is a neglected subject within sustainable architecture, where attention is usually focused on new buildings. Demolition is an option but the alternative of refurbishment is starting to be seen as more sustainable in terms of architectural value, materials use, neighbourhood disruption and waste disposal. Building new is more carbon intensive and carries many wider environmental impacts. In addition, the potential impact of low energy refurbishment is much greener than that of new build, since there are many more existing buildings that will be built in the next 10-20 years, the period over which many CO2 emission targets apply (Baker, 2009).

2. Theoretical background

2.1. Literature review

Thee urban development of historic cities is very challenging, especially when it comes to inner city rehabilitation, which is composed of historic area-downtown of the Prizren city. This is due to the need for a more rational/efficient use of space on behalf of redevelopment, but in the other aspect of traditional buildings that need refurbishment as to keep them in use, whereas rebuilt of them seems as more costly and inefficient solution. Sustainable development is seen according to Häkkinen (2012) that nothing can go ahead without radical changes in architecture, construction and spatial planning, a huge drive to conserve energy, increase efficiency and create zero-carbon buildings, all of which are vital in reducing the environmental impacts of buildings. As stated by Bokalders and Block (2010), planning a sustainable society requires a holistic approach in which we learn from and cooperate with nature. Urban development as cautious exploitation of resources can be understood from the fundamental principles for environmental sustainability. Sustainable society as cautious lifestyle should take into consideration that the transition to sustainable technology and renewable energy sources is not enough to achieve sustainable development. It should include a change of lifestyle (Bokalders and Block, 2010).

Environmental cities are cities with the focal point of the energy use and at the same time, the solution to energy efficiency and reduction of pollution. Conventional wisdom about the environmental impact of cities holds urbanization and environmental quality at odds, "the building sector of today has an oversized ecological footprint, being the single largest contributor to global greenhouse gas emissions and is responsible for more than a third of global resource consumption" (Meyer, 2013).

Baeli (2013) states that the housing stock represents some of the oldest in Europe with 55%. Therefore, the green buildings and residential retrofits are necessary to decrease rising levels of greenhouses gases. Residential buildings are seen as a part of the solution too, where retrofit is participating in the reduction of emissions, avoiding the dilapidation of buildings that have become uninhabitable, helping to future-proof houses against the risks of fuel poverty, and providing comfort for occupants. As a solution, Baeli (2013) sees ensuring the use of old houses in continuation, including financial investment to avoid dilapidation, ensuring their representativeness, cultural identity, and at the same time delivering the levels of reduction in energy use. Retrofit options are more preferable than demolition and a complete rebuild can be recommended from different reasons. A more societal point of view shows the retrofit can be more acceptable than a complete rebuild, as it could potentially create long-term employment. From a psychological perspective the replacement of components and tailoring space organization to new uses can improve environmental quality and satisfaction. Implications for change of use is an important factor as refurbishment is often accompanied by change of use (Baker, 2009). Change of use may bring about changes in purely technical parameters. Change of use may bring about an increase in the energy consumption. This does not necessarily mean that the low energy refurbishment has failed, since the measures adopted have undoubtedly led to lower energy consumption than if absent.

2.2. Legislation and strategies on energy efficiency in Kosovo

From the perspective of enabling energy efficiency in Kosovo, the following legislation and strategy documentation are important:

- *The Kosovo Law on Energy Efficiency* is compatible with EU legislation, specifically with reference to the Directives on energy efficiency for provision of necessary incentives and improvement of the energy efficiency in all consuming sectors (Directive 2004/8/EC, amending Directive 92/42/EEC, Directive 2002/91/EC)
- *Kosovo program for energy efficiency and renewable energy resources 2007-2009* provides the framework for the implementation of energy efficiency and renewable energy in Kosovo.
- *National Energy Efficiency Plan of Kosovo*, represents the first long-term energy efficiency plan which covers the period from 2008 till 2016, sets indicative target for energy saving for the period 2008-2016 (based on the article 4(1) of Directive 2006/32/EC).
- *Draft Law on energy performance of buildings* is oriented towards the promotion of improvements to the energy performance of buildings, taking into account outdoor climatic and local conditions, as well as indoor climate requirements and cost-effectiveness, in Kosovo.
- *Policies for increasing energy efficiency* are developed to increase the efficiency related to the entry into force of the Administrative Instruction on the Labelling of Energy Products, the introduction of excise tax for inefficient light bulbs, mandatory application of energy efficiency measures related to the issuance of the utilisation permit for buildings, the increase in the price of electricity higher than 8.0% and application of block tariffs.

Based on the knowledge from the review of literature and legislation, a list of challenges regarding energy efficiency in Kosovo are given below:

- Implementation of Energy Efficiency (EE) measures is not seen as a priority for the government, but EE is seen as only a legislative “must” to fulfil the gap, aiming EU membership.
- The EE is mainly seen, planned as concept to production of renewable energy perspective.
- The energy production relies on two coal power-plants that produces 97% of overall energy, in paradox that Kosovo is looking for new economic growth, increase opportunities, and enhance quality of life, arising from the development of the energy sector.
- Incomplete legal framework for energy efficiency in residential buildings.
- Incomplete technical regulation regarding energy efficiency and changes on existing regulation on thermal energy saving.
- Lack of human capacities and coordination between organizations at central and local level.
- Lack of environmental awareness campaigns, to change the approach and understanding of the importance of the necessary thermal energy savings in building sector.
- Lack of innovative financing models for energy efficiency investments in the building sector.

3. Methodology

The research is a qualitative and exploratory study. The analysis of the city of Prizren's current historic core district profile is given, together with the strategic documents on conservation/refurbishment, national legislation and strategy documentation on energy efficiency. The simulation analysis of the energy efficiency of the traditional case house is made, based on modelling in DesignBuilder Software, 2015. For obtaining a social impression of the project, a qualitative study was conducted with open-ended questions and 30 interviews with people of Prizren regarding traditional housing in core historic centre of Prizren, presenting the main stakeholder groups: i) inhabitants; ii) municipal officials, and iii) civil society representatives.

The main research questions are:

- Will improved energy efficiency in traditional housing contribute to a more be sustainable solution in economic, social and physical/environmental aspect?
- Does the legislation in Kosovo supports improvement of energy efficiency in traditional housing a development strategy?
- What do the key people of Prizren, think about energy improvement of traditional housing in Prizren/Kosovo as potential towards sustainable urban development of Kosovo cities?

The first hypothesis, based on the climate and envelope data, is "*A traditional Albanian house (such as house Mashkulli), is nowadays not energy efficient due to poor thermal properties, but the use of both passive and active strategies can improve the environmental and energy performance of the building.*"

The second hypothesis is: "B*y improving energy efficiency in traditional housing in Kosovo/Prizren, a more sustainable solution would be reached in economic, social and physical/environmental aspect of development*".

The research methodology is segmented in different phases. In the first phase, the literature review, based theories and best practices on economic, social and environmental impacts of refurbishment vs rebuild, improvement of energy efficiency in traditional housing, building performance, passive design, sustainable urban development and inner city rehabilitation are studied. During the second phase, legislation and strategy documents are reviewed on Energy Efficiency in Kosovo. In the empirical section, the research was divided in two phases BI and BII. B.I. phase is a simulation analyses of a traditional house on building performance in historical core district centre of Prizren (Mashkulli house). U-values of the elements were calculated assuming the thermal properties of the existing building. In B.II phase, a qualitative analysis was conducted, based on 30 in depth interviews. The main driver of these interviews was finding their opinion on the potentials towards sustainable urban development of Prizren by improving energy efficiency in traditional housing in core historic central district of Prizren.

The types of data being used as for this research are divided into two groups, theoretical and empirical sections. Data for theoretical section of the study is based on: Sustainable refurbishment, Strategies for low emission refurbishment, energy use in traditional housing, environmental comfort standards, and passive environmental strategies. Data for the empirical section of the study is based on the conservation plan of the historic core Prizren city district; building detail design plan of the traditional case-Mashkulli house, and interviews.

4. Case study and results

4.1. Analysis on urban planning and architectural design of the neighbourhood/ traditional house-Mashkulli

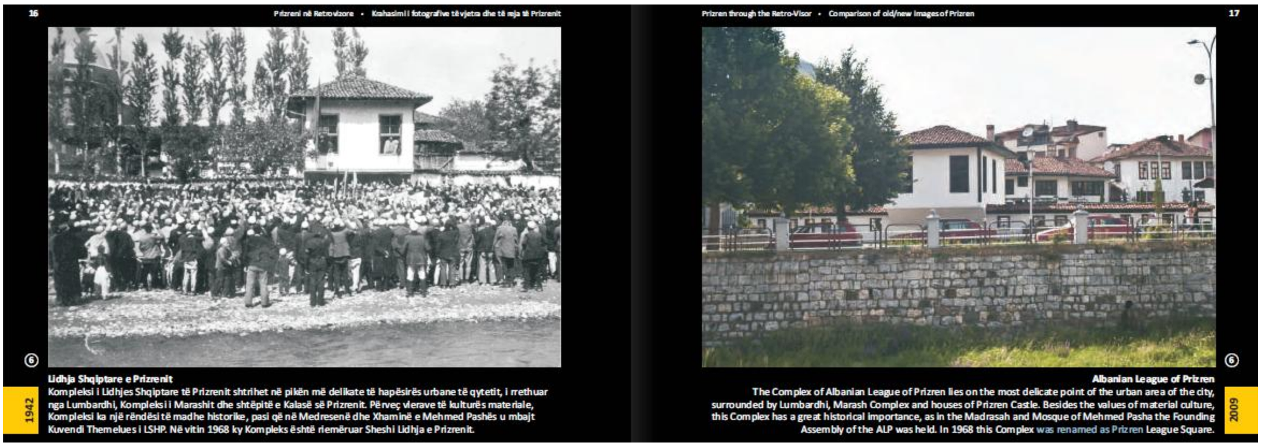

Figure 1: Before and after – neighbourhood of Mashkulli house (Source, EC ma NDRYSHE, 2012)

Prizren is famous city for its old, traditional dwellings. Starting from the Castle called Kalaja that dominates the city, the urban landscape is enriched with numerous historic buildings. Prizren has several urban residences. The diversity of the town's inhabitants, influencing each other in social and cultural terms, has had an impact on building and construction and the legacy of Byzantine and Ottoman culture during the 18th and 19th centuries is visible. Houses with a gallery are representative of the typical Albanian house, in comparison to other places in Balkans. It is surrounded by the National Park-Sharri Mountains, what influence on the climate, which is predominantly continental. Mediterranean climate also reaches Prizren due to Adriatic draught that comes through the river canyon.

Pilot project is a home of the Mashkulli family (Fig.1), an old building of the end of 18th century, in the centre of Prizren, near the Bajrakli Mosques and Medrese, nowadays known as the League of Prizren. By typology, the Mashkulli house belongs to the Urban House typology, accessed via main road parallel with the river Lumbardhi, entrance from the public square of "Prizren League", and then continue with private house garden, green zoning of the neighbourhood. The house is next to the landmark of the city, important node that defines character of a neighbourhood/city, under the conservation plan of the Prizren city (2005).

4.2. Energy Efficiency by simulation analysis – a case study

House Mashkulli is located in Prizren, in the southern part of Kosovo. It is a traditional Albanian house, mainly built from bricks (straw and soil mixture), where south/internal walls are made from stone. The floors and roof are insulated with soil between wooden boards, windows are single glazed with wooden frames. The U-values corresponding to the different envelope elements are calculated and summarised in table 2. This table also displays the required U-values according to passive house standards[1] for existing buildings and the amount of insulation needed to fulfil the requirements assuming the use of Rockwool 201 VARIO (λ =0,034 W/mK). The windows need to be replaced.

Element	Layers	thickness d [m]	thermal conductivity λ [W/mK]	U-value [W/m2K]	PHS U-value [W/m2K]	Insulation needed [m]
Wall - brick	Int. surf. Resistance Lime mortar Soil and straw bricks Lime mortar Wooden beams Ext. surf. Resistance	 0,01 0,16 0,01 0,16	 0,7 0,2 0,8 0,17	0,98	0,15	0,19
Wall - brick, load bearing	Int. surf. Resistance Lime mortar Soil and straw bricks Lime mortar Wooden beams Ext. surf. Resistance	 0,01 0,7 0,01 0,7	 0,7 0,2 0,8 0,17	0,26	0,15	0,10
Wall - stone, load bearing	Int. surf. Resistance Lime mortar Stone Lime mortar Ext. surf. Resistance	 0,01 0,7 0,01	 0,7 3,5 0,8	2,52	0,15	0,21
Ground floor	Int. surf. Resistance Concrete Ext. surf. Resistance	0,1	1,7	2,51	0,15	0,21
Floor	Int. surf. Resistance Wooden board Soil filling Wooden board Wooden beams Ext. surf. Resistance	 0,03 0,19 0,02	 0,17 0,52 0,17	1,09	0,35	0,07
Roof	Int. surf. Resistance Wooden construction Soil and straw filling Clay tiles Ext. surf. Resistance	 0,14 0,16 0,02	 0,17 0,18 1	0,53	0,15	0,16
Window	Single pane, wood			4,80	0,85	

Table 1: overview of U-values of the existing elements, the required U-values according to passive house standards, and the thickness of insulation that is needed to reach these standards.

Prizren has a maritime temperate climate classified as Cfb according to the Köppen-Geiger classification. The main challenge in a temperate climate is the seasonal variation between under-heated and over-heated periods (Figure 2.). This graph represents the monthly diurnal averages for Prizren with the comfortable temperature zones. Figure 3. shows the effect of passive strategies on the indoor comfort in Prizren for the whole year, the summer and the winter. The effective strategies vary with the season. The indoor temperatures are comfortable during 13% of the year. Over the whole year the effective strategies are solar shading, internal heat gains and passive solar gain. This results in 91,4% comfortable hours during the year and reduces the need for active heating systems to 45%. The hours that are not comfortable occur during the summer (8,6%), when the indoor temperature is higher. There are other passive strategies to make these overheated periods comfortable as well, but they will have only a small effect on the total (<5%) and are therefore not considered in this simulation.

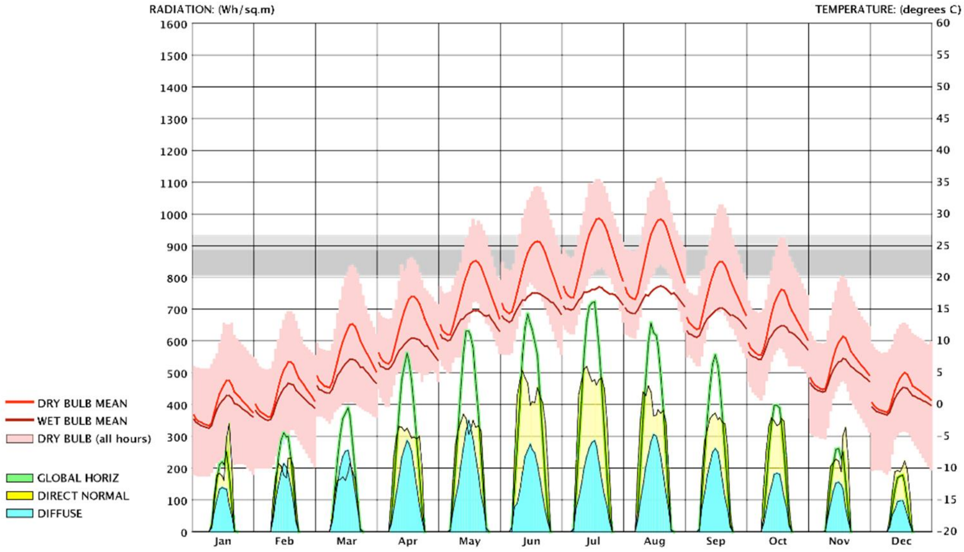

Figure 2.Monthly diurnal averages for Prizren, extracted from Climate Consultant[3]

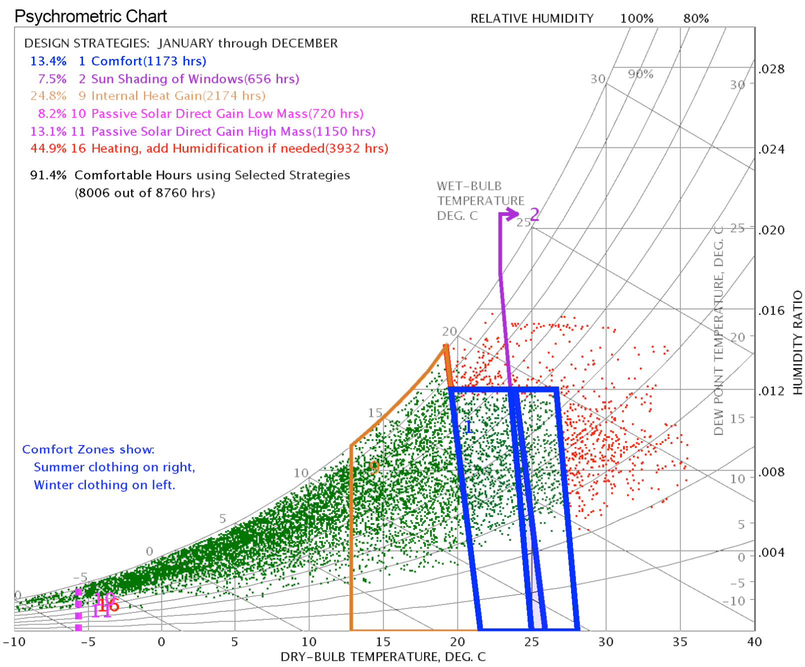

Figure 3: Psychrometric chart with the effect of passive strategies on the indoor comfort (comfortable hours of the total in percent), extracted from Climate Consultant[3]

In addition to these strategies, the shape and form of the building will also affect the energy consumption. A compact shape and no openings towards the north will result in less heat losses through the envelope. Openings towards the south can result in passive gain, but need to be shaded during the summertime to avoid overheating. Some of these strategies are already implemented in the Mashkulli house. The house has a compact design, is closed towards the north, uses thermal mass for solar storage, and has a light coloured building surface to avoid overheating in the summer. The building has a natural ventilation system, but the rooms mostly have openings in one facade, which makes cross ventilation possible only when doors between rooms are opened.

4.3. Research model and results

The building was modelled in Design Builder. U-values of the elements were calculated assuming the thermal properties of the existing building. The climate file used for the simulation was a weather file for Prizren. The building was divided into several zones (living room, hall, kitchen, bedroom), and both occupied and unoccupied zones were used in the simulation to be evaluated as one unit. The HVAC systems in the simulation were a cooling system powered by electricity and a heating system with biomass (wood). The house has no mechanical ventilation, but infiltration is high due to poor air tightness (1,5 ACH). The simulation time was one year, but only typical summer and winter week are shown in the graphs. In order to evaluate the environmental performance and energy efficiency of the house itself, simulations were made both with and without the active heating/cooling systems, for the existing and refurbished house with passive house standards. The HVAC systems were the same, but for the refurbished house, the mechanical ventilation was a fan coil system with 75% heat recovery.

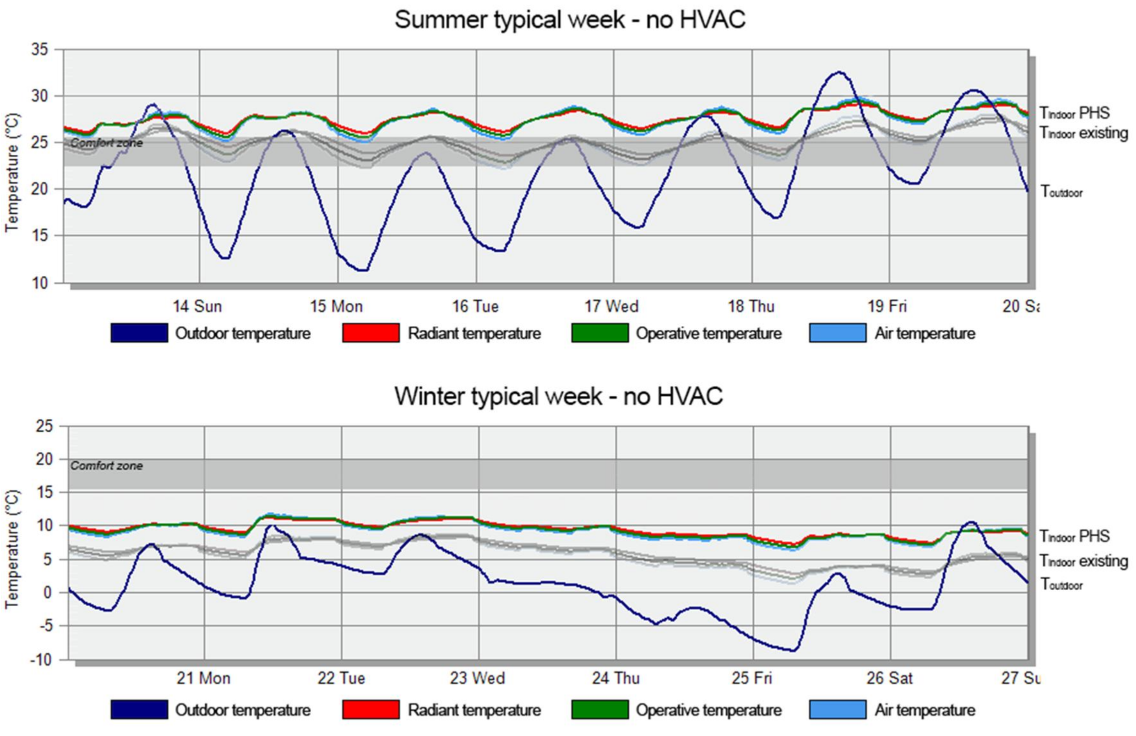

Figure 4: Indoor temperatures (no heating/cooling systems) for a summer and winter typical week

As seen (Fig. 4) that the temperature in the winter is much lower than the comfortable temperature in both cases when indoor temperature is simulated without any heating or cooling system. When passive house standards are applied, the indoor temperature rises throughout the whole year. In the summer it is visible that the indoor temperature can be higher than the comfort temperature, but on average the indoor temperature is within the comfortable temperature range in the existing situation. If the house is refurbished with passive house standards, the indoor temperature in the summer becomes too high and cooling is needed to retain a comfortable indoor climate. This shows that upgrading the house to passive standards is effective in the winter, but results in overheating during the summer.

When the indoor temperature of the house is simulated with active heating and cooling systems, it shows that indoor temperatures in the existing situation are still lower than the comfortable temperatures in the winter. The capacity of the heating system is not high enough to ensure a comfortable climate during the winter. The reason is in the high heat losses due to poor thermal properties of the envelope. When passive house standards are applied, the indoor temperatures are in the comfortable zone. During the summer in both cases the temperatures are lower with HVAC systems than compared to no systems, meaning that there are cooling systems active to lower the temperature in the house.

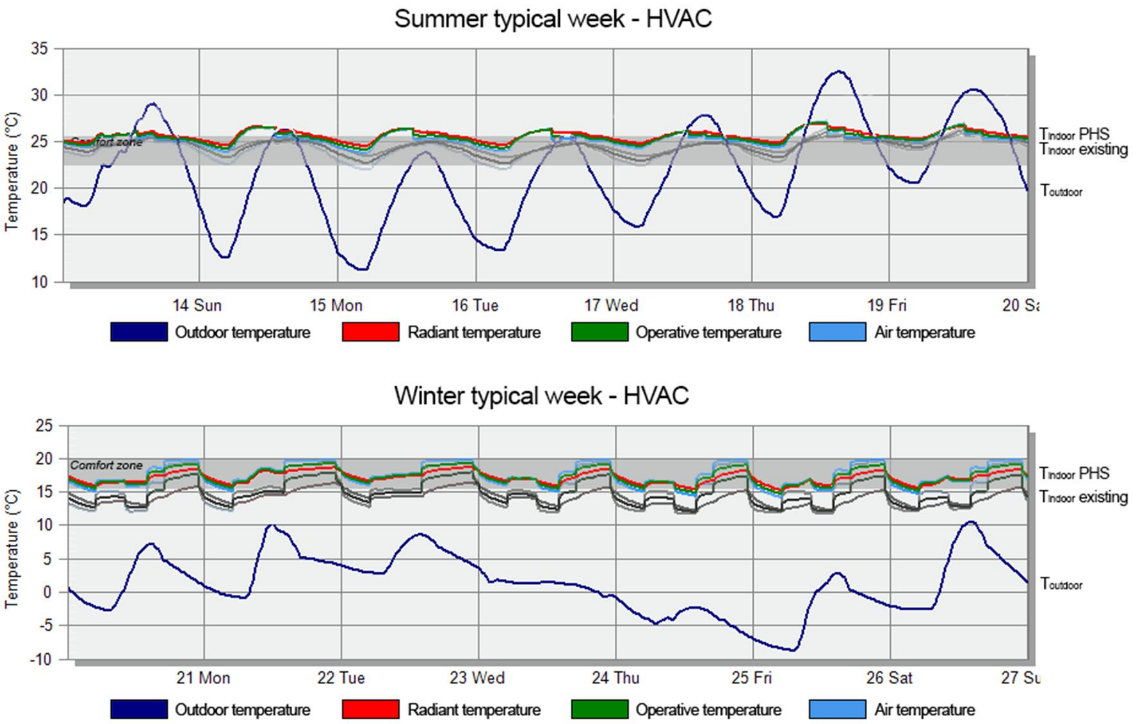

Figure 5: Indoor temperatures when heating and cooling systems are used in house Mashkulli for a summer and winter typical week

The total energy consumption of the house is 180 kWh/m^2, and the heating demand 140 kWh/m^2. After refurbishment, the total energy consumption is 105 kWh/m^2 and the heating demand 62 kWh/m^2. An improvement is 42% on the total energy consumption, and 55% on the heating demand.

4.4. Interview analysis

In total 30 interviews were conducted with key people of Prizren regarding traditional housing in the core historic centre of Prizren and their needs, and the potential for sustainable refurbishment. The respondents were chosen from three focus groups: i) Inhabitants; ii) Municipal officials and iii) Civil society representatives (neighbours, owners of the craftsman shops, students and professors of architecture, ethnology researchers, NGO representatives, academic staff). In total, 27 open-ended questions are prepared. The perceived level of awareness/potential about three aspects of sustainable refurbishment: economic and social/cultural aspect, whereas environmental aspect seen as less important. The opinion of each target group regarding three sustainability aspects of refurbishment. The most expressing warning and enthusiasm is civil society, meaning researchers, professionals, knowers of architectural values, whereas the most un not expressing the challenge were public officials.

5. Conclusions

From the A.I-Literature review, it can be concluded that refurbishment of traditional houses is more sustainable than rebuild or new built areas of housing, in many aspects such as cultural, societal, economic and therefore environmental. From A.II -Kosovo legislation and a strategic review of documents regarding Energy Efficiency in Kosovo, even though housing is considered to be as the biggest exploiter/user of energy, the policies for refurbishment/upgrading of housing are not seen as a priority for the state. Norms and standards aren't set as benchmarking for housing, although ways nor alternatives aren't set in practice (institutional, financial etc). From B.I phase, the simulation and the results show a potentially large decrease in total energy consumption (42%) and a decrease in the heating demand (55%) when the house is refurbished and more passive strategies are implemented. From B.II phase, the interview analyses, the results show that there is a room for improvement in the decision making institutions, taking refurbishment as one of the driving forces for energy efficiency.

From the research questions, it could be seen that those are approved: i)*'By improving energy efficiency in traditional housing would be reached sustainable solution in economic, social and physical/environmental aspect': ii) 'The key people of Prizren, think positively and do see energy improvement of traditional housing in Prizren/Kosovo as potential towards sustainable urban development of their city and of any city of traditional buildings'; iii)* '*Legislation in Kosovo does NOT support improvement of energy efficiency in traditional housing as solution and development strategy'*.

The first hypothesis "*A traditional Albanian house (such as house Mashkulli), is nowadays not energy efficient due to poor thermal properties, but the use of both passive and active strategies can improve the environmental and energy performance of the building."* has been approved. When the envelope of the house is refurbished to reach passive house standards and extra passive strategies are implemented, the total energy consumption of the house improves by 42% and the heating demand is reduced by almost 55% compared to the existing situation. However, the heating demand is still larger in comparison with passive house standards, so this house is not a passive one. *The second hypothesis* has been approved "B*y improving energy efficiency in traditional housing in Kosovo/Prizren city, would be reached sustainable solution in economic, social and physical/environmental aspect of development*". By improving the house, the environmental performance and energy efficiency of the house improves by implementing passive house strategies. In addition, these improvements will have an effect on multiple levels of sustainability, like the quality of life, because of better and more comfortable indoor climate (social), or on better impact of the environment, because it is more energy efficient (environmental), and on energy costs (economic).

International networking from research and development and using experiences to design traditional housing protection via energy efficient refurbishment measures could be beneficiary. The legal framework for EE in residential/traditional buildings, by settling of correlations in legislative framework within the area of energy, housing, spatial planning and building construction is needed.

New strategies for improvement and management in residential/traditional houses regarding energy efficiency followed by the appropriate raising awareness campaigns on thermal energy savings in building sector in general are necessary. Innovative financing in residential buildings through introduction of fiscal policy are needed for the application of customs relief connected with efficient technologies, subsidies on energy auditing costs, energy conservation investment costs and promotional activity costing.

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A conceptual framework for sustainable retrofit project delivery for housing

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Abstract

Some key factors are of prime importance in achieving the ambitious carbon reduction targets set by the European Union. In terms of greenhouse gas emissions, its aim is to achieve a 20% reduction on the 1990 levels by 2020 and an 80-95% reduction by 2050 compared to 1990. It has been established that building energy efficient houses and retrofitting the existing housing stock represent a sustainable way of tackling fuel poverty and increasing social and financial value. In seeking for ways to achieve this, a conceptual framework for ensuring the sustainability of building retrofit programmes was developed as part of this study. It considers sustainability as being driven by five environmental and economic priorities which include: reducing of carbon emissions, reducing energy bills and fuel poverty, increasing energy security, improving health and wellbeing and driving economic growth and creating jobs. However, a recent review of retrofit in the UK West Midlands Social Housing Organisations highlights that the most popular action for retrofitting in the region to date are: loft and cavity wall insulation; replacement of windows and doors; and the upgrade of heating systems. Most recent retrofit programmes, however, used external wall insulation or internal wall insulation where the former is not feasible. A questionnaire was sent to 24 RSLs in the UK West Midlands, some operating entirely within the area and some with stock in other parts of the country as well as the West Midlands. The developed framework provided a flowchart that caters for the integration of the key factors. It recommended that strategy and planning, housing stock data, funding, technical and delivery and tenant engagement are essential considerations in the development of sustainable retrofit solution. Future work will entail the development of the conceptual model into a full model to ensure that the sustainable solution it offers is properly articulated and validated.

Keywords: Building, retrofit, housing, energy, integration

1. Introduction

Increasing the energy efficiency and the energy performance of buildings will be key factors in achieving ambitious carbon reduction targets set by the European Union (EU Directive 2012/27/EU, 2012), (EU, "Directive 2010/31/EU", 2010). In terms of greenhouse gas emissions, its aim is to achieve a 20% reduction on the 1990 levels by 2020 and an 80-95% reduction by 2050 compared to 1990 (EU Directive 2012/27/EU, 2012). Although the reduction of greenhouse gas emissions and the development of renewable energies are potentially achievable, it is likely to be very costly and difficult to carry out (Shorrock et al, 2010).

In the context of carbon reduction, in many European countries, over the last years, there has been a significant concern in retrofitting of buildings in order to make the buildings more thermally efficient and sustainable (buildings are responsible for 40% of our energy consumption). Building energy efficient houses and retrofitting the existing housing stock represent a sustainable way of tackling fuel poverty, and, moreover, with increased social and financial value. This particular interest to building retrofit has been driven by five environmentally and economic priorities as: reducing of carbon emissions, reduce energy bills and fuel poverty, increase energy security, improve health and wellbeing, drive economic growth and create jobs.

The Report no 004 of the Centre for Low Carbon Futures highlights the importance of a rapid, policy driven transition to a low carbon economy in order to achieve mandatory carbon reduction targets. Retrofitting the buildings will take time, which is why this is a priority issue nowadays (Stafford et al 2011).

Generally, there are many pilot projects that aim towards a "nearly Zero Efficiency Building" (nZEB). This takes the "Passive House" standards incorporating a range of technology retrofitted. These include: draft proofing and floor insulation; water saving systems (fitting low volume baths, low flow taps and showers, dual flush WC's); recycle and reuse water (rainwater and grey water harvesting, hot water) and heating systems (Air source heat pumps, ground source heat pumps, combined heat and power units, biomass boilers); upgrade of lighting system (LED lighting, light sensors, voltage optimization and renewable energies, photovoltaic and solar thermal panels, biomass and geothermal systems (Oloke, 2015).

A review of 73 pilot projects around 12 Countries in Europe was made and compared with UK retrofitting (Oloke, 2015). Countries compared were grouped according to climatic conditions, into: Mediterranean countries: France, Greece, Italy, Malta, Slovenia and Spain and non-Mediterranean countries: U.K, Bulgaria, Estonia, Sweden, Germany and Netherlands.

Similarly, the recent (2014) review of Retrofit in UK West Midlands Social Housing Organisations highlights that the most popular action for retrofitting in the region to date are: loft and cavity wall insulation; replacement of windows and doors; and upgrade of heating systems. Most recent retrofit programmes, however, used external wall insulation or internal wall insulation where the former is not feasible.

Generally, providers of social housing have the challenge of providing affordable energy efficient housing. Many tenants are likely to be fuel poor or in ill health and therefore would benefit greatly when the quality of accommodation is improved.

2. Background

2.1 European Union and UK Framework on Energy Efficiency

The objective of Directive 2012/27/EU on energy efficiency (hereinafter: EED) is to establish a common framework for promoting energy efficiency in the European Union. Article 4 mentions that Member States shall establish a long-term strategy for mobilising investment in the renovation of the national stock of residential and commercial buildings, both public and private (EU Directive 2012/27/EU, 2012). The European building stock is extremely diverse and could be differentiated between residential and non-residential use, both public and private. For the residential buildings, a distinction between single-family dwellings and multi-family dwellings is made.

A common form of multi-family dwellings are apartment blocks, usually maintained by a homeowner association (or condominiums or cooperatives of apartment owners). The residential buildings vary considerably from country to country (and from region to region), gathering a large variety of architectural and energy performance characteristics (which depend on the year of construction, building materials, or climate conditions). Depending on the climate conditions, Member States have to invest in energy efficiency differently, for warming or cooling the buildings (or both). Controlling the air temperature in indoor spaces and, in the same time, improving the energy performance of buildings, is a challenge.

The non-residential buildings have a variety of functions (administrative buildings, offices, schools, hospitals, commercial and industrial buildings, warehouses, etc). The uses of non-residential buildings are much more varied than the residential buildings, and therefore the energy use depends on the activities from these buildings.

The UK Government has placed special emphasis on the retrofitting and refurbishment of the UK's existing domestic and non-domestic buildings. It has committed to reducing greenhouse gas emissions by 80% in the year 2050 against 1990 levels. With about one quarter of emissions coming from domestic properties, the need to make reductions in this sector will be necessary to reach the target.

Residential Social Landlords (RSL)'s hold approximately 18 % of the UK housing stock (Fact File, 2013) and therefore a significant amount of the emissions relate to this sector. RSL's are motivated to increase the energy efficiency of their stock, to promote the health and well-being of their tenants, to provide tenants with financial resilience to increases in energy prices, to reduce greenhouse gas emissions and to provide resilience to the potential effects climate change. In a move to improve the quality of the UK housing stock, for example, the Government introduced the Decent Homes standard. RSL's have worked to make their own stock meet this standard and are looking to increase the energy efficiency of their stock further and this continues to be a challenge across the continent.

2.2 Aims and Objectives

In the light of the contextual background to this study, the paper aims to: propose a framework model for sustainable retrofit of housing stock. In doing this, the following objectives were achieved: a review the current position of Registered Social Landlords (RSL's) in the UK West Midlands with regard to the implementation of greenhouse gas emissions reduction in their housing stocks; and review innovative projects that demonstrate innovation in RSL's in order to exemplify the potential of success in the retrofit sector and propose a conceptual framework model for the recommendations of sustainable retrofit of houses.

3. Methodology

Sequel to the review of existing literature, a questionnaire was devised to establish the progress UK RSL's have made to reduce greenhouse gas emissions. Based on the review of exemplars from other EU countries, the questions asked were concerned with strategies and plans that are in place to deal with energy efficiency within their housing stock, information about the energy efficiency of their housing stock, affiliation with bodies that give support in energy related matters, energy efficiency projects that have been delivered, funding and resources. The questionnaire was sent to 24 RSLs in the UK West Midlands, some operating entirely within the area and some with stock in other parts of the country as well as the West Midlands. 8 responses were completed and returned via email. 1 questionnaire was completed via a phone conversation and 1 face to face. Further to the collection of the data, analysis of the same facilitated the collation of the critical issues to be considered further and in the light of the objectives of this work to implement a framework.

Furthermore, in order to highlight the benefits of retrofitting to improve the energy performance of buildings, a range of best practice examples were analysed, compared to some European efforts and summarised. This is the basis for which a framework was proposed and recommendations for future development made.

4. Analysis of the Responses

All the data collated were analysed under five themes. These were: strategy and planning, housing stock data, funding, technical and delivery and tenant engagement. The results in addition to an analysis of retrofit work replication potentials were subsequently used to develop a conceptual framework for the design and implementation of new retrofit scheme.

4.1 Strategy and Planning

This examined the strategy put in place by an organisation to implement retrofit programmes and also the method used to plan and execute the programme. This aspect of the programme should ensure that the most effective project is proposed and designed. 9 of the 10 respondents confirmed having a strategy to tackle sustainability and environmental issues and have a plan to deliver energy efficiency measures. One organisation was in the process of developing their strategy as at the time of the survey. 2 of the respondents mentioned that they have strategies and plans that are reviewed on a regular basis. All of the respondents have roles within their business structure to support the planning and delivery of a strategy. Mostly this overall responsibility lies with one team within an organisation, although in one organisation the responsibility lay across two teams.

Policies regarding the environmental impacts of supply chain were found to be at different stages amongst the respondents. 4 organisations have a procurement procedure in place which included the environmental sustainability of the supply chain working with ISO 9001 and ISO 140001. 3 respondents use the Sustainable Homes Index for Tomorrow (SHIFT) benchmarking and road mapping process to deliver on this point, while the other respondents were currently developing policies.

4.2 Housing Stock Data

The study further sought to interrogate the processes used to manage housing stock data. This helps to provide up-to-date information about the housing stock. 7 of the 10 respondents used a stock database system to manage record and plan energy efficiency measures. A number of databases were in use by the respondents including CROHM (Carbon Reduction Options for Housing Managers), Promaster In4systems, Active H MIS and Eco Homes XB. EPC's (Energy Performance Certificates) and DHS (Decent Homes Standard) were commonly used measure of energy performance. EPC's were commonly carried out during voids. Energy assessments varied from 50% to 100% of the total stock. Transferring EPC data to the stock database was mentioned as being problematic in one organisation. The potential to improve this process and allow an integration with other systems e.g. Building Information Modelling (BIM) is quite high.

4.3 Funding

Several funding options had been considered. Carbon Emissions Reduction Target (CERT), Community Energy Saving Programme (CESP) and Energy Company Obligation (ECO) funding made a contribution to energy efficiency retrofit programmes for most organisations. One respondent was involved in a pilot project using funding from the Technology Strand Board. Other organisations have accessed EDRF (European Regional Development Funding) funding and Solutions 4 Energy. Many of the respondents were unclear what funding would be accessible in the nearer future. They indicated that the uncertainty in funding makes planning ahead difficult. One respondent gave two examples of projects that didn't proceed due to changes in funding at short notice. Another respondent acknowledged that where budgets showed a shortfall it was the 'non-essential' work such as the energy efficiency that would be cut. 7 respondents considered

ECO funding and 3 mentioned the Green Deal Home Improvement Fund. 2 respondents considered the Renewable Heat Incentive as a possibility whilst 1 respondent considered self-funded projects because of the uncertainty of funding. It was also another respondent's noted that the time frame for getting bids in is often to short and resources are not ready available to parachute into project. A consistent approach from the government to promote up skilling in the contractor was also thought to be necessary. Also, one respondent noted that the funding applications were overly complicated.

4.4 Technical Delivery

The RSL's mostly took the fabric first approach – a strategy which took advantage of current funding. Loft and cavity wall insulation has been the main stay of retrofit to date, along with replacement windows, doors and heating system upgrades. External wall insulation featured in many of the respondents more recent retrofit programmes. Some internal wall insulation had also been installed where external insulation is not feasible.

The range of technology retrofitted, in addition to cavity, loft and wall insulation, was however, very broad. The technologies included the following: fitting low volume baths, low flow taps and showers, dual flush WC's, grey water and rainwater harvesting, photovoltaics, solar thermal systems air source heat pumps, ground source heat pumps, combined heat and power units, biomass boilers, LED lighting, light sensors, voltage optimisation, draft proofing and floor insulation. Others measures not specifically energy efficiency measures include the provision of composting facilities, water butts and cycle storage facilities.

Whilst most of the work carried out had focused on energy efficiency, adaption work was under consideration by 6 of the 10 respondents. 4 of the respondents had carried out flood risk assessments. 1 respondent mentioned that they were intending to install ventilation systems in properties that were liable to overheating and another respondent installs mechanical ventilation in properties in the Extra Care scheme housing as they know that their tenants are more vulnerable.

One of the respondents said that they were aware of risks associated with the effects climate change, but considered that affordable warmth and fuel poverty were higher priority and this is where the focus lay at present. For projects involving renewable energy, 3 respondents reported using Feed in Tariff (FIT's) and/or the Renewable Heat Incentive (RHI).

In-house expertise and time was identified as resource that was missing from some organisations. An in-house technical specialist or consultant that could evaluate new technologies and funding that could provide advice throughout a programme. One respondent indicated the need for an on-site technical project manager, independent of the contractor.

The more innovative projects could be considered pilot projects and are being monitored and can be used to inform retrofit projects in the future. One organisation has found the installation of Combined Heat and Power units problematic as they are noisy and cumbersome. It has been difficult to source replacement parts for the units. As the technology has moved on very quickly, the parts for older units have become obsolete. The performance of ground source heat pumps was found to be variable as that the system design is critical to this. 2 respondents have found that projects haven't delivered the expected savings. One organisation has discovered that the electric heating system hasn't provided the savings claimed by manufacturers, especially when residents are switched away from the Economy 7 tariff to more expensive daytime rates. One organisation commented that unexpected problems that occur during a project are not covered by the funding and are costly to the business.

4.5 Tenant Engagement

Energy advice information is delivered in a variety of ways and different combinations of dissemination are used by the respondents. This included more general information on websites, through social media, newsletters and rent statement inserts. More targeted advice was given through home visits, coffee mornings, resident training courses and workshops. One respondent found that energy advice that is given peer to peer was well received following the training of some volunteer residents. Front line staff in one organisation was given access to e-learning and staffs attend resident's meetings to raise awareness. Another lends electricity monitors to their residents. One organisation noted that they have encountered difficulties getting residents involved in energy efficiency initiatives. Another respondent mentioned that advice given to tenants moving into retrofitted properties, where new technology were installed, was not consistent and was likely to dependent upon which officer was involved and whether written instructions are left with the tenant. Tenants that had air source heat pumps installed were found to need very specific instructions as the operating criteria were so very different from what they were used to.

Tenant involvement and understanding was considered by the respondents to be key in retrofit projects. One of the respondents commented that the transition is to be made easy for residents and show casing retrofits is essential.

5. Proposed Framework

In the light of the foregoing, a conceptual framework is hereby proposed for the effective replication of retrofit projects. This will facilitate the implementation of efficient retrofit projects in the UK and across the EU (Bio Intelligence Service, 2013). Evidence suggests that coherent and well-designed schemes are exemplars that offer a very high potential of successful replication with the appropriate modifications and qualifications (Bosseboeuf, D, 2012). It was based on these concepts that a conceptual framework which incorporates the major strands of the outcomes of this research (See Figure 1). The process begins with an identification of the retrofits needs that pertain to a development and also an assessment of relevant successful exemplars (Oliveira et al, 2014; Chrobak et al, 2014). Many times these vary from property to property. However, a mass housing scheme would benefit from a scaled version of a particular programme. A strategy should thus be proposed if none exists and also the use of stock database management can ensue. This will entail the use of various database management systems that will facilitate improved energy performance of the housing stock. These will lead to the estimation of resource requirements especially costs and the cash flow requirements. Depending on the funding available, the technical and delivery needs of each component of the scheme can then be assessed (Audenaert et al, 2014). For sustainability, the tenant engagement needs should also be assessed and incorporated into the programme of development in order to finalize the design and implementation of the new scheme. It is envisaged that future work on this development will include a testing of the proposed framework by Social Housing Providers. In doing so, specific issues and tools experienced can be incorporated using the evidence reviewed in this research and also those more specific to different schemes. Such work may also include the development of a more interactive toolkit that can be used as a decision support tools for the management of Social Housing Retrofit projects.

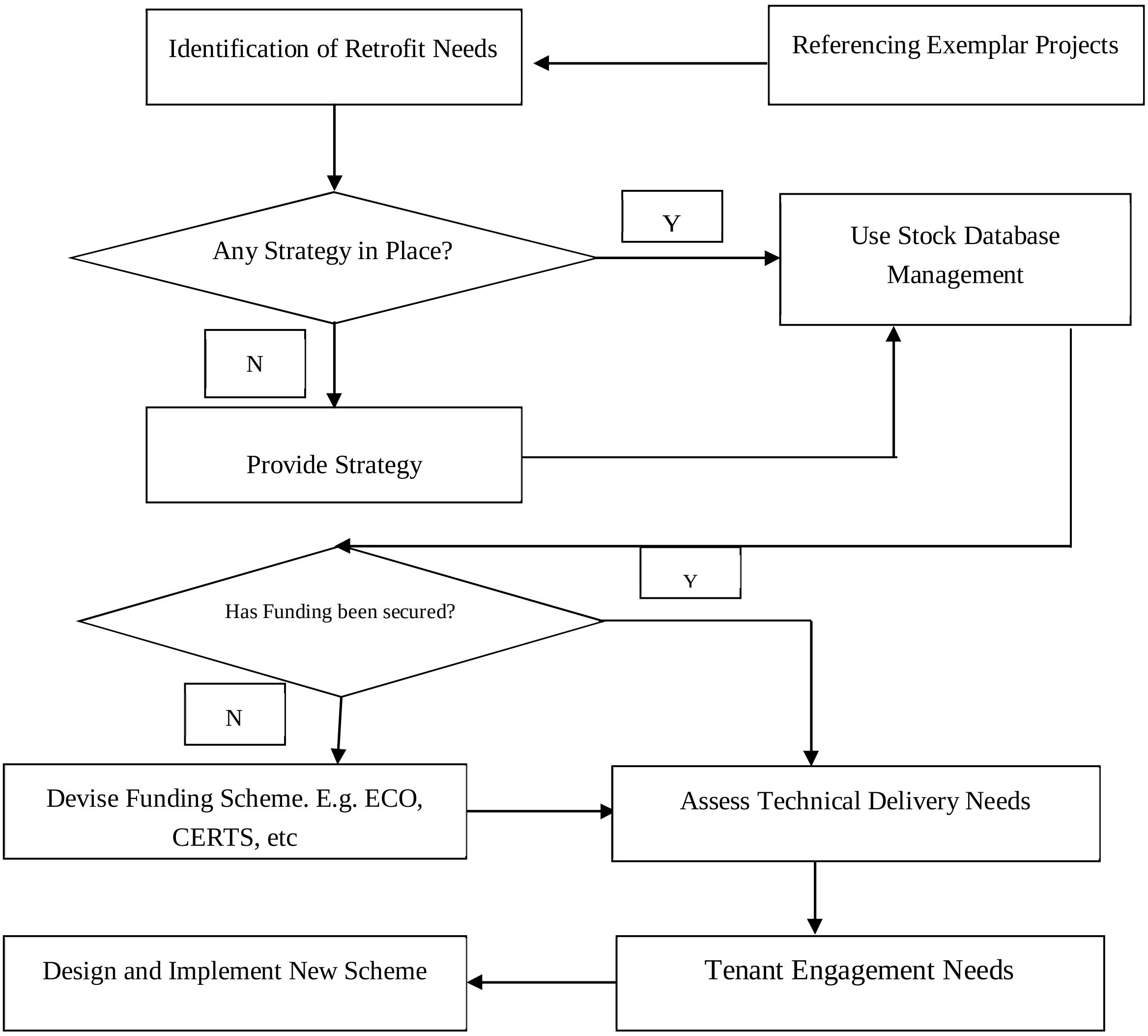

Figure 1: Proposed framework for the design and implementation of retrofit schemes

6. Conclusions and Recommendations

In many European countries, over the last few years, there has been a significant concern in retrofitting of buildings in order to make the buildings more thermally efficient and sustainable. Building energy efficient houses and retrofitting the existing housing stock represent a sustainable way of tackling fuel poverty, and, moreover, with increased social and financial value. To become sustainable, however, the economy has to be based on renewable energy and high resource efficiency and a sustainable approach to the retrofit of the buildings.

This paper aimed to: propose a framework model for sustainable retrofit of housing stock. The work entailed a review of the current position of Registered Social Landlords (RSL's) in the UK West Midlands with regard to the implementation of greenhouse gas emissions reduction in their housing stocks and subsequently presented the exemplification of the successes achieved so far in the retrofit sector after which the conceptual framework model sustainable retrofit of houses was proposed.

It was recommended that strategy and planning, housing stock data, funding, technical and delivery and tenant engagement are essential considerations in the development of sustainable retrofit solution. Future work will entail the development of the conceptual model into a fully - fledged model to ensure that the sustainable solution it offers is properly articulated and validated.

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The effectiveness of the Last Planner System in New Zealand construction industry: Towards an empirical justification

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Abstract

Productivity improvement has been a major initiative of the New Zealand construction industry. Currently the construction sector strives to increase productivity by 20% in 2020. Since 2009 an increasing number of construction organisations have implemented lean construction practices in an attempt to improve their project delivery. These lean practitioners have implemented the Last Planner System (LPS) as a production planning and control system to achieve project goals. Most LPS users have reported satisfactory results from their implementation, however, there is a need to provide empirical support to these claims. This study investigates the usefulness of LPS implementation amongst construction industry users in New Zealand. It determines from the study the level of LPS implementation and provides empirical evidence of the benefits of its implementation in New Zealand. A survey of practitioners' viewpoints is collated using an online survey portal. The data is analysed descriptively and quantitatively to provide empirical evidence of LPS benefits. The study finds that there are some few challenges needed to be overcome within construction organisations before fuller benefits of LPS can be realised.

Keywords: Construction productivity, Last planner system, New Zealand

1. Introduction

There are performance issues connected with the execution of construction projects. Most of the issues are practical requiring deeper understanding as we seek solutions to them (Love, Holt & Li, 202; Wing, Raftery & Walker, 1998). Management of projects in the construction industry can be challenging due to the complex and fragmented character of the industry. Furthermore, poor project management is suggested by Alsehaimi, Tzortzopoulos, & Koskela (2009) as a contributory factor to construction project performance issues. Therefore innovative management approaches have become essential to mitigating construction performance challenges. Subsequently an approach that is commonly described in literature is the use of Lean construction. Other management and research efforts have been suboptimal and tend to be descriptive and explanatory (Koskela, 2008), rather than being practical.

Therefore, central to project performance is the concept of lean construction. Lean construction is a new paradigm that has evolved in response to challenges experienced in traditional management approaches. Within this paradigm, the Last Planner System (LPS) emerged as a tool with special focus on reducing the negative impacts of variability and increasing reliability of workflow for production planning and control (Alarcón & Cruz, 1997; Ballard, Hamzeh, & Tommelein, 2007; Ballard & Howell, 1994; Ballard & Howell, 2003; González, Alarcón, & Mundaca, 2008).

Review of related studies show that in the last decade, construction industries around the world have endeavoured to implement Lean Construction principles and the LPS on their projects. There have been studies using experimental, action research, and empirical methodologies to determine the implementation of LPS and other lean techniques in various perspectives. Examples are studies that assess the effectiveness of the new paradigm (Alarcón, Diethelm, Rojo, & Calderon, 2005), develop strategies and support tools (Alarcón et al., 2005), improve construction performance (Alarcón et al., 2005), and adopt new improvement approaches to the construction sector (Bertelsen, 2002; Hamzeh, 2009). However there is little evidence of the practical implementation of the LPS in New Zealand and of its effectiveness in addressing construction industry problems. Therefore, the current study addresses this knowledge gap by providing empirical justification of the implementation of LPS. The main objective of the study is to determine how LPS has been used among NZ construction organizations toward supporting the current initiatives for 20% increase in productivity by 2020 in New Zealand.

To pursue this objective, an online survey was administered to LPS users in New Zealand and the results analysed. The study provides some empirical justification for the use and implementation of LPS amongst construction organisations in New Zealand.

2. Historical background to Lean Construction and Last Planner System

Measuring productivity and performance issues, enable Managers to identify where and how improvement approaches should be applied in projects. Performance measurement is vital to project management as it addresses a wide range of project management aspects including improving management and control, enhancing middle management functionality, reducing urgent procurement requests, and shrinking project schedules (Alarcón et al., 2005). However accurate measurement of performance by construction organisations is challenging. Quantitative and qualitative methods using performance indicators such as man-power productivity, cost factors, construction speed, and schedule reduction are reported in Alarcón et al. (2005). Value realisation is a significant measure of performance, as suggested by Ballard and Howell (2004), wherein value is provided when customers are enabled to accomplish their purposes for executing projects.

The seminal work of Ballard (1994); Ballard and Howell (1994); Howell and Ballard (1994a, 1994b), have advanced knowledge on work performance within construction projects. Their studies of workflow variability and measuring its variation in the form of plan failure rate on weekly work plan's assignment have been commended. The study results reveal that most construction plan failures are within contractors' control. Workflow variability was found to be persistent and routine rather being spasmodic and small.

Furthermore, Green, Fernie, and Weller (2005); Hopp and Spearman (2008); Spearman and Hopp (1996); Vrijhoef and Koskela (2000) have observed that most performance issues in the construction industry are the consequences of entrenched traditional practices (i.e. myopic view of project parties, high levels of various forms of wastes, low levels of trust, lack of communication and transparency, low customer satisfaction, and high variability). Hence the need for a lean construction approach that advocates collaborative production planning and execution with emphasis on workflow reliability, maximising value for customers, and minimising waste (Ballard & Howell, 1998).

As a major tool in lean construction, the LPS was developed as a tool for the management of construction processes, and continuous monitoring of its planning efficiency (Alsehaimi et al., 2009). The LPS was introduced by Ballard (1993) to members of IGLC-1 (1st meeting of the International Group for Lean Construction). The principles of the LPS were developed at IGLC-2 in 1994 (Ballard, 1994), and further elaborated at IGLC-5 in 1997 (Ballard, 1997). By IGLC-5, the LPS was complete and ready to be introduced broadly (Bertelsen & Nielsen, 1997). The LPS is composed of some integrated components such as the master plan, phase plan, lookahead plan, weekly plan, and planned percent complete (PPC) determination. The adherents of LPS claim that systematic implementation of LPS can bring many advantages and increase benefits to both construction management practice and planning practice (Alsehaimi et al., 2009). Thus LPS has become synonymous to lean construction practice to improve construction projects' performance. More detailed description of the LPS is provided in the following subheadings.

2.1 Last Planner System (LPS)

As earlier indicated the LPS is a production planning and control tool developed based on Lean principles (Kim, 2014). The general objective of lean principles is to support management through the reduction of performance variabilities, enhanced reliability, and continuous monitoring and improvement of project performance. LPS ensures constant stabilisation of workflow and improves productivity (Christoffersen, Sander & Bojsen Jensen, 2001; Hamzeh & Langerud 2011).

It has been suggested that growth in project planning software caused the loss of short term planning for construction projects (Harris & McCaffer, 2006). LPS was developed to address reliability issues at the weekly work plan level, while aiming to cover full planning and schedule development complementary to Master Schedules. Main components of the LPS are: Master plan, Phase planning, Lookahead planning, and Weekly work plan (Mossman, 2009; Koskela, Stratton, & Koskenvesa, 2010). Recent research suggested another phase to the LPS structure: 'Learning', that measures PPC, analyses root causes for non-completions and develops the lessons learned to successfully re-engage incomplete tasks (The Last Planner, 2013)

LPS implementation have been the subject of several studies. Alarcón et al. (2005) studied the implementation of LPS and other lean techniques in over 100 construction projects (between 2000 and 2005). The issues investigated include: 1/ improvements in percent of planned assignment completed, 2/ influence on the level of implementation on project PPC, 3/ Causes for non-completion in projects, 4/ variability of PPC measures, 5/ the impact of IT support on PPC performance, 6/ performance improvements, and 7/ implementation barriers. The findings from Alarcón et al. (2005) study have been used to develop an implementation strategy which includes development of systematic training and research action, proactive interaction between key project organisations, collaboration among companies and a constant search for new ways to improve LPS implementation. Projects may implement LPS in different levels according to the elements of LPS: 1/ at a basic level, LPS can be implemented with emphasis on the weekly work plan and informal Lookahead planning process, and 2/ implementing the LPS using formal Lookahead planning processes. Alarcón et al. (2005) found another situation where formal workable backlog and learning processes had been used in the implementation of LPS. A likely conclusion is that each level of implementation brings about different benefits to projects.

Kim (2014) suggests various benefits attributable to LPS implementation on construction projects. A shortlist would include: 1/ identifying the main reasons for project variances (incomplete prerequisite work, bad planning, and design issues), 2/ achieving continuous improvement through PPC measurement, 3/ successful completion of projects through weekly pull-planning by project teams, and 4/ mitigating problems originated by the project structure. Further benefits include: 1/ realisability of promises which team member made to each other and to the project, 2/ identification of the causes of broken promises and variances through weekly work plan analysis, and 3/ avoidance of repetitive project shortcomings.

In spite of the benefits outlined above, LPS implementation seems suboptimal in different countries and in respective organisations. Alarcón, Diethelm and Rojo (2002) and Alarcón et al. (2005) had identified some barriers to the full implementation of LPS in organisations. These include: 1/ low understanding of the concept of LPS, 2/ low utilisation of the different elements of LPS, 3/ inadequate administration of the necessary information to generate a "learning cycle" and to take corrective actions, 4/ weak communication and transparency among practitioners, and

5/ lack of integration of the production chain. Porwal, Fernández-Solís, Lavy and Rybkowski (2010) have also suggested implementation challenges at industry-level which inhibit the adoption of LPS in industry.

There is evidence to suggest culturally-based factors impact LPS implementation (Alsehaimi et al., 2009). According to Alsehaimi et al, lengthy approval processes by client organisations due to bureaucracy, poor commitment and attitude to timeliness, were unique to Middle Eastern countries. In New Zealand, Fuemana, Puolitaiva and Davies (2013), conclude that the low uptake of LPS across all project types impacts on the full realisation of its benefits. Fuemana et al. (2013) indicate that collaboration amongst project participants underlies productive goals realisable from LPS implementation. They went further to recommend the adoption of other Lean methods and integrated procurement methods to the New Zealand construction industry, as a way of improving collaborative workings.

3. Study Approach

To investigate the effectiveness of the LPS within the construction industry in New Zealand, the study first identified LPS practitioners from information held by Constructing Excellence in New Zealand (http://www.constructing.co.nz/). Lean construction had been offered to the NZ construction industry since 2009, and awareness of LPS as a production planning and control tool is gaining good traction. Although, most of the LPS users have reported satisfactory results, there is a need to provide empirical support to these claims. To do this, the study collected the required data through an online survey (survey monkey) administered to LPS practitioners in New Zealand. The survey contain five (5) key sections including: Demographic information, status of LPS in New Zealand, LPS effectiveness within organisations, barriers to LPS implementation, and benefits of LPS to construction projects. The questions asked were generally in the form of scales, rankings, and open ended types to provide responses used for the analyses. An outline of the demographic information collected for this study is explained in the following paragraph.

There were several related questions covering: job position, years of construction experience and years of professional experience in LPS methodology. The question on job position gives an overview of the role of the study participants. The purpose of the question is to know the background of the participants, which will allow further understanding of the nature of their responses. The results clearly indicates that majority of the participants (66.7%) operate at project management level while 11% are field supervisors. A total of 22% of the participants indicated that they hold other positions that were not listed in the questionnaire. Another question within the demography section relates to the years of construction experience of the participants. The result shows that significant percentage (70%) of the participants have over ten years of construction project experience with only 10% indicating between five to ten years. 20% of the participants have between two to five years of work experience. It is important to note that none of the participants had less than two years of experience within the construction industry.

Participants were further asked to indicate their years of professional experience in LPS practice. Majority of the participants (80%) have between two to five years of experience in the use and implementation of LPS within their organisations. An equal number of participants (10%) have between zero to two years and five to ten years respectively. Comparing these two questions on construction experience and professional experience in LPS practice, it is reasonable to conclude that while most people had a high level of experience in construction project management, lower numbers had good levels of experience on the use of LPS. This is not unusual considering that LPS has only been introduced into New Zealand fairly recently.

The demographic information summarised above suggests that the survey covered the population targeted for the study. The results appear to show that the participants selected for this study are reliable for the investigation of the effectiveness of LPS within the construction industry in New Zealand.

The results of the survey are presented in the next section using simple interpretive and descriptive methods. This is desired to provide an easy read, be more understandable and communicative.

4. Results and Discussion

4.1 LPS status in New Zealand

A summary of the status of LPS implementation in New Zealand is s obtained from study participants is tabulated (see Table 1). The information shows that a significant percentage (33%) have only recently implemented LPS on their projects. Generally practitioners received both external and internal support in the form of: training course, workshops and periodic meetings on the use of the LPS. There is the general consensus that the support received had positively influenced implementation of LPS. Although responding to the level of popularity of LPS within the construction industry, 58% of study participants had indicated that LPS is not yet widespread.

A significant percentage (29%) of study participants had implemented LPS on projects worth over $100 Million followed by 14% on projects worth between $5-20 Million. More than 50% of study participants have applied LPS in all of their projects regardless of the size of the projects (see table 3). Furthermore the survey results show that LPS was mostly implemented during the construction phase (75%) compared to other phases such as: project definition, design, and prefabrication. Primavera is the most common software used for preparing and presenting master schedules by the study participants, while MS Excel was preferred for preparing and presenting weekly schedules. As is observed from Table 1, Primavera, MS Project and MS Excel were used in preparing and presenting Lookahead schedules.

Table 1: Summary of LPS status

Demographic Questions	*Answer Options*	*Response Percent*	*Response Count*
How long ago did your organisation begin implementing the last planner system (LPS)?	*1 yr*	*8.3%*	*1*
	2 yrs	*33.3%*	*4*
	3 yrs	*16.7%*	*2*
	4 yrs	*25.0%*	*3*
	Over 5 yrs	*16.7%*	*2*
How much do you feel LPS implementation is widespread within the NZ construction industry?	*Poor*	*16.7%*	*2*
	Below average	*58.3%*	*7*
	Average	*25.0%*	*3*
	Above Average	*0.0%*	*0*
	Excellent	*0.0%*	*0*
On what scale of construction projects do you feel the LPS can be best implemented?	*Below $5Million*	*0.0%*	*0*
	$5 - 20 Million	*0.0%*	*0*
	$20 - 100 Million	*0.0%*	*0*
	Over $100 Million	*0.0%*	*0*
	All Projects	*100.0%*	*12*
At what phase of construction projects do you normally implement LPS in your organisation?	*Project definition*	*0.0%*	*0*
	Design	*16.7%*	*2*
	Prefabrication	*8.3%*	*1*
	Construction	*75.0%*	*9*
Software used for the following:	*MS Project*	*Primavera*	*MS Excel*
Preparing and presenting the master schedule (n=11)	*3*	*5*	*4*
For preparing and presenting the Lookahead schedule (n=11)	*3*	*3*	*8*
For preparing and presenting the weekly schedule (n=11)	*1*	*2*	*10*

4.2 LPS Implementation on projects

To determine the main driver for LPS implementation on construction projects in New Zealand, study participants were required to indicate amongst a set of drivers, what had been their objective for implementing LPS. The result is tabulated in Table 2 and it shows that the major driver (100% response) for LPS implementation was the need for proper time management and controlling delays, followed by ‘reducing process/production waste’ etc. The result show that project owners had no influence on the implementation of LPS in projects in New Zealand.

Table 2: Main drivers of LPS implementation

S/No	*Drivers (re-ordered)*	*No. of Responses*	*Percentage Response*
1	*Proper time management & controlling delays*	*12*	*100*
2	*Reducing process/production waste*	*10*	*83*
3	*Safety improvement and control*	*7*	*58*
4	*To be ahead of industry on the use of LPS*	*3*	*25*
5	*To be responsive to industry trends*	*1*	*8.5*
6	*In response to Client requirements*	*0*	*0*

The study participants were required to rate the effectiveness of the LPS on their projects. Most of the participants had rated effectiveness of the LPS as above average and excellent, 73% and 27% respectively. This result would suggest that LPS would influence PPC on their respective projects. Considering that Alarcon et al (2005) had found significant relationship between LPS implementation and planned project completion rates (PPC).

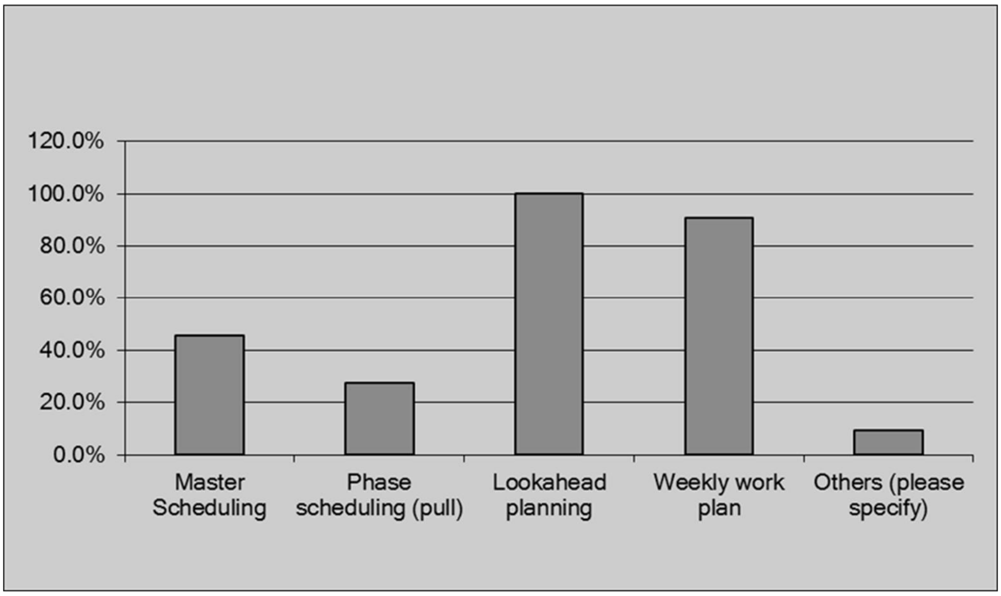

Figure 1. Components of LPS included in planning processes

Furthermore, to identify how New Zealand uses the LPS, study participants were asked to specify which component(s) of LPS is/are included in their planning processes. With this, the level of importance of the components would be identified. The responses are presented in bar chart form in Figure 1. Generally all the components of the LPS are included in their planning processes. However 'phase scheduling' was the least ranked (27%) in spite of its primacy in LPS implementation. Phase scheduling is vital to projects as it can assure the completion of the right work at the right time, and consequently the achievement of project goals (Ballard 2000b). Phase scheduling divides up the master plan into various phases toward developing more detailed work plans and providing the project team with more clear goals. Therefore phase scheduling is the bridge between master plans and Lookahead plans.

To gain a better understanding of the use of phase scheduling, participants were asked to indicate at which project phase it was applied. The study found that phase scheduling was used mostly at the structure phase (67%), followed by more than 50% during foundation and design phases, and 25% to 33% at project definition and closeout phases respectively.

Another section of the survey was designed to ascertain how Lookahead plans were developed during LPS implementation. Lookahead planning allows the breakdown of project activities into operational levels, where constraints are identified, responsibilities assigned and tasks made ready. 73% of the study participants indicated that their Lookahead plans were developed by breaking down master schedule activities. As opposed to 18% that use the phase schedule activities directly. Further, the study participants indicated that Superintendents, Project Engineers, Foremen and Project Managers (in that order) were responsible for the preparation of Lookahead schedules. As noted by Laufer and Tucker (1988), the extent and manner in which users were involved in LPS decision making process can affect the success of the implementation of the tool. The results of the current study would suggest that the level of participation of project participants is adequate in LPS implementation.

Finally, study participants were required to indicate the level of communication and integration that exists within their current project partnerships. The results indicate that the level of communication and transparency among participants vary from average to above average, where communication was ranked above average by 73% of LPS users. The level of integration among project participant was rated similarly from average to above average, 63%, and 27% respectively. Another aspect of the survey desired to determine to what extent knowledge sharing and communication benefitted LPS implementation among New Zealand users. The results showed that 36% of the participants are in strong agreement that knowledge sharing can improve LPS implementation, where 45% are agree and less than 10% are strongly disagree.

Collaboration and active participation of multiple parties is key for the successful implementation of project plans (Laufer & Tucker, 1988). Chinowsky, Diekmann, and Galotti (2008) argue that the management of projects could be considered as the management of social collaborations. Chinowsky et al. (2008) shows through a developed social network model, the importance of communication among project networks, and that through the clarification of roles, high performance results could be realised on projects. Recognition of individual roles through active communication and trust provides individuals with more knowledge of each other's needs and constraints. Consequently, project teams become more knowledgeable and in a position to deliver better performance over time. Collaboration of individuals is a vital part of LPS implementation that differentiates it from traditional planning methods.

5. Conclusions

The objective of the current study was to investigate the effectiveness of the LPS within the construction industry in New Zealand. The study had used a survey instrument administered online to elicit response from LPS practitioners in New Zealand. The results obtained were analysed simply, to provide some empirical justification of progresses made in LPS adoption as a planning and control tool for projects.

The study found a good level of implementation of the LPS in New Zealand. The main components and constituents of LPS as a planning tool are understood and applied by a significant proportion of practitioners. There are reasons to suggest from the views presented that the benefits for LPS implementation are being realised on construction projects. Project participants are aware of their roles and responsibilities towards LPS adoption and a good level of collaboration exist between project participants. It is therefore safe to conclude in the current study, that LPS implementation have been effective amongst practitioners in New Zealand.

Towards more empirical investigations the study suggests that performance data (e.g. PPC) could be obtained from LPS practitioners. This was a limitation of the current study. Also it would be useful to collect information from project owners for whom ultimate benefits are expected. Information on how well their project deliverables were achieved using LPS practitioners as compared to other projects may provide further evidence of the effectiveness of the LPS tool.

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Improving Transition from Engineering to Construction Using a Project Execution Model and BIM

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Abstract

Usually engineering takes place during a given time period, followed by construction. Shorter time from project start-up to delivery gives higher parallelism between project phases. Construction pushed in parallel with engineering places greater demands on the actors. Parallelism calls for increased interaction between engineering and construction. This paper assesses how transition from engineering to construction can be improved with the use of a project execution model (PEM) and utilization of building information models (BIM). Findings are presented in three interdependent dimensions; process, people and technology. Research is based on case studies of major oil and gas projects, where data is gathered through Kvaerner, a Norwegian EPC (engineering, procurement and construction) contractor. Primary focus is on EPC contracts, where engineering and procurement is subcontracted, which corresponds to design-build contracts in the construction industry. The EPC contractor will build in a sequence that is cost effective for them, while the engineering subcontractor prefers to think in a totality until engineering is finished. Parallelism challenge this. To improve transition, it is important with a correlation between how one conducts engineering and how one plan to build. How can deliveries from the engineering subcontractor be produced in an order that fits into the desired build sequence to the contractor? The paper portrays how an alternative contract model is used, how common drivers are established and how the use of a 3D design environment, which corresponds to BIM in the construction industry, is rearranged to support this. "Right the first time" is when a certain quality level is achieved to a certain point in time. Using a PEM supports this by defining requirements on each milestone that must be achieved to reach the desired quality level. If some disciplines are behind and some ahead of a milestone, it will not be "right the first time". How can the engineering subcontractor satisfy milestone requirements to the contractor and deliver “right the first time”? The paper shows how the engineering subcontractor, with certain additions and adjustments to their milestones, can support this. The integrated design and delivery solutions (IDDS) approach relate the findings towards the construction industry.

Keywords: building information model, build sequence, joint venture, milestone requirements, project execution model

1. Introduction

In current practice, engineering and construction phases are not well integrated (Luth et al., 2013), and usually engineering takes place at given period of time, followed by construction. In offshore projects, executed at EPC (engineering, procurement and construction) contracts, construction is often pushed in parallel with engineering. EPC contracts corresponds to design-build contracts in the construction industry, where the engineering and construction are contracted by a single contractor. Influence and inclusion of contractors in engineering in design-build contracts is important since contractors can receive deliveries based on their expertise in buildings solutions (Berard and Karlshoej, 2012). This involves grouping activities into work packages so that construction can start before the design phase is complete (Bogus et al., 2011). To improve transition, it is important that there is a correlation between how one conducts engineering and how one plan to build. When working in parallel, the contractor starts at a certain place and build, and that is the place engineering should have drawings and materials first. The paper assesses how deliveries from the engineering subcontractor can be produced in an order that fits into the desired build sequence to the contractor. This can be fulfilled using a project execution model[1] (PEM), an alternative contract model, common drivers for the project team, together with an altered structure of a 3D design environment[2]. A 3D design environment corresponds to a building information model[3] (BIM) in the construction industry. The paper investigates how the engineering subcontractor can satisfy the milestone requirements to the contractor and deliver "right the first time". The engineering subcontractor can accomplish this by adjusting their milestone requirements in the design phase. Primary focus is on EPC contracts, where engineering and procurement is subcontracted.

The findings in this paper are divided into three interdependent dimensions; process, people and technology. Process, people and technology are identified as core organizational issues (Sacks et al., 2010) or categories used to classify challenges and benefits in an integrated design process (Rekola et al., 2010). To succeed requires a holistic approach, where all three dimensions are mutual dependent of each other. The first part, process, looks closer at parallelism in EPC contracts and how an engineering subcontractor can support this by adapting to a desired build sequence to the EPC contractor. This requires "right the first time" deliveries, with right information at the right time, and milestone coordination between the engineering subcontractor and EPC contractor. To accomplish this requires focus on the second dimension, people, which identifies common incentives and drivers. This includes the possibilities of establishing a joint

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[1] A project execution model (PEM) reflects a logic sequence in critical project activities where progress and quality requirements are aligned at significant milestones. The objective of a PEM is to secure predictability in project execution using a standard methodology well known to the team Kvaerner, 2012b).

[2] A 3D design environment refers to a multi-discipline and object based 3D design integrated with a number of information systems that serves as the main source of information for engineering and construction (Kvaerner, 2012a).

[3] A building information model (BIM) can be defined as a digital representation of physical and functional characteristics of a facility, and a shared knowledge resource for information about a facility that forms a reliable basis for decisions during its life cycle (NBIMS, 2007) .

venture between the engineering subcontractor and EPC contractor, identify drivers to secure alignment to common goals and mobilize new project teams. This also requires focus on the last dimension, technology, which investigates how a 3D design environment (hereafter called BIM) can be utilized to support a desired build sequence to the EPC contractor.

The integrated design and delivery solutions (IDDS) approach (Owen et al., 2009) is applied to discuss whether the findings on process, people and technology are relevant towards the construction industry. The IDDS approach is used to elucidate that these findings are factors that should support performance improvement in the construction industry. The construction industry is under pressure to reduce project delivery times and costs despite increased complexities in today's projects (Jaafari, 1997, Bogus et al., 2005). The approach challenges traditional industry structures and contractual processes, which corresponds with the research presented in this paper.

2. Research method

The research is qualitative and based on case studies. Data is gathered from three case projects in the oil and gas industry through Kvaerner, a Norwegian EPC (engineering, procurement, construction) contractor, executed as EPC contracts. The primary case project has been the topside for one of four platforms of the Johan Sverdrup field on the Norwegian continental shelf, which started detailed engineering in 2015. Secondary case projects have been the topsides for the Edvard Grieg platform and the Eldfisk platform, delivered in 2014. All three consists of a combined living quarter and utility module. Data collection has been conducted by the author through interviews, supplemented with relevant company and project documentation. Data has primarily been gathered from 8 semi-structured interviews, with the use of interview guides, from March 2013 to October 2015. Four of the interviews, had main focus on transition between engineering and construction, three on the use of PEM, and the last on the use of BIM. The average length of the interviews has been 1 hour 47 minutes. Each interview has been conducted with one to two interviewees in key positions in the cases, including Project Manager, Information Manager (responsible for all aspects of information handling in the project), and Head of PEM. The stepwise-deductive-inductive (SDI) method (Tjora, 2012) has been applied to analyze the collected data. The principle of this method is to work stepwise from data to concepts or theories (inductive) and verify these theoretically to the more empirically (deductive). The collected data has been transcribed and used to develop “empiric-close” coding that reflects the contents of the text. The codes have been sorted into larger groups of themes, called categories, and used as a basis to develop concepts that capture central characteristics of observations and findings. This is similar to what Halkier (2011) has described as “category zooming”, as a way to generalize qualitative data. This is a three-step process, from coding and categorizing, through tracing of systematic relationships between categories and finally aiming for conceptualizing.

3. Process

3.1 Parallelism and build sequence

According to Lee et al. (2005), parallelism, or concurrent engineering and construction, is gaining popularity due to the increased demand for shorter time frame of projects. In Kvaerner, parallelism gives greater challenges than if construction can be deferred until after the engineering has completed. The extent of the challenge depends on client's requirements to the contractor. The client sets the scene in terms of how complex the process becomes, by setting the time frame from the contract is signed to delivery date. Longer time frame gives more predictability between the phases. Shorter time frame gives a higher degree of parallelism between the phases. The more parallelism there is in a project, the greater demands are put on the participants in that they know what the sequence and the quality requirements of the project is. This is similar to what Succar (2009) has defined as "BIM stage 2", where engineering and construction is in parallel, and is driven by construction providing design-related services, and engineering increasingly adding construction and procurement information into their BIM. Integration of engineering and construction is not new, and similar terms and techniques have been used to respond to the time and cost pressures in projects (Jaafari, 1997). Parallelism is similar to concurrent engineering (CE), where the aim is to reduce the total delivery time and cost of a project by overlapping activities that are normally performed in a sequence (Bogus et al., 2011). In the last decade, the concept of integrated concurrent engineering (ICE) have also been introduced, where the focus is to "speed up the process by increasing task parallelism and reducing response latency and lag, which decelerate legacy multi-disciplinary construction engineering processes" (Alhava et al., 2015).

Engineering influences all project phases. In Kvaerner's PEM, the design phase consists of three stages with corresponding milestones (M2A, M2B and M2C). During these stages, the BIM is developed to a quality level where the design and all interfaces (between disciplines) are frozen. When the last milestone, M2C ("Global design complete"), is reached, the the BIM should have reached a defined quality level so that the engineering subcontractor can start issuing drawings, and Kvaerner can start construction (see principle in Figure 1).

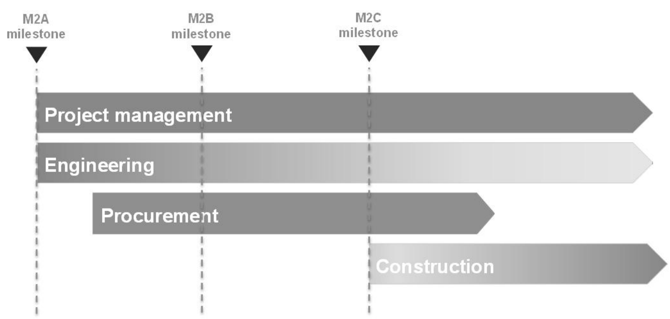

Figure 1 Parallelism between E, P and C (Kvaerner, 2013)

With parallelism in EPC contracts, it is important to be aligned in the sense that there is a correlation between how one conducts engineering and how one plans to build. A common challenge is that Kvaerner will build in a sequence, which is cost effective for them, while the engineering subcontractor would prefer to think in a totality until design is complete. In order to get drawings and materials at the right time when construction is pushed in parallel with engineering, Kvaerner has made a build sequence that engineering and procurement must know of, because they will need to deliver according to it. The ambition to Kvaerner is that engineering is conducted in an order that fits into the build sequence that gives the fewest possible hours in the workshop. The dilemma is that the engineering subcontractor do not know Kvaerner's build sequence, and Kvaerner does not know how the engineering subcontractor conducts their engineering deliveries. Kvaerner’s PEM can describe how it is done and at what status deliveries should be on each milestone, but Kvaerner has to tell the engineering subcontractor what they need to deliver. Kvaerner has therefore spent a lot of time with the engineering subcontractor to explain how Kvaerner's build sequence is and what they require of engineering deliveries, including drawings, materials as well as equipment components, to support this, so that the engineering subcontractor can adapt its engineering deliveries to Kvaerner's build sequence.

3.2 “Right the first time”

According to Kvaerner, the various input factors must have come to a certain level in quality and progress, on a given milestone. If someone goes too far and others too short, it will not be "right the first time". In the design phase, all disciplines should know at any given point in time how far they should have come with their design. If a discipline has come too short and not fulfilled the requirements at a milestone, they can influence the others when they are finished. If a discipline has gone too far, the discipline might need to redo much of what is done while the other catches up, because the discipline have made assumptions that are not met. Similarly, Lee et al. (2005) has stated that successor activities that have to start without complete information from predecessor activities, may lead to a chain of wrong decisions in other related activities. Whoever succeeds to optimize the process best will be the cheapest and fastest.

"Right the first time" is doing it right the first time and not having to do it over again, and is something Kvaerner strive for. Kvaerner’s PEM supports "right the first time" by defining milestone requirements and associated discipline checklists to all stages in each project phase. In each project, the client will have contractual milestones. The milestones defined by Kvaerner in their PEM are distributed as parallel as possible with the contractual milestones to the client, so that it is consistency between these. It is also to avoid communicating a different message to the project team in every project. When the final milestone in the design phase, M2C, is reached, the objects in the BIM are at a quality level that one can begin issuing drawings for construction. The design is frozen, and should by definition not be changed. At the M2C milestone, engineering should have fulfilled the milestone requirements to satisfy Kvaerner's build sequence, so that Kvaerner safely can start construction. This is similar to what Schade et al. (2011) identifies as a quality gate, where design maturity is synchronized and evaluated, and reflects the detailing of the design, in a concurrent engineering approach. When Kvaerner conducts projects with engineering and procurement on a subcontract, both parties has their own PEM. Like Kvaerner, the engineering subcontractor has organized their work in a way where they have milestone requirements and associated checklists (for each discipline). To make sure the engineering subcontractor has come as far as required on the last milestone to start deliveries to construction, their milestone is checked against Kvaerner’s milestone (M2C). The methodology is based on the fact that the requirements that Kvaerner has made for the last milestone in the design phase (M2C), in terms of what the disciplines should deliver and to what quality level, is adapted to Kvaerner's build sequence. The requirements for each discipline at the M2C milestone and the corresponding milestone to the engineering subcontractor is compared through a GAP analysis, to see if the engineering subcontractor are close to fulfilling the requirements at the M2C milestone. They identify the gaps between the two milestones, and go through the checklists for all relevant disciplines, and look at where they need to increase the requirements. Kvaerner wants the engineering subcontractor to use their own PEM, but with certain milestone additions and adjustments, to satisfy Kvaerner’s build sequence. The main reason for this is that the barriers for adapting new milestone requirements are lower when using a familiar PEM. If the engineering subcontractor meet the requirements in the last milestone in the design phase, it is very likely that Kvaerner's build sequence can be used.

4. People

How do you merge engineering and procurement with construction? According to Kvaerner, when working as an EPC contractor with control over both engineering, procurement and construction, rational considerations can be made in terms of how spending and earnings should be, in order to optimize the bottom line. It is the company that determines the optimal sequence and the desired order of deliveries from engineering, procurement and construction in each project. When there are two separate companies, the interests of one may not always easy favored by the other because of different economic drivers. With engineering and procurement on a subcontract, there can be different contract models between the EPC contractor and the engineering subcontractor. As soon as these two parties have a contract regime that exist between them, the engineering subcontractor will work according to their drivers - that often do not correspond with the drivers the EPC contractor has. It is typically the contractual terms to the engineering subcontractor that drives them. If they have day penalties on deliveries, or reduced compensation if they spend too many hours, they work according to that. But then it might be that they are not as concerned about whether the quality of the deliveries is 100%. According to Jaafari (1997) each actor in a project tends to manage their own scope in a way that minimizes their own exposure to risks and maximizes their gain, which may lead to divergence of objectives of the parties from project objectives.

According to Kvaerner, the engineering subcontractor can work according to a fixed price or paid per hour with a profit, in a subcontract. They must take responsibility for their deliveries - either through performance milestones or through milestones with day penalties. If drawing quality is too poor, drawings must be recalled and updated on their own expense. A subcontract can work out if the contractor requires defined drawing deliveries, and can set fines or bonuses on deadlines. They can probably agree on a better order of the drawings (in relation to the build sequence). Kvaerner emphasizes that it is important that the contractor and the engineering subcontractor have common drivers related to engineering deliverables. This leads to another variant, a joint venture, where the two parties share a common bottom line. According to Owen et al. (2010), contractors can operate integrated on individual projects, or establish temporary joint ventures, to provide cost, time and delivered quality benefits through more integrated processes. The understanding throughout joint venture is that if the engineering subcontractor (or contractor) do not manage to deliver, there will be no bottom line to share. For Kvaerner this is the most effective, because then they do not need to be as aggressive in trying to follow up the engineering subcontractor as in a traditional subcontract. Then they are partners, both knows what applies, and have the same drivers. In the agreement Kvaerner has made with the engineering subcontractor in the primary case project, the parties have established a joint venture for a joint EPC, where they are "joint and several" responsible. This means in practice that if one part is not performing, it has a consequence for the other. If one part goes bankrupt, then the other part must complete the work the other should have done. They are mutually dependent of both parties performing and they share profits on the bottom line in a percentage distribution. It is a model that better prepare for an improved transition between engineering and construction, because they have a common driver. The engineering subcontractor only get their expenses covered through invoicing, and only get the profits from what is left of the cash balance in the end. This means that the engineers at the engineering subcontractor should be motivated to perform and deliver as planned. If not, they can go from sharing profits to covering deficits afterwards.

It might be that despite establishing a joint venture, the motives for the two partners can be different. It may be so that the engineering subcontractor that works for Kvaerner can lose more on another contract than the contract in question, if they do not make a greater effort. They might choose to withdraw personnel and move over to the project that has greater challenges or that has a greater risk associated with it. The engineering subcontractor that works for Kvaerner can also work for several other construction yards, which has no build sequence, not the same requirements to a build sequence, or does not have the same requirements to a PEM that Kvaerner has, which can make the adoption more challenging to accomplish. In this case they must reach down to every discipline and get them to understand that now they need to satisfy another build sequence, which is another way to deliver on. Kvaerner point out that there are mechanisms that can support this. They can both select key personnel. Both parties must then approve the competence of key personnel that the other deploy into the project. By exchanging CVs on key personnel, they both can be assured that they are putting on experienced and competent personnel, on equal terms. There will be penalties if any of the personnel are withdrawn from the project. This will prevent the ability to juggle too much with personnel and competence. Both parties should feel equally safe for doing the best they can. A key to influence and train engineers is the use of a PEM with common milestone requirements, so that engineering can be executed in a manner that is adapted to Kvaerner's build sequence. Because the bottom line is the main driver, the project team do not need any additional drivers. As long as Kvaerner manage to explain what the requirements are and why the requirements are the way they are, the engineering subcontractor get insight in what is needed to be able to increase the bottom line. To support this, they carry out what they call inductions, which is an introductory package for the engineers as they come aboard the project.

For Kvaerner, success is also related to the competence and experience of the project team. Most project participants bring along experience from the last project – in terms of both methodology, requirements and deliverables. It will always be a challenge to include those who were part of the project last time when an engineering subcontractor mobilizes for a new project together with

Kvaerner. If they repeatedly get more common projects ahead, they can adapt to each other better. Kvaerner has experienced that if they have 70% engineers who have been part of a project team that worked according to the requirements in Kvaerner's PEM, there is a great chance that it goes better in the new project than the last time. If they have 30% engineers who have worked according to the requirements in Kvaerner's PEM and 70% beginners, there is a great chance that the new project will not turn out well. To succeed in future EPC projects, it is important to seek a form of strategic alliance with the preferred engineering subcontractor, and use the same from project to project. Experiences from strategic alliances that Kvaerner has today with engineering subcontractors, indicate that there are virtually no conflicts.

5. Technology

When the engineering subcontractor works in the BIM without the contractor having set the boundaries for the different sections, they work relatively unhindered. Disciplines work with the entire platform, because many of the objects modelled go through several sections. Kvaerner has experienced that to get a discipline to split the model in objects that are going onto to the different sections, when the boundaries are set, is a challenge to accomplish, and increases the complexity, with many interfaces. It is an added cost, and more time consuming, because the discipline must spend time to go in and out of the sections. There is a maximum limit to how much parallelism one can manage in that context. The splitting of the BIM towards fabrication and construction are based on the main areas as defined by the contract. The sub areas, called fabrication assemblies, are defined by Kvaerner to control the parts that are sent out for fabrication. All necessary documentation, including drawings, are related to each fabrication assembly. FAS (fabrication assembly section) express the horizontal area, and FAV (fabrication assembly volume) the volume above. FAS is the first that comes into production. FAV is established when they have added several sections that are finished. Some of the planned activities go towards the area, while some of the activities goes towards the volume. There are certain activities that requires several volumes composed simultaneously. For instance, a cable can not be cut from volume to volume, and must be drawn as one cable. Cable activities are planned against all volumes it goes through A pipe can be split, because it must be welded together.. Piping activities may be connected against each FAV, because they can draw out the pipes and welds between them. Fabrication assemblies are similar to what Jaafari (1997) define as clusters, referring to particular parts of the project. Clusters can include relevant front-end activities, procurement and construction activities. Each cluster can be assigned to a team and executed as an integrated part. Similarly, Luth et al. (2013) states that sequencing knowledge and methods, in addition to construction means, can be incorporated in the BIM, in order to reach a sufficient quality level to produce drawings for construction.

Anumba and Evbuomwan (1997) define the aim of concurrent engineering (CE) to reduce lead times and improve quality and cost by integrating fabrication in design, and maximizing parallelism. When engineering starts it is required that all large and heavy equipment are identified. According to Kvaerner, the disciplines need all design parameters of what they call critical packages (weight, where bolt holes are, where pipes are to be connected, how cables should be plugged in etc.). That is governing because the disciplines need to get this to fit together (the floor needs to support the weight, any rotating equipment must withstand the rotational forces etc.). The bigger and more expensive equipment, the longer time it takes to fabricate. It is therefore important to get this equipment ordered as early as possible, to get the vendor drawings and to get it delivered on time. The sequence of purchase orders is made based on criticality. Kvaerner define criticality in terms of how much equipment (i.e. the information on the equipment) are of importance for the design development, and is categorized from 1 to 3, where 1 is the most demanding equipment ("long lead items") and 3 is the least demanding. Preliminary information of equipment is based on the initial purchase orders and used as important input to the fabrication assemblies. The information is updated when the orders are finalized.

6. Discussion

Are the findings on process, people and technology in this paper relevant towards the construction industry? The IDDS approach, which aims to utilize BIM and make sure that improvements in construction projects are based on a combination of process, people and technology, is used to assess this. IDDS consist of four main elements; collaborative processes, knowledge management, enhanced skills and integrated information and automation systems (Owen et al., 2009). Process, people and technology are closely related and mutually dependent. Findings on process can be related to collaborative processes and knowledge management, where the latter also have a close interface towards people and technology. Findings on people can be related to enhanced skills, while findings on technology can be related to integrated information and automation systems (see illustration in Figure 2). The conditions and main challenges each of these elements address, have been briefly identified, followed by how key findings on process, people and technology can address these.

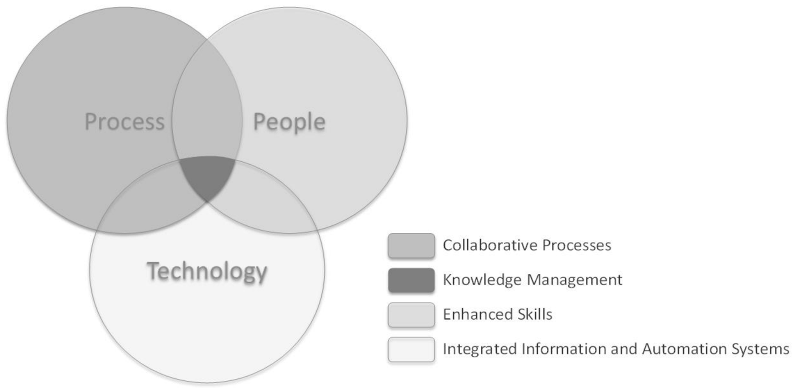

Figure 2 Relation between process, people and technology and the four elements of IDDS

Collaborative Processes: Improved design and delivery through better coordination and integration is essential. To support this, information technology tools will need to provide increased capability for knowledge sharing and development, rather than for just information exchange, aggregation and storage. Collaborative approaches, linked with an effective knowledge management system, would facilitate this. Further benefits may result from adoption of new approaches to work processes being developed in other sectors (Owen et al., 2010). Kvaerner's ambition is always to build in as short time as possible and have as high parallelism as possible and as few working hours as possible, but at the same time meeting the quality requirements. To be able to work integrated, the EPC contractor must describe the build sequence for the engineering subcontractor, so that they manage to deliver their drawings and materials into that specific sequence. PEM shall ensure that the status on the engineering deliveries at the last milestone in the design phase satisfies Kvaerner's build sequence.

Knowledge Management: Codified knowledge in companies typically exists within individual groups (discipline, trade, function) and is seldom shared with others. Applying knowledge management, which includes codifying, using and constantly updating critical knowledge and business processes, is only done in a few leading companies (Owen et al., 2010). PEM supports "right the first time" through milestone requirements, to make sure engineering has come as far as required to start construction. Kvaerner’s milestone requirements in the design phase are compared to the engineering subcontractor’s corresponding milestones. The gaps are identified, and additional requirements are added to their milestones. In that way the engineering subcontractor can keep their own milestones but with certain additions (or deductions) to support Kvaerner’s build sequence. The core to success is that Kvaerner is able to get the message out to the disciplines. Kvaerner’s PEM, which is knowledge management in practice, has two functions in respect to that; tell the disciplines what they should have done at a given milestone and to check whether it is achieved.

Enhanced Skills: Increased performance requirements and complexity in construction increase the need for integration skills. Furthermore, project management in integrated projects need to focus on personnel with shared technical knowledge and integration experience as key selection criteria. Knowledge of prior projects and current requirements, will foster integrated work processes both between and within specific project phases and major activities (Owen et al., 2010). A joint venture with a common bottom line, that Kvaerner and the engineering subcontractor has established, with clearly defined project goals, which the parties have to align to, will increase the motivation to integrate for both contracting parties. The main advantage of an incentive-based contract, such as joint venture, is its potential to unite the objectives of the project team with project objectives. Kvaerner must get the engineering subcontractor to adapt to their build sequence and not what they have done towards other EPC contractors. That is what Kvaerner and the engineering subcontractor have spent time on in the relevant case project. If Kvaerner manage to get a new project with a majority of the same personnel, it would further improve integration.

Integrated Information and Automation Systems: Moving towards partial integration and automation of engineering, procurement and construction, will increase the overall performance of a project. This includes extracting information for fabrication from the design model. Further progress will require providing more complete design information models for use in in construction (Owen et al., 2010). This is what Kvaerner has moved towards, when they split the BIM in sub areas, called fabrication assemblies. These are developed to be able to define and control what is sent out for fabrication. Drawings and all other relevant information is related to each fabrication assembly. Kvaerner has three categories of criticality, which is related to design and delivery time on equipment. Information on equipment is based on the purchase orders, and will be updated as the orders are finalized. This is used as important input to the fabrication assemblies.

7. Conclusions

This paper has identified how transition from engineering to construction can be improved, based on experiences from offshore projects in the oil and gas industry through Kvaerner, executed as EPC contracts (design-build), with engineering and procurement on a subcontract. The results are structured according to three interrelated dimensions; process, people and technology. The first dimension, process, is related to parallelism and build sequence. Construction is pushed in parallel with engineering, because of the short time frame from contract is signed to delivery date. To get deliveries at the right time, Kvaerner has made a build sequence, according to their project execution model (PEM), that engineering and procurement must know and deliver according to. At the last milestone in the design phase, M2C, the design should be at a quality level that is required to start construction. PEM supports “right the first time” by defining requirements on the milestones in the design phase. The M2C milestone is checked against the corresponding milestone to the engineering subcontractor. The gap is identified and any additional requirements are added to the milestone to the engineering subcontractor, so that they can satisfy Kvaerner’s build sequence and deliver “right the first time”. The focus for the next dimension, people, is related to common incentives and drivers, and how Kvaerner can make sure that the engineering subcontractor adapt to the build sequence and align their milestones. Through a joint venture, where they share profits on the bottom line in a percentage distribution, the incentives are higher for both parties to satisfy, compared to a standard subcontract, because they are mutually dependent on each other. It is crucial that Kvaerner can influence the disciplines to adapt the design and deliveries to Kvaerner's build sequence. Success is related to the use of experienced and competent personnel on both sides in the project team that are commercially conscious to what mechanisms apply in the contract, and act according to that. The last dimension, technology, is related to the use of BIM and how it must be split into sub-areas, fabrication assemblies that contain all relevant information and is optimized for Kvaerner’s build sequence. Criticality related to lead-time on equipment and availability of correct vendor information at the right time will be important input to fabrication assemblies. The IDDS approach (Owen et al., 2010) is applied to increase the relevance of the findings towards the construction industry. It consists of four main elements and identify challenges in the industry on BIM and process, people and technology. Several of these challenges have been addressed with the findings in this paper, which increases the relevance towards the construction industry. Future research will focus on gathering additional data related to process, people and technology and analyze that to further develop concepts, for adaption towards the construction industry.

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Transformation of Emerging Building Materials Reuse Industry through Mapping Sustainable Architectural Design Processes using BPMN

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Abstract

In the United States, new building material reuse and de-construction businesses are currently emerging as an alternative to demolition contractors. A national association organizes a bi-annual conference and vendors from all around the country gather to share their business experience, challenges and networking opportunities. These businesses are helping society by reducing material waste, achieving LEED Resource Reuse credits, and creating job opportunities. They suffer, however, from the absence of a "system of information exchange" that would streamline their business processes, establish a supply-and-demand chain, and connect vendors, brokers and contractors with designers and architects.

This study presents an innovative restructuring of the traditional Design-Bid-Build process that enables the reuse of resources. The restructuring transforms the DBB project delivery method into an Integrated Project Delivery method by including the sustainability stakeholders in the early phases of the design process. We developed this model by capturing expert knowledge using a Delphi research protocol and the Business Process Modelling and Notation standards (BPMN). The proposed business process mapping workflows are integrated with the BIM Project Execution Planning Guide developed by the Computer Integrated Construction Research Program at the Pennsylvania State University (2010). Our work also identifies the critical decision nodes within the proposed process maps and suggests a decision-support framework that aid architects and building stakeholders when integrating sustainable building solutions regarding reusable materials. The Knowledge Capturing Process utilized in this research was applied using a qualitative method and a modified Delphi research protocol with the research participants. Triangulation with literature and built case studies were performed and the results were integrated in an illustrated detailed blueprint set of BPMN maps, which were then used to reach consensus with the industry stakeholders.

Keywords: Building Materials Reuse, Waste, Process Mapping, Decision Making, Resource Based Design Build, United States Materials Marketplace

1. Introduction

Waste from building construction and demolition activities are increasing everyday. Landfills almost everywhere in the world - except the United States - have reached their capacity and despite the environmental and economical global crisis, we continue to generate more waste than ever. When we realize the negative impacts of deconstruction and demolition activities on the environment, it becomes necessary to think about innovative ways of reusing and recycling building materials in new construction (CIB, 2002, Dorsthorst and Kowalczyk, 2002) or, perhaps better, recycling our thoughts about making use of materials waste. Studies show that construction and demolition activities are the primary source of waste worldwide. For example, demolition waste in England alone has been estimated at 91 million tons in 2003 (Osmani, 2008) and construction and demolition waste constitute about 40% of the total solid waste stream in the United States (USGBC, 2003). As critical and creative players in the building making industry, architects are confronted today with their role in waste crisis. We can find this sentiment expressed in Kevin Lynch's last book, *Wasting Away*, when he suggested that: *"Architects must begin to think about holes in the ground and about flows of materials"* (Lynch and Southworth, 1990). Although known primarily for his transformational inventions in energy, Thomas Edison (1847-1931) also warned us that, "*Waste is worse than loss. The time is coming when every person who lays claim to ability will keep the question of waste before him constantly. The scope of thrift is limitless."*

Traditionally, architects' primary focus is on building design and construction; very little thinking is spent on un-building and deconstruction (Falk and Guy, 2007). Architects typically view the building as permanent structure that should make lasting and timeless statements, and very few think of what happens to the built environment at the ends of its life. An increasing body of knowledge on waste management and waste diversion from construction sites already exists, but almost none is focused on the role of the architect in reducing waste. The questions that arise for this problem include: What is the role of the architect in improving waste prevention and reduction through design (Erkelens, 2003) How can salvaged and reclaimed building materials be incorporated in new construction? And what is the process of evaluating and selecting salvaged materials?

The emerging building material reuse vendors and de-construction contractors in the United States are faced with big challenges from the absence of a "system" to streamline their business process, establish a supply and demand chain, and connect them with designers and architects. Nevertheless, additional obstacles, such as quantities required, storage, scheduling and recertification, add more pressure on this industry to get it off the ground. Successful case studies of reuse in building projects still remain as rare, experimental and unique. , They also differ greatly from one to the other in the incorporation of building material reuse. One example is the Big Dig House in Lexington, MA, designed by Boston-based architecture firm, Single Speed Design, which successfully reused steel beams and concrete slabs salvaged from the Big Dig project in Boston (Fettig et al., 2006). The processes of designing and implementing reused materials were unique and very specific due to numerous factors. Understanding the process of how these initiatives became successful is an important part of this study.

2. Building Materials Reuse Market

2.1 Current Status

Although there are substantial environmental, economic and sustainability benefits for using reclaimed materials, the market is virtually untapped and extremely fragmented. At the time of this writing, only 1% of reclaimed materials are used in new building projects in the UK (Gray, 2011), a percentage that should be higher. One of the barriers has been a lack of information about sourcing and the reuse of materials in design and construction, including knowledge of specifications, standards, liability and performance. But there are economic barriers too, including the cost of extraction in deconstruction, the limited flexibility and quantity of reclaimed materials, and problems of storage and the double handling of materials between sites. In addition, medium to large building projects cannot take advantage of the reclamation industry, because the salvage supply chain is not yet established nor equipped to deal with large orders.

The United States Environmental Protection Agency (EPA) has listed a number of organizations under the Construction & Demolition Materials subcategory of its Waste and Resource Conservation category. The EPA stated that throughout North America, hundreds of used building material stores sell materials for construction and renovation projects. Materials (such as used lumber and bricks) and other items (such as doors and windows) are salvaged primarily from remodelling projects, pre-demolition salvage, and the growing practice of deconstruction that leads to the selective disassembly of buildings for the reuse and recycling of parts. Among the list is the Building Material Reuse Association (BMRA), which is a nonprofit educational organization whose mission is to facilitate building deconstruction and the reuse or recycling of recovered building materials in the United States. Members of BMRA include deconstruction contractors, salvage businesses, architects, recycling coordinators, etc. The organization operates on a national level in North America; in 2011 it reported that the number of reused building materials centers has grown rapidly over the last 15 years, estimated at over 1000 nationwide. The organization offers information on building materials reuse, deconstruction, and green building practice. It organizes a national conference on building materials reuse, deconstruction, construction and demolition waste recycling, and offers training and other educational opportunities. Although this association has been organizing conferences nationwide biannually for more than 15 years, its members are still suffering from a system that can connect them to architects and designers and streamline the sourcing and procurement workflow. The “yellow pages phone book” style of listing deconstruction businesses and salvaged materials vendors on the association website has failed to help this emerging industry get off the ground, with the result that there are still limitations on the supply and demand chain.

A serious attempt to establish that missing supply demand chain is currently being realized. Based on the idea of the Circular Economy, the project titled ‘*United States Materials Marketplace’* was launched with the support of three major world organizations: the United States Business Council for Sustainable Development (USBCSD), the World Building Council for Sustainable Development (WBCSD), and the Corporate Eco Forum (CEF). The United States Materials Marketplace was initiated as a pilot project in the summer of 2015 to test the feasibility of a national exchange where traditional and non-traditional industrial waste streams could be matched with new product and revenue opportunities. The US Marketplace is currently establishing the software platform of materials exchange on the web, a framework that we suggested in our article (Ali, 2012), proposing that a national level materials exchange repository was critical to the success of connecting with architects. The US Marketplace is currently focused on wasteflows from large industrial companies such as General Motors, Nike, and some building materials manufacturers such as Armstrong. Manufacturers from the building product sector will join the marketplace as it gains momentum.

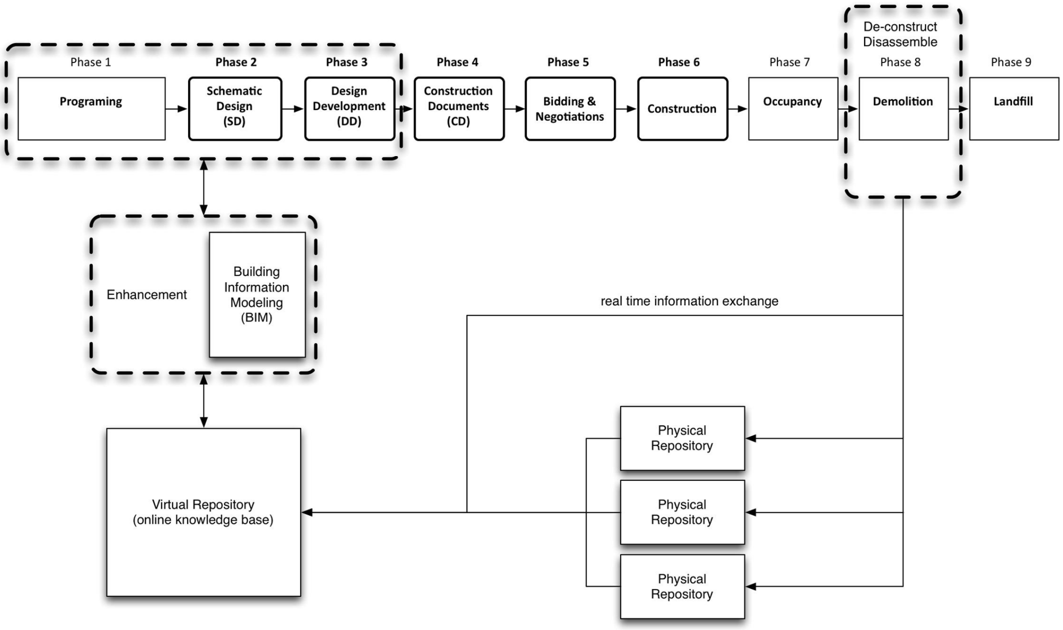
3. Resource Based Design Build

The astonishing volume of solid materials waste represents not only a demand on landfill sites but also a disregard for the material and energy resources contained in these components (Thormark, 2001). While there is a significant body of research related to construction and deconstruction of buildings and construction waste management (Osmani, 2005) the majority of these studies or proposals only indirectly suggest the importance of the architect in this process. Indeed, it could be argued that, for non-residential buildings, the architect is the key decision-maker in designing for reuse. While many architects would consider the reuse of salvaged building components in their designs, and a few architects have already implemented designs with a significant amount of component reuse, a current barrier to wide-scale implementation of design for reuse strategies is the lack of an easily accessible and usable platform for comparing and evaluating alternative reused building components. We propose that this platform could easily be connected to Building Information Modeling (BIM) through a decision support framework. Through this study, a new decision-support structure for designing buildings with reused materials will be developed. The outcome will be a new mechanism that will transform the architectural design process to one that better supports design for reuse. The broader impact will be a reduction in the volume of building-related waste, the creation of new job opportunities with emerging de-construction industries, and a profound impact on the US economy. The Dutch firm SUPERUSE Studios suggested the term “Resource Based Design” as they explored design with wasteflows through their Harvesting Map platform in the Netherlands.

3.1 Proposed Design Scenario

Our proposed design scenario is envisioned as follows: an architect designs a new building while utilizing Building Information Modeling (BIM). The proposed building is “dissected” as a process in BIM and an inventory of the building components is generated. This component inventory is archived for future reference and is used as input to the decision-support process. Concurrently, other buildings nearby or within (harvesting map) proximity either have been or are in the process of being de-constructed. An inventory of the available components from these de-constructed buildings is generated, including essential information of the necessary decision-making attributes, along with similar information from manufacturer refused products (wasteflows) and salvaged warehouse stores and vendors. A platform for all of the above information is called a “Virtual Repository,” which will be an online local/national/global library of reclaimed and salvaged building materials and components. This Virtual Repository will be linked to all available Physical Repositories (reclaimed materials warehouses, deconstruction sites and industrial manufacturers) and live updated with all available materials with necessary information the design team needs in the design process. A simple representation of the workflow can be seen in Figure 1. (Note that the architectural design process is not linear but investigative in its nature).

Figure 1: The Proposed Design Scenario (Ali, 2012)



In the future, the previously mentioned BIM inventory from today's design will be activated when the building is de-constructed to provide an efficient mechanism for inventorying salvaged components. For the proposed new design, each component in the new building is compared with components in the Virtual Repository. Here comparisons are processed through the decision-support framework using the decision-making attributes. These attributes include, but are not limited to, assessment of age, possible fatigue and weathering of the reused component, structural integrity, history, appearance, size and dimensions, and ease of alteration. The matching process will be both direct and indirect based on the processing of the attributes. Direct matches are when a needed component, such as a steel beam, is matched to an available component. Indirect matching will occur when the evaluation of attributes identifies a salvaged component that can be potentially adapted for use as a new component (Roberts, 2005). This process can be referred to as creative re-purposing (for example, when a set of exterior wall panels can be reused as suspended ceiling panels). In addition, the decision support process compares other factors such as costs, embodied energy, and transportation distance. As part of the attributes for reused components, information such as images, as-built drawings, specs and other visual information of the component, are also accessible to the design team.

3.2 Critical Assumptions

There are three critical assumptions that need to be addressed when building the decision support framework and mapping the design workflow for using reclaimed and salvaged building materials and components. While these assumptions will be critical to the ultimate success of this research, the focus will be at the building design level with the assumption and recognition that these other levels will influence the ultimate platform of the proposed framework. These assumptions can be summarized as the following:

1. Establishment of a Supply-Demand Chain mechanism between de-construction sites and reuse stores and salvage warehouses. As the market of salvaged and used materials becomes viable, widely acceptable and profitable, a refurbishing process such as modifying, sorting, coding and re-certifying will take place. Collectors, re-manufacturers, wholesalers and retailers will convert the salvaged materials into usable products. These wholesalers and retailers will perform a vital function of aggregating the supply and demand system. The design team will recommend from this supply chain's inventories and purchasing mechanism will be established.

2. Establishment of a Standardized Universal Online Virtual Marketplace for Reclaimed Building Materials. In this study, the online marketplace of reclaimed and salvaged building materials and components is called "The Virtual Repository." It is described in the previously proposed design scenario (figure 1) as an essential component of the decision framework. The development of this marketplace will depend heavily on the successful identification of a number of attributes and necessary information related to the reclaimed and salvaged building materials and components. It is our vision that this online marketplace will be connected with salvage warehouses and online exchange vendors through a system of information exchange. This could be similar to, for example, the on-line inventory database from the used car parts industry.

3. Time and Scheduling of Purchasing Materials. The decision on whether or not to use reclaimed and salvaged building materials depends very heavily on issues related to the purchasing these materials. In a typical design process, the timing of comes after the bidding phase. The decision of purchasing reclaimed and salvaged materials, on the other hand, needs to come very early in the design phase in order to secure these items.

4. Experts' Views on Business Process Mapping

The data, which we collected from a modified Delphi mining process and face-to-face interviews, were largely inductive (meaning that these specific data leads to general patterns). Therefore, a whole text analysis that involved identifying, coding, and categorizing patterns in the data was conducted. Since literature suggests that there is no single correct way to analyze qualitative data, our analysis wasn't a linear process. Instead, it involved spiraling back and forth between various stages. Strauss and Corbin argued that the grounded theory procedure could be stopped after step six if the researcher is only interested in a thematic analysis or concept development (Strauss and

Corbin, 1998). Following the solicitation request from our preliminary forecast questionnaire, two groups of participants were identified for further data collection. The first group was face-to-face interviewed (Table 1), while the second group was virtually interviewed. The actual participants in the face-to-face interviews were nine and nevertheless satisfying to the researcher. The structure of the interview sessions was designed to elicit expert judgment and opinions to structure the findings efficiently. Knowledge capturing process was carefully planned in order to maximize the quality of data gathered.

Table 1: Face to face interview participants

Interviews	*Building Material Reuse Stakeholder*
Interviewee 1	*Community development (Habitat for Humanity)*
Interviewee 2	*Government agent*
Interviewee 3	*Architect*
Interviewee 4	*Building Materials Reuse Consultant*
Interviewee 5	*Deconstruction Contractor and reuse store*
Interviewee 6	*Reuse store and BMRA member*
Interviewee 7	*Research Architect and Government Agent (U.S. Army Construction Engineering Research Laboratory)*
Interviewee 8	*Researcher, Industry Educational Association - BMRA*
Interviewee 9	*Deconstruction Contractor*

4.1 Knowledge Capturing Process

Each participant of the focus work group remained anonymous. That is, the members were individually asked the same set of questions in every round of the Delphi process, without disclosing their identities to the others. Consequently, participants did not have to worry about being forced to a final outcome in the first round of the opinion soliciting sessions. They had the opportunity in succeeding rounds to modify their answers in light of the responses from others or stick to their original opinion. Rounds of these opinion-gathering sessions were conducted until the group reached a consensus. The same set of questions was sent to other stakeholders who expressed interest in participating in the study but who could not attend the group session. After the first round of interviews, the researcher organized, coded and analyzed the responses, then prepared a second round of questions which were conducted through an online survey tool. We used our initial UML maps - as seen in figure 2 - which presented the traditional DBB workflow to guide the participants and engage them in the discussions

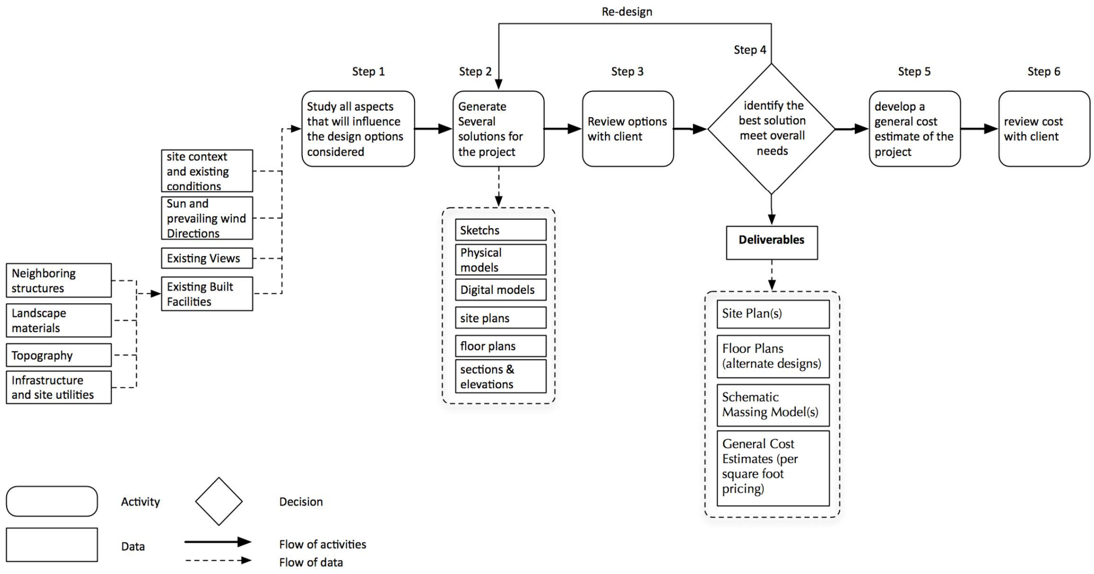


Figure 2: Traditional DBB Schematic Design Phase UML Map Workflow (Ali, 2012)

4.2 Designing the Review Process and Workflow Mapping

Essential to mapping the building materials reuse design process were the design and construction of a number of flowcharts and maps. A standard modeling language from the Business Information Technology domain was consistently adopted throughout the mapping process; a series of initial UML activity diagrams (later updated to BPMN diagrams) illustrated critical participants, communications, data and contingencies. Specifications of the knowledge artifacts involved in the process were structured in a concept map. The UML activity diagrams represented the Building Materials Reuse process (BMR) incorporated in new construction. Three major players in the process were identified: the architect, the BMR consultant, and the Reuse store vendor/broker. All processes were supported by data and information, which were placed in a separate swim-lane along with the other swim-lanes for the participants (Figures 3,4). The flow of information is represented using doted arrows. Solid arrows represent the start and the end of each activity. Diamonds represents major decisions taken by all project stakeholders. Each decision node represents a decision model, the complete discussion of which is beyond the scope of this paper.

DBB Schematic Design Phase: The Schematic Design phase is presented in three maps. First a traditional DBB process updated from UML to BPMN. Second, level one new BPMN process including preliminary BMR activities. Third, level two new BPMN process including detailed BMR processes. A description of the three maps as follows:

SD2a - Traditional DBB Schematic Design Process: Typically, this phase includes developing several preliminary design options or iterations for review and selection of a preferred scheme. Some important activities take place such as: reviewing of the project program with the client, developing spatial relationships, providing preliminary design concepts, obtaining input from the landscape architect, presenting of design concepts to the owner (concept floor plans, sections, elevations 3D model, etc.), obtaining the owner review and input, and finalizing schematic design deliverables. In addition, a thorough study of zoning and building codes and regulations is much needed

SD2b - New Schematic Design Process Level 1: This process starts with identifying all influential aspects of the project design (figure 3). Within this activity, the design team investigates the existing structure on site (if there is one), and identifies its potential for deconstruction, and materials that could be salvaged. Additionally, part of the data gathered for the process includes an identification of available reclaimed materials (including the virtual marketplace), so it can be priced and incorporated into the design. Today, more demands on estimating an accurate project budget by the end of the SD caused primary materials selection to be made early through SD. In addition, design teams are projecting building systems at the end of SD since it is too late to expect systems and material discussions to happen during DD phase. To achieve this, some architectural firms practice in a highly integrated method that allows them to typically meet several times in SD with structural, MEP, civil engineers, landscape architects, etc. therefore, all material choices are being made earlier as they impact updates to cost, thermal performance, etc. BIM has been an efficient medium to achieve this integration.

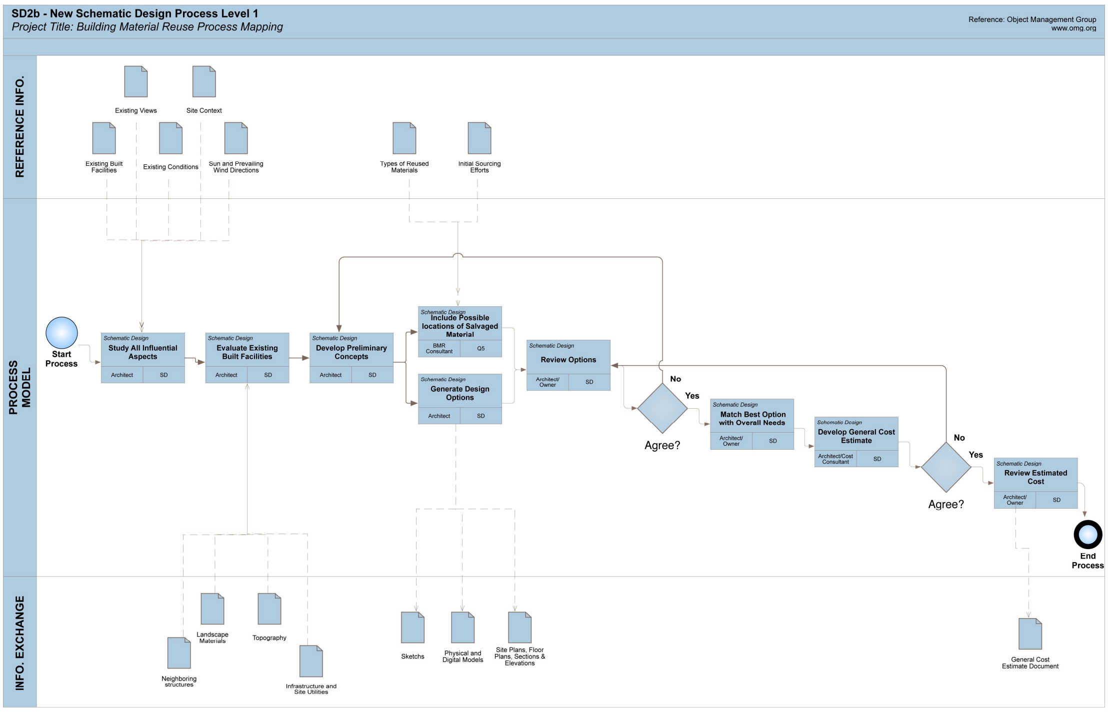


Figure 3: SD2b - New Schematic Design Process Level 1

SD2c - New Schematic Design Process Level 2: On a higher detailed level, this process expands on the activities of the previous level. At the information gathering stages, as shown in (figure 4), a list of potential materials from existing buildings on site is generated. To distinguish between functional reuse versus creative reuse, some of the materials are identified as "function-constrained." For example, a set of windows of a particular size would require a specific layout to be reused. Other materials are "function flexible," which can be used as finish materials or textures, with the expectation that dimensions can be modified as needed (for example, doors used as paneling, lumber used as trim, etc).

During this phase, the design team also brainstorms ideas for detailing material assemblies to allow for future disassembly. Some important information such as historical context as it relates to surroundings, site and region are included at the beginning of the process. This type of information would emphasize the importance of the in-depth knowledge of the social and economic history of the existing buildings. In that regard, and before reviewing the cost with the owner, design alternatives are introduced that may exceed the budget, but add significant value in regards to character and authenticity of the project. Some of the featured activities within the process include: identifying potential material supply for reuse, generating several strategies for material reuse, explaining benefits of reuse to client, and adding to deliverables "target material reuse percentage".

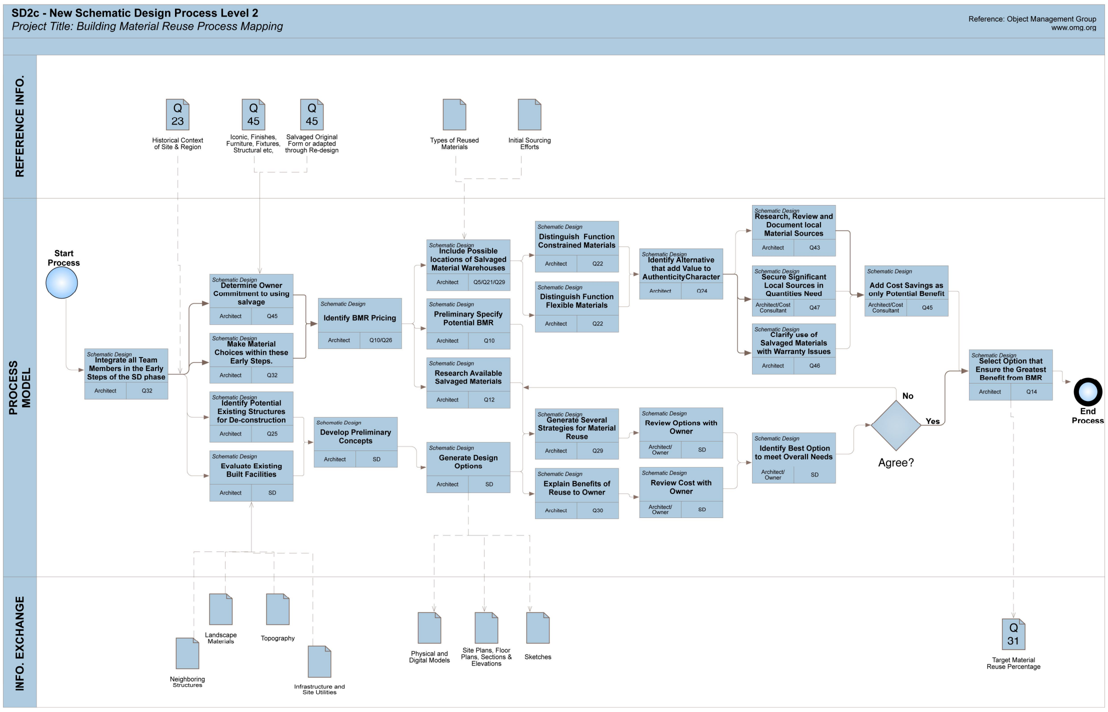


Figure 4: SD2c - New Schematic Design Process Level 2

5. Discussion

The work we presented in this paper suggests that design with reuse requires a paradigm shift in the required knowledgebase and the way information flows within the Design-Bid-Build process. Unfortunately, the structure of this paradigm shift is not known and hasn't been well defined. Since knowledge forms the core of building a Decision Support Systems (DSS) for a design team in order to consider reuse, it is necessary to capture the required knowledge and information from the industry experts through a Knowledge Acquisition (KA) process. This knowledge can then be used to 1) identify the building material reuse criteria and 2) to build a prescriptive decision model and 3) to map the process design of the current traditional architectural design workflow and the proposed one. The overarching goal of this study is to use the building material reuse knowledgebase for 1) building a Unified Virtual Repository database to be connected to all available physical repositories and share a unified standard of information. 2) When the Unified Virtual Repository is integrated with Building Information Modeling (BIM), the DSS can work as a feedback and feed forward support for architects and designers as they consider building material reuse in new designs and constructions. We found that it is essential for a new role to emerge among the project team stakeholders. This role could be labeled as "Reuse Consultant." Our initial idea was based on giving the architect the ability to make sound decisions on materials and components by providing structured information through the Building Material Reuse Virtual Repository. Architects in the US have already been given more control of the delivery of design to construction managers. The need for an additional stakeholder to join the project team from the early stages is revealed to be critical. The recent emerging businesses like PlanetReuse (a reclaimed construction material broker) are a perfect example. PlanetReuse is making efforts by utilizing technology to build a marketplace platform. InvenQuery is a system currently beta-testing is looking at on-boarding 20-30 stores with plans to put as many of the 1,100+ reuse centers in the US as possible.

6. Conclusion

In this paper we presented the untapped opportunity of streamlining a process of materials exchange between vendors and designers. To map the Building Material Reuse process, three stages of process mapping were essential. First, an overview map which addressed the relationships and the workflow between the different phases of the traditional Design-Bid-Build process and the proposed Building Material Reuse design scenario. Second, a set of detailed process maps that defined and detailed each of six critical phases of the DBB process related to BMR. Each phase of the six phases was detailed in three maps, a traditional process map and two levels of new process maps that were divided into level one and level two. Finally, a set of five strategic maps were developed to synthesize the overall process and to highlight the most important processes within any project delivery method. We only presented an example of transforming the traditional DBB Schematic Design phase into the new two-levels BMR integrated SD phase to illustrate our work. Additional details on our mapping process and the Delphi Knowledge Capturing process will be presented in future studies. The recent development of the US Materials Marketplace is very promising and the global support behind the project only makes us hopeful about the future of the circular economy.

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Barriers to On-site Waste Management Innovation in Building Construction Projects

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Abstract

This conceptual paper provides an early review of literature on on-site waste management innovation to support a proposed research project to investigate barriers seen to constrain adoption decisions in building construction projects. The environmental, economic and social benefits of on-site waste management innovation are discussed; and a proposed integrated framework is presented to establish a starting point for empirical research aimed at exploring the uptake of innovative on-site waste management practice in Australian building construction projects. This paper makes a theoretical contribution to the understanding of project-based organisations within an important empirical setting, namely the Construction and Demolition (C&D) waste management innovation system. Future research by the authors will involve the execution of the proposed research program. Applied outcomes from the proposed research will include the development of effective strategies for industry clients and practitioners to increase levels of on-site C&D waste innovation in building projects.

Keywords: Waste, Innovation, Building projects, Sustainable construction

1. Introduction

There are formidable challenges associated with resource depletion that require greater attention to reclaiming the embodied energy of existing building stock, and decreasing the energy required to construct new buildings though innovative waste management strategies. To address these challenges, an innovative approach to on-site waste capture and segregation practices is required. This can involve the uptake of on-site processing technology to reduce transport requirements and associated environmental impacts.

Effective product, process and/or system innovation adoption on construction projects can result in improved program performance, decreases in cost and potential improvements in the quality of project outcomes (Rose & Manley, 2012). In response to the challenges of environmental sustainability, global experts have called for greater investment in innovation aimed at reducing whole-of-life building energy consumption, in light of estimates that greenhouse emissions from buildings can be reduced globally by 30% at no net cost, by 2020 (IPCC, 2007). Technological and process advances in on-site separation of C&D waste offer reduced contamination by capturing and segregating materials for effective processing, while on-site re-use through systematic deconstruction techniques enables greater recovery of material resources (Chini & Bruening, 2005).

By identifying the behavioural barriers to adoption of innovative practices, detailed educational interventions can be implemented to improve on-site waste management practice in building projects. Against this background, a large scale research project has been proposed to improve resource and energy efficiency within the Australian building sector, through increased adoption of innovative on-site recycling and re-use of building materials and components in the Construction and Demolition (C&D) waste stream.

This paper is the result of the first stage of the project, involving an early literature review and development of a integrated framework that will be used to guide the first stage of the research, namely: to define the key system participants and activities in the C&D waste management innovation system in the Australian building industry and identify the barriers to on-site waste management innovation. The paper conceptualizes the building construction supply chain as an Open Innovation System, which is extended by applying the adapted Project Based Product Framework (PBPF) to define the C&D waste management context, and proposes Innovation Diffusion Theory (IDT) and Theory of Planned Behaviour (TPB) to explore the decomposed beliefs and behavioural intentions of system participants and subsequent adoption behaviour within this context.

2. Innovation in C&D Waste Management

Innovation in on-site separation, processing and re-use of C&D waste offers significant social, economic and environmental benefits over traditional methods, including reduced transportation requirements (Hyder, 2011). Advances in on-site separation can reduce the contamination of building waste by capturing and segregating materials for effective processing, while on-site re-use through systematic deconstruction techniques enables greater recovery of material resources (Chini & Bruening, 2005), thus reducing the embodied energy impact of buildings. In the proposed study, on-site C&D waste management innovation can be categorized into: 1) process and technological innovations in the capture and segregation of C&D waste on-site; 2) advanced fixed or mobile on-site reprocessing technology for material and product reprocessing; or 3) new processes or technology in the on-site re-use of waste materials and components.

Despite research attention in developing strategies to reduce, re-use and recycle C&D waste, implementation of these strategies in practice has been limited (Yuan & Shen, 2011; Tam, 2008). In Australia, the C&D waste stream produces the highest tonnage of waste in comparison to all other waste steams (Municipal Solid Waste and Commercial and Industrial Waste) comprising 18.2 million tons produced nationally in 2010-11 (Hyder, 2011). Of this material, mixed C&D waste represents the majority of waste that is disposed to landfill, emphasizing a need to improve on-site separation/reprocessing and minimize waste contamination (DSEWC, 2012). A recent Australian federal government study (DOE, 2013) pinpointed four key actions required for improvement in recovering resources from the C&D waste stream: (1) Design products and buildings for their eventual deconstruction to enable resource recovery and reduction of embodied energy; (2) Reduce the contamination of waste in the capture and segregation of materials at their source (on-site); (3) Encourage the uptake of recovered materials through improved specifications and knowledge of material and product applications; and (4) Conduct research and development into overcoming market and technical barriers to the uptake of innovative applications. To address these key priorities requires significant change in how C&D waste is re-used and recycled on building sites with particular emphasis on increasing the uptake of innovative practices and technology through behavioural change. Attention is also required to improve the diffusion of C&D waste management best practice across the conservative building industry; seen as a key barrier to uptake (Damptey et al., 2010).

Promotion of construction innovation requires a clear understanding of key organizational barriers constraining uptake. This is particularly relevant to construction project-based organizations that face inherent difficulties in innovative knowledge sharing and benchmarking global best practice (Rose & Manley, 2012). This organizational dynamic has resulted in negative perceptions towards the value of innovation despite persisting regulatory intervention. National and global innovation studies have indicated that regulation should be undertaken alongside policy responses aimed at encouraging more positive attitudes to innovation (OSTP, 2008). Similarly, recent sustainability management research has called for greater emphasis on improving the processes that support the introduction of sustainability technologies, not only to be driven by market demand but also mediated by the vested interests of a wide range of industry stakeholders (Schweber & Leiringer, 2012). By encouraging more positive attitudes towards innovation and addressing underlying problems of conservatism, performance improvement across the construction supply chain can be achieved.

Assuming waste management innovation uptake is centrally driven by key system participant diffusion, the proposed study will map the C&D waste management innovation system and explore the behavioural barriers to the adoption of advanced waste practices, and thus, develop strategies for innovation system improvement within building construction projects. This will build upon the global literature emphasizing the specific need for further research into understanding practitioner attitudes towards C&D waste re-use and recycling (Yuan & Shen, 2011; Teo & Loosemore, 2001). As a starting point, this paper proposes a novel theoretical frame where the building supply chain is conceptualised as an Open Innovation System, which is extended by applying the adapted Project Based Product Framework to define the C&D waste management context, and integrates IDT and TPB to explore the decomposed beliefs and behavioural intentions of key system participants.

3. Integrated Framework

The proposed integrated framework shown at Figure 1 takes a different approach to the common construction innovation models currently offered, with emphasis on system-wide analysis of project-based innovation within the Project-Based Open Innovation System (PBOIS). Existing models have tended to focus on a firm-level innovation management that has lacked explanatory power when dealing with the complexities of the traditionally fragmented project-based construction supply chain (Hartmann, 2006), with an emphasis on the relationships and interdependencies in the built environment product system. Indeed, the project-based nature of production in the construction sector creates unique challenges to the adoption of innovation, compared to say, the manufacturing sector, for example. The temporary nature of teams makes it difficult to build up the strength of relationships often needed for successful innovation. In addition, the project to project production method implies a discontinuity which makes the accumulation of knowledge within project based firms difficult. The regulatory and institutional context shapes, and is shaped by, the supply network, project-based firms and projects, with the technical support infrastructure playing a similar role.

This exploratory paper of on-site waste management innovation is based on an international review of peer reviewed journals and industry reports to support proposed empirical research aimed at investigating barriers seen to constrain adoption decisions in building construction projects. It draws on highly cited articles and industry reports published between 1985 and 2013. The articles dealt with the adoption of waste management innovation in Australia. Content analysis was employed to define waste management innovation in view of the integrated framework, shown in Figure 1. The authors each independently allocated the themes arising in the literature to the activities and actors shown in Figure 1. Following this, the two sets of analysis were merged and triangulated to arrive at a consensus understanding of the nature of on-site waste management innovation as a foundation to the proposed empirical work.

The paper draws upon previous work in the application of Open Innovation Systems in complex project-based environments (see Rose & Manley, 2012) and focuses on a specific type of project-based innovation from an integrated system perspective, contextually tailored to the unique vertical and horizontal supply chain relationships within this system (e.g. inclusion of the waste reprocessing firms as a potentially critical knowledge link across project organisational boundaries). Further, drawing for the first time upon the integration of Innovation Diffusion Theory (IDT) and Theory of Planned Behaviour (TPB) as a lens to interpret the decision-making of project-based construction organisations in the PBOIS, the proposed study will result in a deeper and more finely-grained understanding of the barriers to building innovation across complex supply chains than is currently possible with existing approaches.

Gann and Salter's (2000) seminal Project-Based Product Framework (PBPF) is adapted and treated as an Open Innovation System (OIS) (Gassmann, 2006; Rothwell, 1994) to provide context for our study. This adaption takes into account for the key players and dynamics associated with waste management. The relationships between stakeholders and their reliance on one another are emphasised to source external ideas for innovation. The open innovation knowledge links are represented as arrows in the model. This extended framework provides a rich context in order to interpret and assess the beliefs and behavioural intentions of organisations within a project-based open innovation system. C&D waste reprocessing firms are uniquely positioned in the PBOIS; these manufacturing-based organisations interact with project-based organisations (e.g. contractors and consultants) at both the end of a building lifecycle i.e. at demolition stage (purchasing sorted C&D waste) and in design and construction stages (sale and integration of recycled materials/products). The inclusion of the C&D waste reprocessing firms adds an additional dimension to the innovation system, as they potentially act as key knowledge brokers in the diffusion of C&D waste management innovation in both design/construction and demolition/disposal stages.

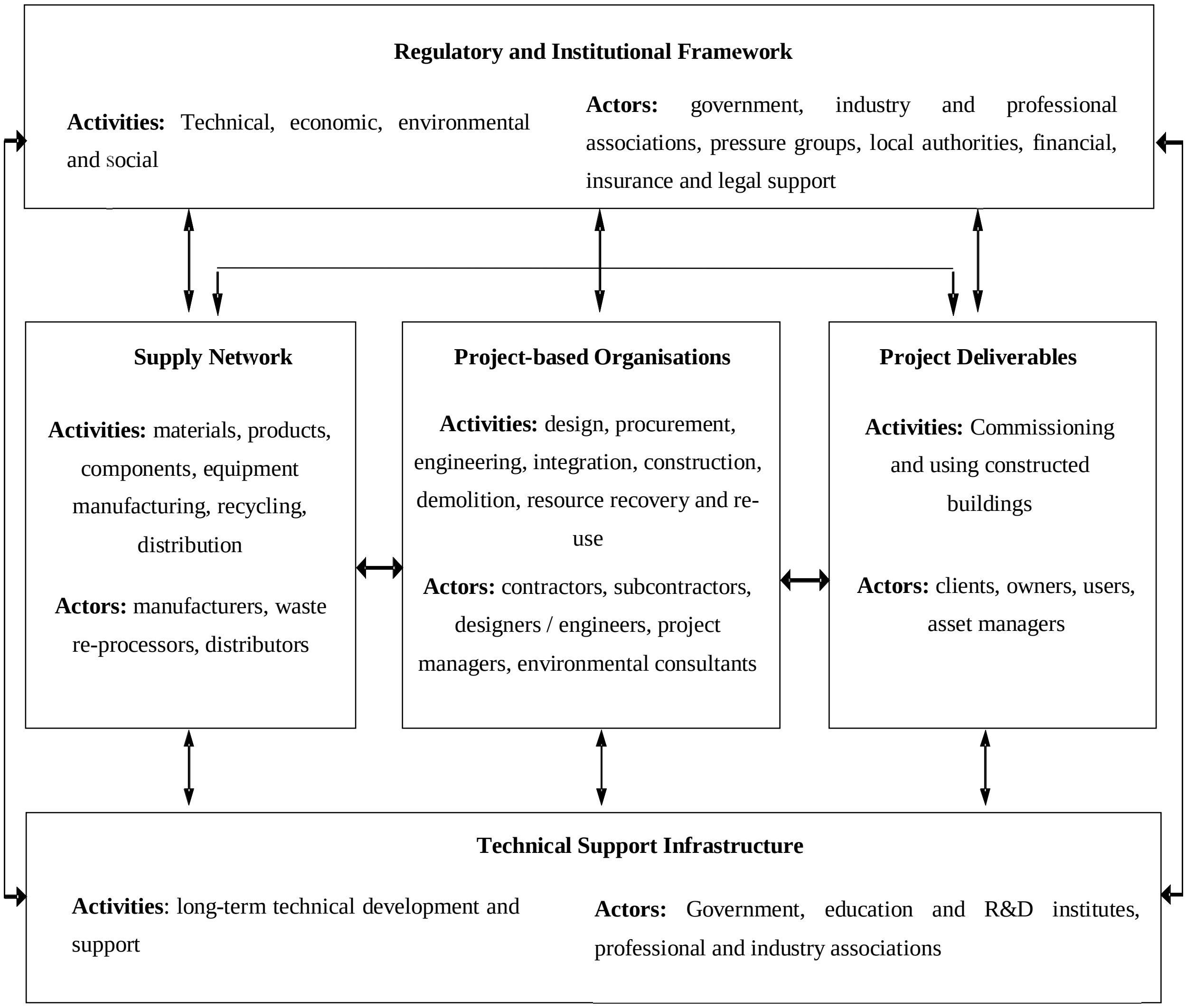

Figure 1: Project Based Open Innovation System (PBOIS), based on Gann and Salter (2000)

Further, to interpret the beliefs and behavioural intentions of project-based organizations within the C&D waste management innovation system, the two key behavioural decision-making theories; TPB and IDT, are integrated. Variations of this integrated IDT/TPB model have been applied to explore user intentions to adopt technology in the area of information technology (Shih & Fang, 2004) and marketing (Taylor & Todd, 1995). This is the first time it will be applied in the context of a project-based environment as defined by the extended PBOIS. The integrated IDT/TPB model is shown at Figure 2.

TPB is a well-known behavioural theory that hypothesizes actual behaviour as a direct function of behavioural intention, as the weighted sum of attitudes, subjective norm and perceived behavioural control (Ajzen, 1985). TPB is one of the most influential and commonly employed theories to explain intentions to use new technology (Mathieson, 1991). Despite the usefulness of TPB as a foundation theory to explain behavioural intentions of construction practitioners (Teo & Loosemore, 2001), it is contended that a decomposition of attitudinal drivers is required to better understand the relationship between antecedents of intention and relationship between attitudinal structures towards innovation adoption (Taylor & Todd, 1995). Thus, key innovation characteristics that influence adoption attitudes drawn from IDT (Rogers, 2003), are integrated and combined with TPB to improve its explanatory power within an innovation system context.

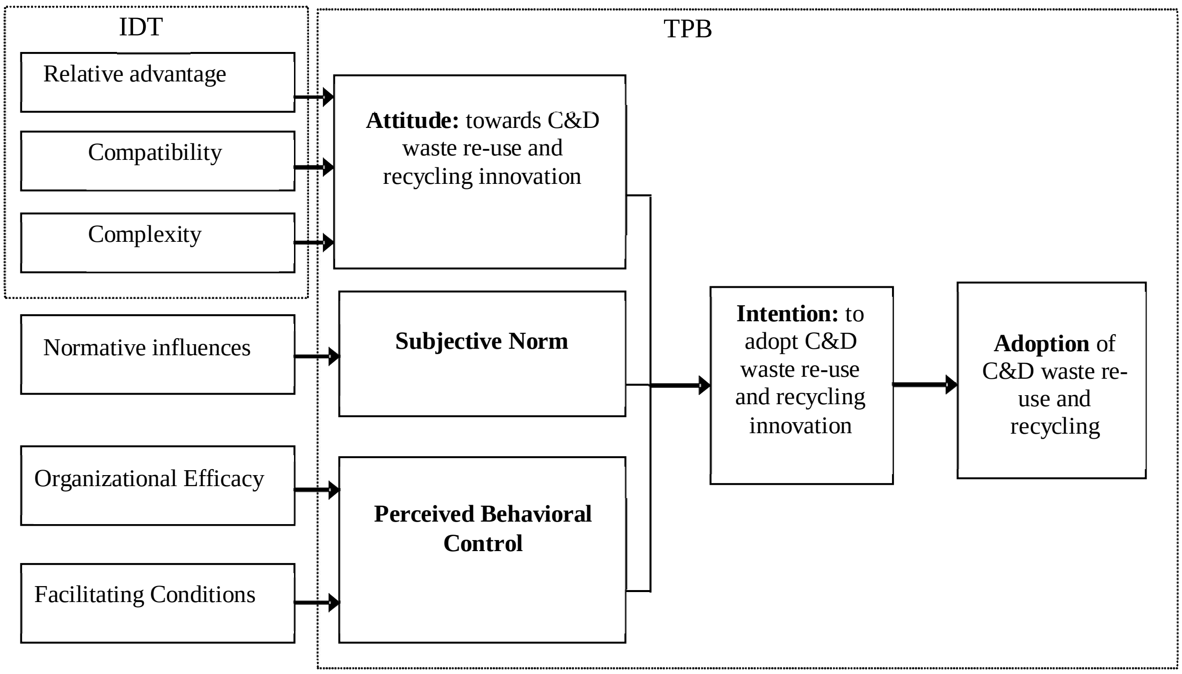

Figure 2: Innovation Diffusion Theory (IDT) and Theory of Planned Behaviour (TPB), based on Shih & Fang, (2004)

In summary, the model proposes IDT (innovation specific) contributes to the broader TPB constructs where IDT can usefully be integrated to inform the antecedents of potential adopter *attitudes*. According to the model, behavioural intention is then a function of attitude, subjective norm and perceived behavioural control. The actual behaviour of project-based stakeholders to adopt innovation is a direct function of this behavioural intention. According to the integrated IDT/TPB framework, it is predicted that to increase adoption of on-site C&D waste management innovation, project-based organizational managers (as the decision-makers in this context) need to have a positive attitude towards the innovation, perceive support from individuals and groups around them; and control over the adoption process and outcome. It is expected by mapping C&D waste management innovation via system-wide analysis within the Project-Based Open Innovation System (PBOIS) will provide a more finely graded interpretation of the behavioural barriers constraining adoption across the innovation system.

4. Mapping of the on-site C&D waste management innovation system and adoption behaviour

Drawing upon the theoretical frame, the empirical stage of the research will aim to define the key system participants and activities in the C&D waste management innovation system in the Australian building industry. This research component will comprise an inductive semi-structured interview program. Semi-structured interviews will be conducted with selected representatives across six key sectors involved in the C&D waste management stream: (1) clients, (2) managing contractors, (3) subcontractors, (4) consultants, (5) waste re-processers and (6) material manufacturers. Interviewees across these six key sectors will be purposefully selected based on their level of experience and understanding of C&D waste management practice in the building construction industry. It is envisioned a total of 60 interviews will be conducted, with ten from each sector as recommended (Eisenhardt, 1989). The interviews will elicit salient perceptions of on-site C&D waste management behaviour (including adoption barriers) and define the relationships across stakeholders in the supply chain, as conceptualised in Figure 1. Key industry bodies will be recruited as research supporters through extensive researcher networks (including access to leaders of national construction industry associations) to assist in the identification of suitable interviewees.

Taking an integrated, non-linear view of the supply chain allow researchers to draw rich data about individual sector perspectives, and triangulate perspectives on innovation adoption behaviour across the six industry-stratified sectors. This stage will reveal knowledge gaps and policy shortcomings that currently constrain the uptake of innovation. A qualitative approach is proposed in order to explore in-depth the complex relationships and interdependencies within the innovation system. Access to a rich data set during the formative stages of the project will provide the foundations for the development of a valid and robust model. Although the sample will be enlarged if required via a snowball sampling method, it is anticipated 'data saturation' will occur with this sample size. Content analysis will be used to code the interview transcripts; NVivo software to classify, sort and arrange the data; and comparative techniques to draw out the most influential factors.

The proposed empirical work will derive focused innovation system data within the context of a specific innovation type at project organisational level. Drawing on the innovation system dynamics and current adoption activity data, it is envisioned a quantitative survey will then be undertaken to identify the most important predictors to the intention to adopt on-site waste management innovation by project-based organisations in the building construction industry.

5. Conclusions

Current waste volumes from Australian construction projects have reached concerning levels, with 6.25 million tons of C&D waste buried in landfill in 2013. Similarly, the embodied energy in the existing Australian building stock is equivalent to ten years of national energy consumption, reflecting the significance of innovation in the recovery of resources at building end-of-life (DSEWC, 2012). Compared to conventional C&D waste disposal methods, there is the potential for greater than 90% of building recycling to be routinely achieved if supply chain organizations give priority to waste recycling measures (Damptey et al., 2010). However, advanced waste recycling and re-use practices on construction projects remain low (Yuan & Shen, 2011). It is argued that comprehensive research is required into how practitioner attitudes influence C&D waste management behaviour from an integrated innovation system perspective.

The proposed research presented in this paper will build upon previous research in seeking to understand practitioner attitudes towards C&D waste re-use and recycling, and for the first time, proposes an integrated framework to explain on-site C&D waste management behaviour through an innovation system lens. It will focus on the beliefs and behavioural intentions of project-based organisations as the key actors in the adoption of on-site C&D waste management innovation. Although the focus is on project-based organisations, we also will explore the roles and influences of the supply network (e.g. manufacturers and waste re-processors), building clients and end users, the technical support infrastructure (e.g. research and development) and the regulatory and institutional framework (e.g. state and local government regulators) on innovation adoption decisions.

Although the framework is yet to be validated through empirical research; it is anticipated that the results from the future empirical work will shed new light on the innovation system supporting the adoption of innovative on-site waste management initiatives. Nevertheless, it currently provides a solid foundation for future research within this innovation area. Applied outcomes from the proposed research will include the development of effective strategies for industry clients and practitioners to increase levels of on-site C&D waste innovation resulting in positive environmental, social and economic outcomes.

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Who should be leading in the process of successful SCM implementation in construction?

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Abstract

Despite the critical role of a client in enabling supply chain integration, parties on the supply side of the construction supply chain – the lower tiers of the construction supply chain – are believed to be able to develop into more integrated production systems, independently from the demand. Main contractors are acknowledged to have a central position in the management of supply chains, offering great potential in the effective integration of their supply chains. This is deemed to be necessary as construction supply chains are fragmented, complex, highly uncertain and with many stakeholders requiring a leading actor to coordinate the process and relationships – projects are characterised by a high supplier involvement. This study sets out to explore the differences between the organisations involved at the lower tiers of the construction supply chain, focusing specifically on the internal SCM organisation of main contractor and supplier organisations, and their direct inter-relationships. SC Maturity levels are formulated according to relevant SCM concepts and based on Holti et al.'s (2000) seven principles of SCM organisation, and used to examine the relative SC Maturity of eight large main contractor and supplier organisations within the context of the Dutch construction industry. A case study, representing a construction supply chain initiated by a main contractor as a result of ongoing poor financial performance during the economic crisis and the existence of high failure costs, is further investigated to examine the SC Maturity levels based on one of the principles in more detail. This way the paper starts a discussion towards the development of an improvement framework and brings up the need for a more mature supply chain integrator, an organisation leading in the process of SCM implementation.

Keywords: SCM, Supply Chain Maturity, main contractor-supplier collaboration, construction supply chain, leadership.

1. Introduction

The construction industry is widely criticised for adopting highly adversarial and fragmented approaches to relationships, where design is separated from production and there is a lack of suppliers' involvement at the early stages of projects (Egan, 1998; Bresnen & Marshall, 2000; Chan et al., 2003). Although fragmentation originally occurred in response to highly variable workloads and subcontracting developed as a flexible way of dealing with these, it has resulted in complex contractual relationships and discontinuity of teams (Fulford & Standing, 2014). Several studies have underlined the need for radically different approaches to supply chain relationships that achieve 'customer delight' and minimise turbulence in stakeholders' relationships (Latham, 1994; Cox & Ireland, 2002; Pryke, 2009) and there has been a move towards better supply chain integration, and the formation of strategic partnerships and collaborative agreements between supply chain actors since (Akintoye et al., 2000; Holti et al., 2000; Briscoe & Dainty, 2005; Rimmer, 2009).

As part of this movement, the search for new and more integrated approaches to the construction supply chain has taken on a renewed importance for many organisations operating within the wider construction industry (DTI, 2003; Holti et al., 2000), also in the Netherlands, following the large number of recommendations in PEC's final report (2003) and following the British vision on collaboration as described in 'Rethinking Construction' (Egan, 1998). At the lower tiers of the construction supply chain, the supply side, however, there remains a paucity of properly documented examples of successfully implemented Supply Chain Management (SCM) initiatives (Cox & Ireland, 2002; Aloini et al., 2012). Construction projects are characterised by a high supplier involvement and rely heavily on subcontracting (Mbachu, 2008). Subcontracting has been adopted as the dominant procurement strategy as a consequence of the uncertainty faced by main contractors in obtaining continuous work and the need to accommodate the different, increasingly specialised and complex, requirements of each project (Tam et al., 2011). The low levels of repetition increase the unpredictability of the flow of work (Vrijhoef, 2011). Major developments, such as the increased use of integrated contracts, have resulted in a shift of responsibilities from client to main contractor. A consequence of this increased responsibility is that main contractors require capabilities and knowledge which do not belong to their own core competences and need to be purchased from suppliers (Bemelmans et al., 2012) – main contractors increasingly depend on their suppliers, both for realising projects and for achieving the required performance in these projects (Bemelmans et al., 2012). The term suppliers covers subcontractors, material suppliers and service suppliers.

While several studies underlined the importance of main contractor-supplier collaboration (Kale & Arditi, 2001; Cao & Zhang, 2011; White & Marasini, 2014), there appears to be a belief that existing SCM initiatives are adopted by contractors in order to increase their profitability at the expense of other members of the supply chain (Dainty et al., 2001). The increasing percentage of project turnover which is spent on buying goods and services does provide opportunities for collaboration and emphases the importance and significance of managing suppliers (Bemelmans et al., 2012). Contractors are willing to develop closer relationships (Ross & Goulding, 2007), but implementing SCM seems a long-term, complex process and requires a certain level of understanding and therefore learning throughout the supply chain. SCM also questions the functional structure of many organisations as these can impede effective collaboration internally and subsequently collaboration with its direct suppliers (Van Weele, 2008).

This study sets out to explore the differences between the organisations involved at the lower tiers of the construction supply chain, focusing specifically on the internal SCM organisation of main contractor and supplier organisations, and their direct inter-relationships (Broft, 2012; Pryke et al., 2014; Broft et al., 2016). SC Maturity levels are formulated according to relevant SCM concepts and based on Holti et al.'s (2000) seven principles of SCM organisation, and used to examine the relative SC Maturity of eight large main contractor and supplier organisations within the context of the Dutch construction industry (Broft, 2012; Pryke et al., 2014; Broft et al., 2016). A case study, representing a construction supply chain initiated by a main contractor, is further investigated to examine the SC Maturity based on one of the principles in more detail. This way the paper starts a discussion towards the development of an improvement framework and brings up the need for a more mature supply chain integrator, an organisation leading in the process of SCM implementation.

2. Conceptual development

2.1 Supply chain relationships in construction

Construction is a complex systems industry, managed through projects involving multiple, temporary, and transient organisations (Kumaraswamy et al., 2005; Pryke, 2012). The largely sequential approach typically supports a lack of integration between design, construction and maintenance methods, leading to inefficiencies, inferior value and poor margins (Holti et al., 2000).

A supply chain is described by Christopher (2005, p.17) as "a network of organisations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services in the hands of the ultimate consumer". Attention is nowadays focussed on ensuring competitive advantage for the integrated supply chain (Green et al., 2005) – businesses no longer compete as a sole business entity, but rather in a 'supply chain versus supply chain' manner (Lambert & Cooper, 2000; King & Pitt, 2009). In construction, a supply chain is characterised as (Vrijhoef & Koskela, 2000):

§ Converging at the construction site – the object is assembled from incoming materials and through different services;
§ Temporary – one-off construction projects are produced through repeated reconfiguration of project organisations; and
§ A typical make-to-order supply chain – every project creates a new product or prototype.

These characteristics are often seen as peculiarities of the industry and prevent the attainment of flows as efficient as in manufacturing (Koskela, 1992). The relationships required for the delivery of the constructed product among main contractors and suppliers are often weak and difficult to manage (King & Pitt, 2009). This is largely as a result of the fragmented nature of the industry and its notorious dependence on subcontracting and competitive pricing (Morledge et al., 2009) – the management of the discontinuous exchanges in project-based industries is problematic due to the discontinuity of demand for projects, the uniqueness of each project in technical, financial and socio-political terms, and the complexity of each project in terms of the number of actors involved (Skaates et al., 2002; CrepsinMazet & Ghauri, 2007).

Rapid technological development in both products and services has driven main contractors to adopt outsourcing strategies involving external suppliers rather than develop in-house capabilities (Cox & Ireland, 2002; Green et al., 2005). The main contractor, the principal construction organisation that manages a construction project, executes only a small part of the product by its own personnel and its own production facilities (Dubois & Gadde, 2000). The low barriers to entry, proven by the large amount of small and medium-sized construction-related enterprises, is a characteristic of the industry that encourages fragmentation (King & Pitt, 2009). Competitive pricing is also promoted through procurement strategies often pursued by clients, such as design-and-build, which favours the lowest bidder (RICS, 2006). As a result of the industry's fragmentation and prevalent competitive tendering, relationships are often opportunistic with main contractors competing to win work through competitive pricing whilst reducing the quality of the end product in order to improve profit margins (King & Pitt, 2009). The consequences are poor production processes, limited ability or willingness to innovate due to lack of investment, late project delivery and budget overrun (Morledge et al., 2009). Fragmentation however, must not be seen as strictly problematic. The involvement of many different specialised firms in projects does not necessarily cause low levels of efficiency. On the contrary, it has been claimed that this could just as well increase the efficiency of resource allocation and speed of information exchange between parties (Pryke, 2002).

The ability to build collaborative relationships is also hindered by the prevalent adversarial relationships brought in by opportunism, lack of trust and inequitable allocation of risk. While suppliers are often regarded as individualistic and only motivated by profit, contractors are viewed as opportunistic when it comes to winning bids, usually transferring risk to the lower tiers of the supply chain (Cox & Ireland, 2002). More often than not, it is clients rather than main contractors that take the initiative towards building good relationships with their supply chain.

2.2 An integrator of the construction supply chain

Intense and often global competition, high technological standards and rapidly changing market demands have pressed manufacturing industries to manage processes throughout the supply chain in an effective and efficient way (Cagliano et al., 2006). The high levels of alignment and repetition within these supply chains have led to highly productive and fast operating strategic coalitions of firms (Kirche et al., 2005; Zailani & Rajagopal, 2005; Kim, 2006). The construction industry on the contrary, knows two typical problems resulting from high levels of fragmentation and low levels of repetition: lack of control and decreasing performance – the industry supposedly shows low levels of performance and backwardness in many respects (Woudhuysen & Abley, 2004) – which tend to reinforce each other throughout the supply chain because of causal relationships within the supply chain (Pryke, 2002). The main objective of SCM is to enhance mutual competitive advantage and this can be achieved through improved relationships, integrated processes and increased customer focus (Pryke, 2009).

For this reason, the interest in adopting SCM techniques has been growing in the construction industry since the 1980s (Segerstedt & Olofsson, 2010), but many applications of SCM in construction have been limited to the management of construction materials and long-term arrangements with suppliers (Vrijhoef, 2011). One of the supply chain principles from manufacturing that could be reconceptualised and applied to the specific context of construction (Vrijhoef, 2011) includes the introduction of the role of the supply chain integrator in the supply chain – one of the critical phenomena lacking in the construction industry is the recognition of a generally accepted focal company initiating the integration of the supply chain. This focal company coordinates and ties together all flows through the supply chain as if it were an extended enterprise (Figure 1).

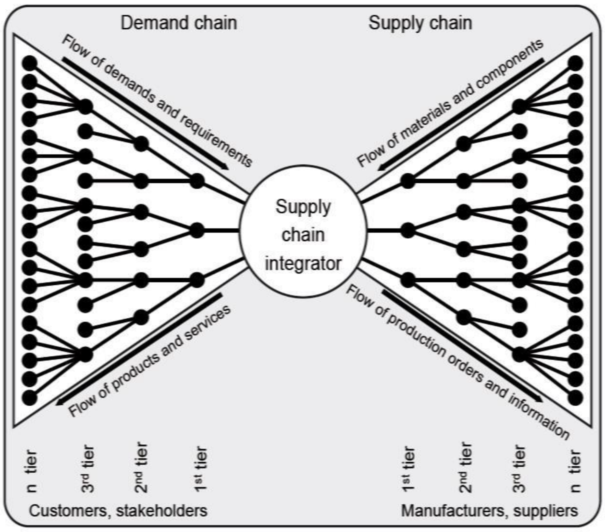

Figure 1: Supply Chain Integrator (Segerstedt & Olofsson, 2010, pp. 349; Vrijhoef & De Ridder, 2005).

Holti et al. (2000) do offer an approach to managing supply chains in which they recommend single point responsibility to the client and describe a collaborative model of overall leadership in achieving value for money, to effectively integrate supply chains. This integration knows two complementary senses: At project level – an integrated supply chain requires a productive balance of leadership of both the design and the construction or delivery processes – and over time across projects (Holti et al., 2000). This is deemed to be necessary as construction supply chains are fragmented, complex, highly uncertain and with many stakeholders, requiring a leading actor to coordinate the process and relationships (Holti et al., 2000). One of the other main concepts however, is that all supply chain partners have the potential to contribute to the aggregation of value (Holti et al., 2000) – all supply chain actors need to be able to make a full contribution to ensure that the client's needs are fulfilled and that value creation is maximised. The client and chosen procurement method are both critical in enabling supply chain integration and project-independent construction. However, independently from the demand, parties at the supply side may evolve towards more integrated production and business formats, through projectindependent collaboration with other parties in the supply chain as well as internalisation of neighbouring activities or businesses (Vrijhoef & De Ridder, 2005).

Pryke (2009) acknowledged the central position that main contractors play in the management of supply chains, offering great potential in this leading role. It is believed that main contractors have more influence on the organisation of the project and on the performance and quality of the work of its suppliers (Latham, 1994). Despite the fact that they have such an important role in channelling client demand through their own supply chains, main contractors are overlooked when it comes to research and useful advice (King & Pitt, 2009). Moreover, implementation of SCM by main contractors is relatively slow (Green et al., 2005) as SCM is often seen as a project-specific approach in construction rather than a central strategy such as in industries like aerospace and car manufacturing (Green et al., 2005; Womack et al., 2007). In addition, within a main contractor's organisation, the management function is typically disconnected from the production function on site as if it were two separate organisations: "one for the management function and one for getting the work done. The two organisations do not coordinate their work, and they are characterised by different goals and viewpoints" (Applebaum, 1982).

2.3 Towards SC Maturity in construction

SCM is a new way of thinking about management and processes, in order to coordinate supply chains more efficiently, by managing the associated relationships to deliver customer value, through innovation and continuous improvement (Cooper & Ellram, 1993; Christopher, 2005; Pryke, 2009; Blanchard, 2010; Fulford & Standing, 2014). It can be categorised into four different levels (Harland, 1996):

1. The management of an internal supply chain integrating the activities of a firm;
2. The management of a dyadic relationship between two immediately connected suppliers;
3. The management of a chain of businesses with which a firm has no contractual relationship; and
4. The management of a network of interconnected businesses involved in the ultimate provision of a product to customers.

The management of the different levels is necessary as they form an integral part within a greater context: the supply network. Dainty et al. (2001) and Pryke (2009) describe SCM in construction as the management of the network of relationships within which firms are embedded. A holistic view is required for each of these levels to ultimately contribute to performance improvement and customer delight within the industry (Pryke, 2009). This contribution is fundamental in the creation of competitive advantage, which reflects the influence of efficient and constructive network relationships on a firm's short-term financial position and long-term competitive power (King & Pitt, 2009; Van Weele, 2010).

Holti et al.'s approach (2000) involves essential ingredients for a construction company (level 1) to function in a SCM-driven environment (Figure 2), described as seven principles. The first principle 'Compete through superior underlying value' is concerned with enhancing the value of what is actually delivered by improving quality and reducing underlying costs. Members of the construction supply chain use their capabilities to collaboratively take the 'right' costs out in order to achieve competitive prices and mutual benefit. This requires a good understanding of the client's perception of value, in principle defined as a combination of a lower price and higher quality, and insight into cost components, the protection of margins, and the elimination of waste and inefficiency. This main principle depends on embracing the other six as a mutually reinforcing set. 'Define client values', the second principle, involves a more rigorous way of value assessment – client value being defined as a built-up and clarification of the functional requirements, the design character and the target through-life cost (TLC) profile for the desired building. The third principle 'Establish supplier relationships' encompasses commitment to forming long-term relationships with a small number of suppliers in each key supply category around major and core-business, still allowing variety and flexibility for varying types of projects in varying regions. Essential are the project-independent characteristics and the need of commonly identified and clear business goals for the overall supply chain at the outset. ‘Integrate project activities’ is the fourth principle and describes a mechanism for the choice of strategic long-term partners through which effective management of the partners that collaborate on a project can be achieved. The goal is to resolve all design-related issues at key interfaces at an early stage by creating clusters and use concurrent engineering, with specialist suppliers involved early in the process to create commitment to subsequent phases. The fifth principle ‘Manage costs collaboratively’ employs a unique approach to dealing with and optimising costs, referred to as 'target costing', where suppliers work backwards from the client’s functional requirements and the maximum market price for the item. Margins are then disengaged from risk allowances and costs through ring-fencing, providing the security to look at underlying costs. ‘Develop continuous improvement’ is the sixth principle aiming to achieve decreasing prices and/or improving functionality and value for future projects. It is a vehicle for achieving longterm performance improvement that cannot be achieved over the life of one project and therefore, involves agreed long-term relationships where component and process costs are continuously reduced through systematic planning and process improvement. Lean principles and kaizen events are made a regular, reliable and long-lasting occurrence by taking control of the supply chain (Blanchard, 2010).

‘Mobilise and develop people’, the final principle, responds to the substantial cultural change needed in the construction industry in order to successfully implement SCM. This includes the mobilisation and development of employees through four key mechanisms: a visible, systematic commitment from the top, the facilitation for project teams, training in new skills and economic incentives.

Figure 2: The seven underlying principles (Holti et al., 2000).

The seven principles outlined above demonstrate that implementing SCM encompasses the recognition of essential SCM elements internally, within an organisation. The aim of this study is to outline the differences in SC Maturity of main contractor and supplier organisations, and to underline the need for greater degree of main contractor leadership, in order to improve the internal organisation of both types of firms, and subsequently achieve greater collaboration between them.

3. Research method

Given the exploratory nature of the study, a qualitative approach was considered the best-suited for this research (Blumberg et al., 2011). Data collection was largely based on primary data, which, building on Yin (2014), was gathered from semi-structured interviews with representatives from main contractor and supplier organisations.

From an earlier pilot study (Broft, 2012; Pryke et al., 2014; Broft et al., 2016), it was evident that the companies involved in the study had several uncertainties regarding their own and their partner's position and role in an effective SCM collaboration. It seems that most barriers in the relationship flow from these uncertainties and that supply chain integration cannot be established when the parties involved are not integrated themselves. Therefore the conclusion was drawn that it would be beneficial to give the companies a system of self-evaluation as an indicator of SC Maturity and feedback to enable them to integrate internally and thus facilitate gradual and meaningful implementation of SCM within the entire chain (Broft, 2012; Pryke et al., 2014; Broft et al., 2016).

The first part of the main study thus focused on the analysis of the current SCM status of all individual companies involved (Broft, 2012; Pryke et al., 2014; Broft et al., 2016) – four large main contractors and four larger suppliers, operating in the Dutch construction industry, were included in this research. The participating companies, like most other European firms, had been confronted with a difficult economic climate, during the period of this research, characterised by increasing competitive pressures and profit demands. The research was limited to the managerial level of the companies and involved respondents with the responsibility of implementing SCM. Table 1 provides an overview of the participating companies and representatives.

Table 1: Overview of organisations involved.

MAIN CONTRACTORS			
Name	**Position**	**Company**	**Company Profile**
Interviewee 01	(Ex-)Director Purchasing	Organisation 01 (BN)	Construction, development, infrastructure, services and specialist activities.
Interviewee 02	Director Purchasing	Organisation 02 (BM)	Construction, mechanical/electrical services, civil engineering, property, PPP.
Interviewee 03	Director	Organisation 03 (DV)	Construction, real estate and infrastructure.
Interviewee 04	Director	Organisation 04 (WB)	Housing, social/commercial properties, and renovation.

SUPPLIERS			
Name	**Position**	**Company**	**Company Profile**
Interviewee 05	General Director	Organisation 05 (GV)	Supplier/manufacturer of aluminium windows, facades, doors and blinds.
Interviewee 06	Business Leader	Organisation 06 (GB)	Precast concrete floor systems and other concrete construction elements.
Interviewee 07	Director	Organisation 07 (TV)	Plumbing and sanitary installation company.
Interviewee 08	General Director	Organisation 08 (BV)	Manufacturer of the interior door/frame package.

The themes and accompanying questions for this analysis were derived from the seven principles, described in Section 2.3. Maturity levels were developed after the interviews were held with the highest maturity level representing the ideal elements of an SCM organisation according to Holti et al. (2000). Jointly, the current score provides a relative comparison of SC Maturity among participating companies rather than an absolute measure. This relative comparison is used to differentiate between SCM elements, and to compare the two different types of companies and relate this comparison to the different role perspectives. Section 4.1 and 4.2 include a description of the findings.

The leading role of main contractors is further investigated in a case study, the second part of the research, in which a main contractor decides to form long-term agreements with thirteen suppliers in its key supply categories. This main contractor believes in collaboration and initiates the integration of its supply chain. The study then examines the maturity of all supply chain actors involved at the start of their collaboration based on the most important principle (Section 2.4). The themes around Principle 1 include insight into cost components, margins and the level of waste (Holti et al., 2000). Again, the two different types of companies are compared – research is extended to project/site level. Table 2 provides an overview, including some basic facts, of the fourteen supply chain actors.

Table 2: Overview of organisations involved in case study (facts based on 2015).

	Discipline	**Location**	**Turn-over**	**Amount of employees**				
		(region)	**Total**	**Total**	**Fixed**	**Flex.**	**Office**	**Site**
Contractor T	Main contracting	Utrecht/Overrijsel	188 mln.	258; 65	60	5	35	30
Supplier T1	Finishing	Overrijsel	15 mln.	125	95	30	25	100
Supplier T2	Plastering & Finishing	Zuid-Holland	15 mln.	150	40	110	20	130
Supplier T3	Timber structures	Groningen	-	89	58	31	23	68
Supplier T4	Concrete contractor	Friesland	53 mln.	209	186	41	57	152
Supplier T5	Finishing	Overrijsel	26 mln.	300	100	200	25	275
Supplier T6	Production of precast concrete	Friesland	21.1 mln.	80.8	65.4	15.4	19.2	61.6
Supplier T7	Production of doors	Gelderland	38.3 mln.	157	-	-	45	112
Supplier T8	Tiling	Overrijsel	35 mln.	58	28	30	4	54
Supplier T9	Production of wooden frames	Friesland	5.5 mln.	38	25	13	8	30
Supplier T10	Contractor of storages	Overrijsel	137 mln.	243	243	-	-	110
Supplier T11	Tiling	Noord-Holland	7.5 mln.	45	-	-	4	41
Supplier T12	Installation technology	Overrijsel	59 mln.	513	347	166	-	409
Supplier T13	Production of carpentry	Gelderland	17 mln.	119	95	24	34	85

4. Research findings

This section presents the research findings. It should be noted that the research findings have limitations presented by the chosen research methodology. The findings concern only a limited amount of main contractor and supplier organisations and need to be tested using quantitative research in order to be representative of the industry.

4.1 The relative SC Maturity of eight construction companies

The analysis of the research findings is based on the developed SC Maturity levels. Emphasis is placed on the current characteristics of the organisation and its level in implementing important SCM elements. The scores achieved in relation to the themes are summarised in Table 3. The individual ratings as shown in this table mirror the status of each participating organisation against Holti et al.'s (2000) ideal SCM organisation. The table shows scores that range between 0 and 3, and just occasionally reach higher than 3, for both main contractors and suppliers. As set out in Section 2, the construction industry is known to be a challenging industry for SCM implementation (Aloini et al., 2012).

The ratings achieved for Principle 1, 5 and 6 are the lowest across the seven principles. Principle 1 ‘Compete through superior value’ requires insight into the build-up of costs and clarity about ‘right’ and ‘false’ costs, however, this clarity seems to be missing – “*The construction world is familiar with the concept of failure costs, but nobody knows how high these costs are or even what the real definition involves*” (Interviewee 02, BM). Findings in relation to Principle 5 ‘Manage costs collaboratively’ reflect practices that favour short-term financial gains, such as non-legitimate risk transfer, contradicting SCM. Principle 6 ‘Develop continuous improvement’ was found to be well-understood, however doubts exist on how to correctly implement it in a project-environment. Some of the issues raised by interviewees were the difficulty of applying project-specific knowledge to other types of projects (Interviewee 01, BN) and the fact that knowledge often resides with people (Interviewee 07, TV).

Table 3: Overview of the themes and SC Maturity ratings.

	BN	BM	DV	WB	GV	GB	TV	BV
General								
Insight into the construction supply chain	0	2	2	2	0 / 1	1 / 2	3 / 4	3 / 4
Principle 1: Compete through superior value								
Insight into profit/turnover level	0	1	2	0	0 / 1	0 / 1	2	2 / 3
Value adding activities and wastage	-	0	2	2	1	1	2	2 / 3
Principle 2: Define client values								
Client's wishes and specifications	0 / 1	2 / 3	3	1 / 2	1 / 2	1	3 / 4	1
Customer delight	1	2	3	3	1	3 / 4	3	3
Principle 3: Establish supplier relationships								
Black box of subcontracting	0	1	1	3	1 / 2	1 / 2	2	2 / 3
Strategic partners	0	3	1	2	1	2	3	3
Principle 4: Integrate project activities								
Partner involvement	1	1	1 / 2	2	1 / 2	2 / 3	2 / 3	2
Integration of processes	0	0	2 / 3	2 / 3	1 / 2	2	2	2
Principle 5: Manage costs collaboratively								
Initial price	2	1 / 2	2	2	1	1 / 2	1 / 2	1 / 2
Risk management	1	1	3	1 / 2	0 / 1	2	2	2 / 3
Principle 6: Develop continuous improvement								
Continuous improvement	0	1	3	1	0 / 1	1	1 / 2	3
Principle 7: Mobilise and develop people								
Development of people	0	2	2 / 3	1 / 2	1 / 2	3	3	3

4.2 A relative comparison of main contractors and suppliers

Comparing the two types of companies, it is easily noticed that Principle 4 and 7 are better exercised by suppliers. Principle 4 ‘Integrate project activities’ encompasses the involvement of partners and the integration of processes and activities, which due to a supplier’s greater specialisation is found to be more straightforward to manage. Principle 7 ‘Mobilise and develop people’ could be explained with similar reasoning as individuals are of greater importance in the delivery of actual value in relation to their particular speciality. In addition, although the variation in scores is not high, it should be noted that main contractors, largely considered by Holti et al. (2000) as the leaders of SCM implementation, do not score particularly high in order to take up that role.

4.3 A case study: Another comparison

The fourteen companies involved in the case study are linked through long-term agreements for the construction of dwellings in three different regions of the Netherlands. For most of the key supply categories the main contractor has selected one supplier, except for categories related to the finishing stage, where the main contractor prefers to work with one supplier per region. All selected partners (see Table 2) are evaluated to indicate their SC Maturity at the beginning of their collaboration, following the method used in the first study. This Section focuses on the findings in relation to three themes – insight in cost components, margins and waste levels – and a total of eighteen sub-themes, characterising Principle 1 (insight in cost components is added to the original themes in this second part of the research). Table 4 gives an overview of the scores achieved, in which the sub-themes are averaged and reduced to six.

With regards to insight in cost components directors (showed as bold) on average show a higher score, sometimes even reaching 3.4 or 3.8, compared to other functions within the companies. In all cases, knowledge of general costs is limited to the own organisation and therefore, in most cases does not exceed a score of 2, and risks are known differentiating from score 0.7 to 3. Production companies (Supplier T3, T4, T6, T7, T9 and T13) seem to show unusually high scores on some elements, most probably due to their early involvement and a strong dependency on a limited amount of other partners.

Table 4: Overview of the three themes (Principle 1) and SC Maturity ratings.

	Insight in cost components			**Insight in margins**	**Insight in waste levels**	
	Material/Labour	**General costs**	**Risk**	**Margins**	**Hours**	**Duration**
Contractor T	2.8	2.6	2	2	1.6	3
Supplier T1 *	**3.4**; 1.6	**2**; 0.6	1	**2**; 2	**1.6**; 2.3	2
Supplier T2	2.2	2	0.7	**1**; -		1
Supplier T3	**2.2**; 1.4	2	2	**2**; 0	1	**1.6**
Supplier T4	2.4	1.6	1.5	2	1	1.5
Supplier T5	**2.6**	**2**	**2.5**; 1	**2**; 2	1.3	2
Supplier T6 *	2.8	**2**	1	**2**; 2	0.3	2.6
Supplier T7 *	**3.8**	**1.6**	**1**	**2**		
Supplier T8	2	**2**; 2.6	4	**2**; 2	**3**	**2**
Supplier T9	1.4	**1.3**	2	**2**; 0	**2**	3; 2.6
Supplier T10	1.8		**2.5**		**1.3**	2
Supplier T11	**2**; 0.6	**2**	1.5	**2**; 0	**1**	2
Supplier T12 *	1.5	1.6	3	1	2	3.8
Supplier T13	**3.2**		2.5	**2**; 0	**2**; 1	**2**; 2

It could be concluded that all companies have an equal insight into margins, limited to their own level (score 1 or 2) and therefore, no insight into their direct partners' nor suppliers' margins. Insight in waste levels differs from score 0.3 to 3.8. The companies that score higher turn out to be familiar with the Lean philosophy (marked with *) and its implementation within their processes. Even so, insight is limited to just parts of the process – their own process – rather than the total process. The main contractor, again, does not score particularly high regarding all three themes.

5. Conclusion

SCM can support the move away from traditional adversarial relationships prevalent in construction supply chains and provides an opportunity for the delivery of more value to clients. This value is derived through collaborative working, easier knowledge transfer and the creation of long-term effective working relationships. This study focuses on collaboration at the lower tiers of the construction supply chain, particularly the collaboration between main contractors and suppliers – this collaboration was described as challenging with characteristics that obstruct successful implementation of SCM – and it describes the potential of main contractors as focal companies or supply chain integrators.

With their central position in the management of supply chains, it is believed that main contractors have more influence on the organisation of the project, and on the performance and quality of the work of its suppliers. This research uses Holti et al.'s approach (2000), which involves single point responsibility to the client with a collaborative model of overall leadership in achieving value for money, to effectively integrate supply chains, and its seven principles to investigate the maturity of different supply chain actors. The developed SC Maturity levels proved to be valuable in reflecting the environment in which the participating companies attempted to deal with SCM, and to compare the internal organisation of the two different types of companies with regards to essential SCM elements. It has shown that firms are faced with many barriers in the process of SCM implementation. Organisations were found to be particularly struggling to compete through superior value, manage costs collaboratively, and develop continuous improvement within their supply chains. The findings also underline the low SC Maturity of main contractors. Further investigation, based on a case study involving an initiated supply chain, reveals the limited insight in margin levels, many unknown components in costs and differing knowledge of waste – most organisations, including main contractor organisations, only seem to focus on information within their own boundaries.

The findings of this study have a number of important implications for future practice. First, the study highlights the need for a greater degree of main contractor leadership – especially when main contractors would need to take the important role as supply chain integrators – and improved internal organisation of both types of firms in order to achieve greater collaboration at the lower tiers of the construction supply chain. In addition, this paper lays the basis for further development of the SC Maturity levels and the first steps towards changing it into a usable improvement framework that could be applied to main contractors' (and suppliers') SCM activities.

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Design Management – Learning across trades

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Abstract

The Architecture, Engineering and Construction industry (AEC) has a potential to increase its productivity and increase the value of its projects. There is a common apprehension that the overall performance of AEC industry has not evolved at the same pace as the performance of other comparable industries. The increasing complexity of AEC projects that follows the rising focus on energy efficiency and sustainability renders it even more important to reduce the deficiencies in building design. The AEC, shipbuilding, and offshore construction industry are all project-based industries, mainly consisting of designing and manufacturing unique products for different customers. These similarities make the comparison of these three trades interesting. In addition, the offshore construction industry and shipbuilding industry are typically both recognized to have a high level of complexity. As AEC-projects get more complex, this renders knowledge transfer between these industries pertinent. This paper reports on a pilot study, undertaken in order to identify main differences and possible similarities between the trades, specifically questions pertaining to the management of design. The methodological approach chosen consisted of a literature review, a document study, and interviews with key participants from an AEC contractor, a shipbuilder, and an offshore contractor. The interviews were carried out as group sessions with two or more participants at a total of 11 sessions. In this paper we highlight two key processes, planning and coordination, and furthermore, we present the learning potential between the different trades.

Keywords: Design Management, Planning, Coordination

1. Introduction

The AEC (Architecture, Engineering and Construction) industry has a potential to increase its productivity and to increase the value of its projects (Bråthen, 2015; El. Reifi & Emmitt, 2013; Mejlænder-Larsen, 2015). Different authors have criticized the AEC industry for its ability to evolve and increase its performance (El. Reifi & Emmitt, 2013; Hansen & Olsson, 2011; Pasquire et al., 2015; Rios et al., 2015). Industries such as the offshore construction (OC) and shipbuilding (SB) industries have evolved faster than the AEC industry (Grimsmo, 2008). As AEC projects increase in complexity, could the industry learn from other trades who are recognised as tackling such complexity? The OC and SB industry are typically both recognized as being characterised by a high level of complexity (Aslesen & Bertelsen, 2008; Lia et al., 2014). In addition, the AEC, SB, and OC industry are all project-based industries, mainly consisting of designing and manufacturing unique products for different customers. These similarities make the comparison of these three trades interesting.

This paper reports on a pilot study with three Norwegian companies from these industries. The main objective was to find the similarities and differences in order to identify potential improvements for design management in the AEC-industry, while the actual process of learning is beyond the scope of this paper. The research has revealed some specific areas – like planning, coordination and design management – where the potential for learning across the trades is especially high. At the same time it must be acknowledged that the contextual frameworks of the trades vary, making a direct replication challenging. The research was carried out according to the following three research questions:

- What characterize projects in the three different industries?
- What key process characteristics stand out as of particular importance?
- What learning potential lies in these key characteristics for the AEC-industry?

Typically, the AEC-industry is characterized by strong sequential mindset (Kestle & London, 2002). This influences both project and design management(Knotten et al., 2014). The potential value creation depends on reciprocal design processes, which are difficult to plan and manage (Hansen & Olsson, 2011). A potential value creation is well recognized in the theory, but only to a limited degree implemented in the industry. Our findings aim to analyze to what extent this gap can be addressed, using insights and practices from other industries

2. Theoretical Framework

The three different industries (AEC, SB and OC) can all be classified as engineering-to-order firms. This means that the firms in those industries know little to nothing about what specific to produce before the customer delivers a receipt i.e. all production is customer driven. Furthermore, engineering, design and production activities are all part of the customer order lead time (Bertrand & Muntslag, 1993). Although firms in the three industries described in this paper are all engineering-to-order firms, there are some areas those kind of firms usually differs (Bertrand & Muntslag, 1993): the complexity of the products, the degree of customer specificity of the product, the lay-out and complexity of the production process, and the characteristics of the market and competitors

The AEC industry is a fragmented industry, relying on many different actors from the start to finish of the project (Kerosuo, 2015; Zidane et al., 2015). This can cause problems with communication and teamwork within the construction projects. As Dainty, Moore, et al. (2007) describe, large project based organizations can experience communicational challenges between the temporary project and the permanent functional organization. Further, given that a construction project are organized in several phases and consists of several different actors from different organizations, more opportunities for communicative problems can arise. This typically arises out of the fact that different organizations involved in the project have different tasks, cultures and objectives. The scope of work in the AEC industry also varies from i.e. refurbishment of a house to multi-billion-hospital project, differencing in both economical size and complexity. The scope also affects the organization of the projects in competence, size and culture (Dainty, Green, et al., 2007).

The OC industry is characterized by outsourcing services, relying on different vendors to do one or more of their activities. This is a strategy used by OC companies to cut costs and focus on their core competencies (Khan et al., 2003). E.g. a company producing housing rigs on an oil platform have their core competencies in producing those houses and might have less experience in IT services. A service necessary to administrate the production of those houses, but not a service that the company can compete with other pure IT company on. Therefore, outsourcing of this service might be a cost reduction for the company, as to the opposite of having an internal IT division. However, later years there has been little proof of cost savings with outsourcing (Olsen, 2006). Furthermore, there is evidence that the industry have started outsourcing high complexity engineering services in addition to services like IT-support (Olsen, 2006).

The SB industry is characterized as an industry with clusters of several different companies working together in alliances to form the whole supply chain (Wickham & Hall, 2006). The industry is competing in a global marked, which has changed the Norwegian industry over last two decades to work more multi-located and dispersed (Kjersem & Emblemsvåg, 2014). The increasing complexity of the vessels task leads to more complex products (Aslesen & Bertelsen, 2008). Kjersem and Emblemsvåg (2014) view the flexibility of the Norwegian industry as a competitive advantage, being able to produce complex vessels adapted to each client's needs. Dugnas and Oterhals (2008) list four key-production phases in SB, hull fabrication, primary outfitting, final outfitting and testing. The hull is typically produced in low-cost countries, whilst the outfitting is done at a Norwegian yard.

The characteristics of these three industries impose differences in the design process and management. Trying to achieve learning across the trades requires a deep understanding of these characteristics and their consequences.

Several theoreticians argue that there is a difference in managing a design project vs. a production project e.g. (Boyle, 2003; Jerrard & Hands, 2008). The design process is more challenging since it is not a purely linear process (Boyle, 2003; Knotten et al., 2014). The importance of design in order to create a successful project are commonly highlighted (e.g. (El. Reifi & Emmitt, 2013)), and the importance of a design management to ensure the value of the project (Hansen & Olsson, 2011).

The design phase is regarded as one of the most challenging parts of a project, and the management of the early design phase in particular. There is the general nature of the process, which varies from a creative reciprocal process to a straight sequential production process (Knotten et al., 2015).

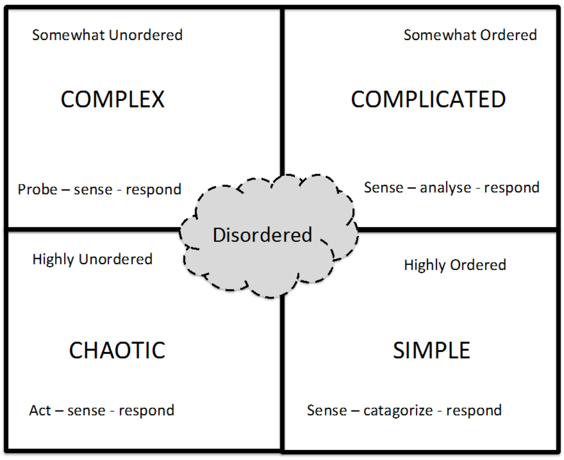

Figure 1: The Cynefyn framework adapted by Walker(2015)

Projects can be looked upon as complex, yet the complexity can be defined in many different ways. A complex system has many typical characteristics such as it involves a large number of non-linear interacting elements, in which a small change can produce large major consequences (Snowden & Boone, 2007). Snowden and Boone (2007) use the Cynefyn framework to describe the context of the situation. The framework describes five different domains, in order for a manager to make de appropriate choices. The domains are simple, complicated, complex, chaotic, and disordered. See Figure 1.

The Cynefyn framework of management is also relevant for understanding complex AEC projects (Klakegg et al., 2010; Walker, 2015). This is especially true regarding design and design management, where the processes themselves are complexly interdependent (Knotten et al., 2014; Knotten et al., 2015)

Kalsaas et al. (2014) argues for Scrum as a tool to work with complex design problems, thus trying to make complex system simpler, short-sighted and to capture critical activities. Scrum is an iterative and incremental project management approach, that delivers result in increments called sprints (usually a 2 – 4 week iterations, however, it's up to the management team to evaluate the needed sprint intervals). A sprint starts out with a planning session and ends up in a review. The planning session is a box meeting where the scrum team is dedicated to develop detailed plans for the sprint. The review meeting is where the scrum team meets the stakeholders and managers to assess and review the state of the business, market and technology. There is also a short daily sprint meeting where scrum team members address the questions: "what did I do yesterday?", "what will I do today?" and "what impediments are in my way?" (E. Hossain et al., 2009; M. A. Hossain & Chua, 2009).

A major trend within the AEC-industry is to adapt VDC and Lean principles to the design management, but is also using elements from Scrum and Agile thinking. The OC and SB started with elements from Scrum and Agile thinking, but have also adapted Lean Principles.

A challenge of planning in design vs. standard management planning is that the design process consist of both sequential processes and reciprocal processes(Knotten et al., 2014). Typically the creative design process of problem solving as described by Lawson (1997), are viewed as reciprocal. The reciprocal interdependent process are thus difficult to plan since cutting them short they fail to discover the best solution and letting them run indefinite creates a progress problem for the whole project (Knotten et al., 2015). Olsson et al. (2015) suggests the use of agile methods in order to deal with reciprocal activities.

How to implement the new knowledge between the trades is not a part of the paper. It is noteworthy, however, to mention some of the research done in the AEC industry concerned with the question of barriers of learning. Skinnarland and Yndesdal (2014) points out problems with unlearning, organizational structures and norms as barriers of learning. Christensen and Christensen (2010) raise the question of the difficulties of learning because of syntax, semantics and motivation between the trades in AEC projects.

3. Methods

This paper compares characteristics of the AEC-industry with those of the SB- and OC industries respectively, by studying internal documents and interviewing key stakeholders. Primarily, this case study was carried out according to the recommendations of Yin (2014). According to Yin (2014) "a case study is an empirical inquiry that a) investigates a contemporary phenomenon within its real-life context, especially when b) the boundaries between phenomenon and context are not clearly evident. (…) In other words, you would use the case study method because you deliberately wanted to cover contextual conditions".

The bounding of the case is to understand how different trades execute design and design management. Each of the companies represent a large actor in their trade and have invested in measures for integrated methodology for design management, in order to be a lead actor in their trades. The research has been done by interviews and presentation of their way to conduct business. The sessions are semi-structured interviews letting the informants present and placing follow up questions. There are conducted 11 group interviews, which are transcribes. Along this there is done a literature review concerning design management & engineering management according to the recommendation of Bloomberg et al. (2011).

4. Findings

The study shows that the AEC industry is usually set up with consultants and contractors apart. Few, if not none contractors have their own design crew. The designers and engineers are there procured at each project. A typical constellation would be a sub-contractor responsible for the function of his deliverance, i.e. responsible for the design as well. This means that the project team is new and there actually is an opportunity to gain new experience for the team. This seems not to be exploited; instead, a post-project evaluation is planed in order to learn the key-takeaways of the project.

The architect and consultants are often hired directly by the client at an early stage of the project to make a brief. If the contract is a design-build, the architect and/or the consultant might be transferred to the contractor. This might lead to a conflict of interest between the architect pursuing the goal of a perfect building and the contractors view to only build what is in the brief.

The ship builder (SB) differs in several major aspects. Firstly, is the project a customized or a standardized ship project? The standardized ship is a known design with a few options that can be chosen. Changes from that or completely new designs are viewed upon as a customized ship.

Secondly, if the project is to be built at the builders own yard or at a remote yard in e.g. Asia. Will the whole ship be built off-site or parts for an onsite assembly? This is solved in different ways depending on the complexity of the ship and the timeframe.

Very often, the designers take out a previous design as a starting point when they try to fulfill the client´s requirements of speed, handling and function. The function and the planned whereabouts of the ship is important since this affects critical design solutions as e.g. the power plant, hydro dynamics and the design. A ship operating in artic weather needs a different layout in order to minimalize the icing of the ship. The feasibility of the projects starts with the alignment of hydrodynamic capabilities, engine possibilities and propulsion, deeming these as the most important problems to solve. When this is solved, the design of the hull can finish and production starts. The engineering process is often parallel between design and production, narrowing the options of change as the parts are finished produced. The SB has an own department of engineers to develop the projects. When the project is realized, an engineering department takes over, very often with a complete new team. The transition is often made through a “kick-off” meeting and a common “audit” of the project. The engineering team consists of in-house personal, though they can be multi-located. The multi-located engineers have different cultures and this can be a challenge for the manager of the engineering.

The planning of engineering is based on deliveries to the production, as in drawings. This is monitored by a computerized planning system linking working hours to drawings. This does not monitor the value creating processes.

The offshore construction company (OC) delivers a part of a larger production system, and therefore has a lot of predefined interfaces both in space, weight, and technical requirements. All these are predefined before commencing the work. Even though the company deals with EPC (Engineering-Procurement-Construction) contracts, the company can be viewed as a supplier. The clients of the company are mainly large OC companies with long experience that knows what they need and what they want.

Like the SB, the OC has its own design team. However, the OC has a design team that consists of the same members through the whole design process. When the workload is high, they hire in extra crewmembers to the projects to help offload some of the work from the key members of the design team. Keeping the same design team thru the whole process ensures that the knowledge gathered from early design phase is brought thru the whole design process. To ensure that knowledge from construction is brought into design, key members from construction are brought into early design. However, if the construction members have a lot to do at the production site, they usually do not have time to participate in the design meetings.

Another clear advantage with having all the design trades in-house is the teamwork on each project. When the members know each other, they do not need a lot of team building exercise to get to know each other before the project starts. Further, they all have the same organizational culture. This ensures that they all work to achieve the same goal of the project and the company. The trust between the different design team members is already build before the project starts.

The design process at the OC follows a stage-gate model with clear deliveries at each stage. At the start of the project, key members of the design team collaborate and agree on a matureness level needed to proceed to next stage. The maturity level of each stage can typically be the Level of Detail (LoD) on a model and the placement of those elements in the model. The designers use BIM as a main tool for design. When an area in the model reach the correct maturity level for the given phase that area is frozen in the model. Not allowing the designer to do further changes within that area on the model. E.g., pipe-support needs the numbers and sizes of the pipes to be modeled correctly, when they are finished modeling the pipe support they freeze it and gives it a predefined color, which means that the option to add more pipes or alter the size is of the pipes is not gone.

When the BIM is considered finished and the client approves of the design, detail drawings are drawn in 2D. Designers in low cost countries sometimes handle the detail drawing process, to cut cost and to offload work from the company designer. Although, the design is complete and no new elements are brought in when this process starts, it requires a strict quality control system. Furthermore, it is very important that the decision to move to detail drawing phase is acknowledge by the client and that client understand that a change order after the detail drawing starts will be costly. Figure 2 shows a comparison of the design process in the different trades.

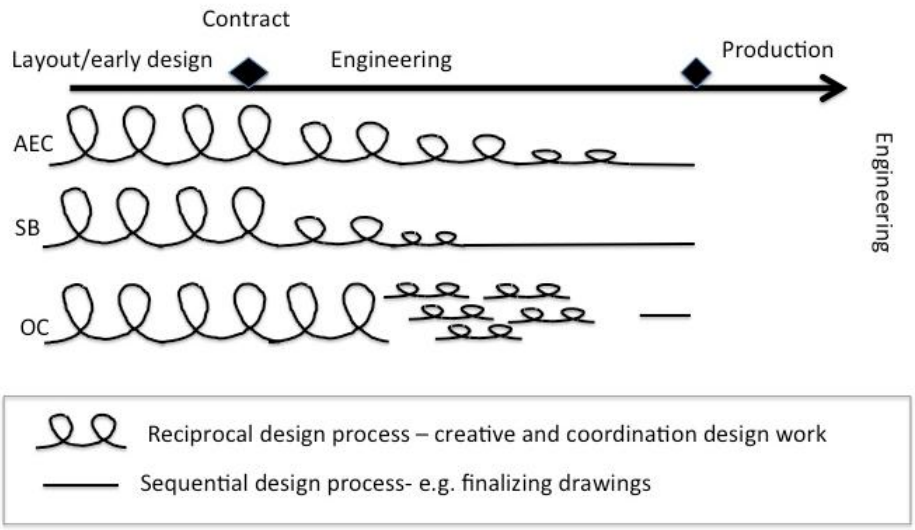

Figure 2: Design process in different trades

Before fabrication, the fabrication-engineering department takes the detailed 2D drawings and makes fabrication drawings. Those drawings are very detailed and focused on the information needed for fabrication. E.g. details of steel bolts and bends needed for the fabrication. The members of the engineering-fabrication department all have long experience from working in fabrication. They understand what is needed and how detailed the drawings and description needs to be.

The complexity of the products, processes and context varies from the different trades. There is a difference between an office building, Platform Supply Vessel (PSV) or an oil derrick. The complexity can differ in technical challenges, interconnections, time frame and other dependencies. Yet some of the tasks are similar. Design or engineering is about transforming the needs of the client and user to a finished product. In table 1 we present some of the key characteristics of the trades.

Table 1: Key characteristics of the trades

	AEC	OFFSHORE	SHIP-BUILDING
Project-based production	Yes	Yes	Yes
Unique products	Yes	Yes	Yes
Use of Sub contractors	Yes	Yes	Yes
Own design team	No	Mostly	Mostly
Common production site	No	Yes	Yes
Prefabriction	Some	Yes	Yes
Contracts	DB	EPC	EPC
Competition	Local	Global	Global
Professional Clients	Mostly	Yes	Yes

5. Discussion

The characteristics of the AEC-, Shipbuilding (SB) - and Offshore Construction (OC) industries are discussed previously in the paper and summarized in Table 1.

Through the results from our studies we ended up with two important key processes where we think the potential of improving is important, notably planning and coordination.

Planning is an important part of design management. The planning processes between the three industries are partly similar. Production methods usually set the framework for the design plan. This is usually carried out by an assumption of what production material (e.g. drawings) needs to be finished at what time in order to have an efficient production. However, using drawing as a measure of design creates some challenges. The drawings are the deliveries from the design process to the production process and just measuring according to that, do not say anything about the quality and value of the product, i.e. the design. Furthermore, the design process is inherently a creative reciprocal process (Knotten et al., 2015), creating challenges in coordination and planning of the design process (see Figure 2). Spending more time designing can increase the value of the product, by a better design. However, the project is time restricted and knowing when the correct point to stop the creative process is difficult. A focus on more than just deliveries of drawings is needed. The SB tried to estimate the workload by experience of making drawings. More drawings make more workload. For the AEC contractor, drawings were more a tool to check of finished work and measuring progress. The OC had a different approach and measuring maturity for the designed products. This meant that there was a focus on getting the product right in the BIM, rather than to just measure produced paper.

The use of coordination tools such as BIM differenced also in the studied cases. In the AEC industry, the use is still on a modest level of detail. The models main purpose is for coordination and visualization of solutions, and as the foundation of drawings. The SB used BIM in the detailed engineering, as at coordination tool. The OC had set a purpose for the use of BIM, and this was linked to stages of the design phase and to the development of the design. At certain level of the design-phase, the model would be at an agreed level of detailing (LoD). When this was coordinated, through model checks, the design was frozen and the elements marked in a particular color, letting everyone understand that these components were at certain stages. Components also evolved during the design phase, from placeholders to detailed models of the real thing.

What learning potential lies in the key characteristics for the different trades? The way OC uses BIM as coordination and planning tool is one of the key characteristics the other trades could learn from.

In planning for the design phase there is a focus on reaching the product, which are drawings for production. By using the amount of drawings, you get a timeframe for the design process. However, the OC focused more on the task and the objects in the model, and using that as milestones in planning the design. This is a planning method that both the AEC and SB can adapt and use. This would be more of a stage gate method(Klakegg et al., 2010), where maturity, objects, decisions, together with production and procurement would dictate the plan. This together with collaborative planning(Bølviken et al., 2010; Fundli & Drevland, 2014) would help to create better plans.

Using BIM in larger extent to coordinate the work would benefit the AEC. Still there is a hang to use drawings for coordination, but by using the model as the OC uses it would reduce the amount of drawings. This together with the plan would help to get a more efficient design phase. The OC uses sprints to address complex engineering issues; the AEC uses a variation of ICE. The use of sprints, by clearly defining objectives, stakeholders and a timeframe is an efficient way to deal with complex problems(Lia et al., 2014).

6. Conclusions

A comparison of the AEC, Shipbuilding (SB) and Offshore construction (OC) industry shows that there are a lot of similarities, but also some differences, as presented in table 1. The main differences are that the SB and OC, have in-house design teams, fixed production sites and are competing on a global market. There are also several contextual differences regarding framework, culture etc. The similarities are mainly in the fact that they are project-based producers of unique products, and they have similar contracts forms. This makes the industries useful to learn across the trades.

In this paper, we highlighted two key processes, the planning and coordination of the design phase. These are equally important to all of the trades. The approach to plan and coordinate the design phase is different from each trade, but they are struggling with some of the same issues.

This pilot study shows that the AEC has learning potential by implementing planning and coordination methods used by the OC. The OC have implemented a new way of planning and executing the engineering, thus exploiting more of the benefits of BIM. By producing production drawings at the last responsible moment, they let the coordination processes last longer, leaving time for the design to evolve and mature. See figure 2. The OC has as the other trades a reciprocal design process before contract. After contract all designs processes are somewhat reciprocal, but the OC is divided in smaller concrete task. By using agile approaches such as sprints, OC can work through design challenges efficiently. After the reciprocal coordination work, the finalizing of the drawings is viewed as a sequential process.

In this paper we have compared the industries and identified the learning potential across trades. How the AEC industry should implement the methods of the OC industry is not discussed here Research carried out on learning within the AEC industry identifies, however, several barriers to learning. It would be safe to assume that these same barriers also would apply for learning across the trades.

As this is just a pilot study the next step is to try out the suggested improvements in AEC projects, and report of the findings there.

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Role of Power and Sense Making in the Briefing of a Small Renovation Project

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Abstract

This action based qualitative case study research studies the role of power and sense-making in the briefing process in three small university renovation projects. It is essential for the heads to understand the role of power and sense-making in projects in order to pay attention to a sound decision making process. However, every project faces situations where the powerful heads are forced to decide how to continue when the sense-making process is too lengthy and the stakeholders are not able to tell what they want with the limited resources. This paper answer the research questions: how the power affects the decision making, and how sense-making can be organised in order to reach better decisions.

Keywords: Renovation project, briefing, decision making, sense making, power

1. Introduction

At early stage of the project the broad scope and purpose of the project and its key parameters including overall budget and program need to be agreed. This process is called briefing, also known as architectural programming in the USA and Asia. During briefing a client's requirement is clarified and the design team is informed of needs, aspirations and desires, formally or informally (CIB, 1997). The transfer of decisions and all the information enables achieving a better understanding of the requirements and preferences at the project inception stage (Jenkins et al., 2012).

There are following challenges linked to briefing: lack of identification of client needs; inadequate involvement of relevant parties of the project; inadequate communication between those involved in briefing; insufficient time allocated for briefing; briefing information still given during late design and construction stages; and contractor having no real understanding of client objectives (Barret and Stanley 1999, Kamara and Anumba 2001; Yu et al 2005) . This paper focuses on the level of identification of the needs, aspirations and desires during the decision making process. The decisions are made by those who have power to make decisions and due lack of time with bounded rationality of the above mentioned needs, aspirations and desires of the stakeholders. The decision makers try to make sense of the situation and make decisions.

The research is qualitative aiming at describing the sense making challenge and role of power in strategic briefing. The case study analyses three small renovation project. This paper answer the research questions: how the power affects the decision making, and how sense-making can be organised in order to reach better decisions. .

The paper introduces in the chapter two the briefing process and how the decisions are made during briefing in other words how the stakeholders make sense and use their power. The chapter three introduces and analyses the case study. The chapter 4 discusses the finding and chapter 5 makes the conclusion.

2. Decision Making During Briefing

The large construction projects planning is shown to be a time-consuming process, in which design disciplines carry out their design and analyses separately, and the number of possible iterations is low (Flager et al., 2009, Eastman et al. 2011).To enable creating the alternative design solutions, a decision-making process is needed to specify where project goals and functional needs are mapped (Schade et al., 2011). Iteration is natural to design and should be allowed between the client and practitioners in the construction process (Thomson, 2011, Sidwell,1990). The iteration process is believed to improve the quality of the end result.

2.1 Briefing process challenges

Successful briefing identifies, understands, defines, and communicates effectively the needs and requirements of the client and stakeholders to the project team. There are number of success factors that help to define a brief (Yu et al. 2006). In this paper we are interested in the decision making. The success factors for decision making during briefing are proper priority setting and good record of decisions made. The successful decision making is also linked to avoiding conflicts that means consensus building prior to decisions. (Yu et al. 2005).

According to the survey made by Yu (et al. 2006) the most important critical success factors for briefing in descending order of importance are: open and effective communication with stakeholders; clear and precise briefing documents; clear intention and objectives of client; clear project goal and objectives; thorough understanding of client requirements; experience of brief writer; team commitment; identification of clients requirements; agreement of brief by all relevant partners; sufficient consultation from stakeholders; holding workshops with stakeholders; control of the briefing process; realistic budget and programming; consensus building ;and honesty of the team members.

2.2 Power and Sense Making

In order to make good decisions the decision makers need to know what they know and what they don't know. The understanding of not knowing something leads to a sense making process either in shared mode or alone. Fast (et al. 2011) argue that power will, via an elevated subjective sense of power, lead to an overestimation of one's understanding in decision making.

Power is unequal control over valued outcomes (e.g., Emerson, 1962, Keltner, Gruenfeld, & Anderson, 2003, Fast et al. 2011). There is also evidence that experiencing an elevated sense of power – defined as the subjective sense that one is powerful and influential, regardless of whether this is actually the case (Anderson et al. 2012) – coincides with confidence-inducing states, such as optimism, risk-taking and exaggerated perceptions of control over outcomes (Fast et al., 2009).

Project partisipants need to acquire knowledge about the implementation of their tasks and project situation as well as opinions of different stakeholder groups. This learning process can be called sense-making in other words making sense of how the opinions of others, situations, problems and proposed solutions effect on how the project is implemented. The understanding vary between individuals, which means that the organizational learning (i.e., project teams' and project-based companies' learning) needs at least partially made possible through sense-making together in order to make it possible for individuals to understand what is done. With the help of sharing, the organizational learning transcends the individual level of learning (Koskinen & Pihlanto, 2008). According to Koskinen (2014) sense-making and negotiation of meaning are ongoing processes in project-based companies. Their roles are particularly strong within the projects in which the organizational learning takes place through problem-solving activities (Cyert & March, 1992; Levitt & March, 1988).

Smith (2012) found out that the project sense-making is social and partisan; enactive in other words created with artefacts that are tangible; it is dynamic, changing over time; the sense is driven by indivivuals. So sense is

1) based on single group power – the group of people are able to decide what is right and what is wrong
2) based on two party deal. The project scope is negotiated between a client sponsor and a supplier organisation from whom the delivery of the project is commissioned.
3) based on multiparty alliance – there might be different parties with whom the project owner negotiates (Smith 2012)

3. Case studies

There are three case studies that illustrate the sense making process and the role of power in them.

3.1 Case 1: Small renovation of a kitchen and open office

The case is a small renovation project (budget around 30 000 Euros) of a university facility. The project was important for the end-users of the facilities since they needed updated facilities to improve the collaboration between the doctoral students. The head of the department initiated the project proposal. The stakeholders during the briefing process were facility users (professors, lecturers, researchers, doctoral students), designer, and facility management service. Decision during the briefing was to implement the change by using a small renovation by using only new furnishing in order to fit more doctoral students into the facilities the staff rooms were not changed. The coffee room got new door and lightning was fixed. The facilities were actually owned by another company that was also linked to the project. So even such a small project involved the end users, owner (client organisation), the facility managers (from the university and from the owner), and the acceptance from university that had to prioritise the funding for new furnishing and possible rent rise due to the renovation.

Description of the sense making in the briefing process:

- The initiator (head of the department) empowered the stakeholders the doctoral students and professors and others after having a permit from the facility management to start the process. The head talked with the professors separately about their viewpoint.
- The sense-making process was an ad-hoc process where everybody could tell about their wishes and complaints about the old facility spaces.
- Designer came to discuss with the head of department and made measurements.
- A voting of the colouring was arranged.

Role of power

- The facility manager could use power when he told that you can have the project if you are fast enough this year and make fast the proposal for his heads
- The head of the department used power when she discussed with the designer and selected the viewpoints to him without any proper drawings or notes.

The fast project

Table 1: Case study findings of the department spaces

Fact	***In the case study***	***Reason***
Project overall objectives were not clear	The end users did not know what kind of issues were possible due to lack of understanding budget possibilities	The facility manager was not tightly involved in the process. The brief was not expressed in a written format.
Process – hurry	Superiors had more **power** than they actually wanted to use	There was no timetable or planned the process – everybody worked ad hoc
Unstructured Briefing Process	Short-sighted view of the needs The process was not planned there was no information what was going on.	The long term plans were not discussed Sense making process was not open
Conflict management	The team did not agree on the colour of the walls the green colour irritates still some people	The team did not pursue to find consensus.
All stakeholders did not participate briefing	The end-users did not know the boundaries like budget	The facility managers did not give budgetary boundaries or long term possibilities
Long term view	There was a need to modify the facilities after less than two years after the renovation	The long term view was lacking and soon
Sense Making and Power	Sense was based on two party deal (the department and facility management)	The decision making was done in collaboration with the facility manager and the department

3.2 Case 2: Small renovation of a lobby and restaurant

The case is a small renovation project (budget around 200 000 Euros) of a university facility. The project was important for the university owner since they wanted to test new type of public spaces at universities. The end-users of the space found the goals also very important.. The researchers initiated the project proposal. The restaurant was found to be ful all the time but many users of the restaurant complained that during rush hour the spaces were noisy and functionally also poor. The open space was empty almost all the time.

Description of the sense making in the briefing process:

- The initiator (researchers) empowered the stakeholders (the whole university students and all the staff) to answer the questionnaire where their wishes of the spaces were asked. More than 100 responses were got.
- The designer group made proposals based on the survey
- A voting of the best design was made together with researchers, students, facility owner and university facility manager.
- The university heads had started meanwhile projects that were considered more important than the public space project.

Role of power

- Empowering the university staff and students in describing their wishes for the public space done too fast without negotiating with the university heads.
- There were other projects that were seen more important for the university and the project was postponed for future.

The postponed project

Table 2: Case study findings of the public space project

Fact	***In the case study***	***Reason***
Project overall objectives were not clear	The end users did not know what kind of issues were possible due to lack of understanding budget possibilities	The facility manager was not tightly involved in the process. The brief was not expressed in a written format.
Process – hurry	The researchers did not wait until an official decision was made	No agreements were made and the research group processed in good will
Unstructured Briefing Process	There was no officially stated requirements. For how to start a briefing process	The long term plans were not discussed Sense making process was not open
Conflict management	The stakeholders never met	The consensus was never discussed
All stakeholders did not participate briefing	The end-users did not know the boundaries like budget	The facility managers did not give budgetary boundaries or long term possibilities
Long term view	The university facility managers selected the projects without discussing about them openly. No strategies were presented	The long term view was lacking
Sense Making and Power	Single stakeholder group made the cancelation decision	Though the stakeholders were empowered the university made the postponing decision alone.

3.3 Case 3: Renovation of a University Building

The case is a renovation project (budget around 300 000 Euros) of a university facility. The project was important for the university since the facility did not fulfil the current needs when the public restaurant moved away. The university owner initiated the project proposal.

Description of the sense making in the briefing process:

- The initiator (owner of the facility) empowered the stakeholders (the university staff representatives and some randomly selected students, facility owner and the professional construction experts like architect) to participate in a collaborative design stage where first the goal was set and then the concepts were generated and finally an illustrative mock up and models were presented for everybody who was interested.
- The professional designer made proposal based on the collaborative design stage
- The owners and construction professionals evaluated the costs and made a priority check for the project
- The real design started after the commitment from the university was got.

Role of power

- Empowering the university staff and students in describing their wishes for the spaces was done openly and also the professionals were invited to participate in the decision making.
- The university was able to see how important the project was for all the stakeholders and made the positive decision.
- The professionals analysed the concepts and models when finalising the design. The stakeholders were deeply involved.

Table 2: Case study findings of the public space project

Fact	***In the case study***	***Reason***
Project overall objectives were not clear	The end users did not know what kind of issues were possible due to lack of understanding budget possibilities	The budget was not set before the process. The brief was carefully described
Process – hurry	The process was short but well structured	The process followed a four day long Charrette like model
Unstructured Briefing Process	Look above	The process followed a four day long Charrette like model
Conflict management	The conflicts were solved	The consensus pursued via discussion
All stakeholders did not participate briefing	All the participating stakeholders got a deep view of the needs	The process was open. But everybody did not participate.

Long term view	The vision was clear for everybody	The vison was first created in the process
Sense Making and Power	Sense was based on multiparty alliance	The collaborative decision making was aim of the structured process.

4. Discussion

The research questions were

1. How the power affects the decision making?

- Empowering the stakeholders requires orderly process. In case one the stakeholders were empowered but the process was not orderly and the stakeholders were only partly empowered

- There are three different types of sense modes related to power and all of them were used during the case renovation projects.

2. How the sense-making can be given to stakeholders in order to empower them in the decision making process and finally get better decisions.

- Orderly process where all the stakeholders are involved right from the beginning till the execution ensured the outcomes to be realised.

The hurry situations create easily situations where the decision makers use power and in addition the powerful situation can give overconfidence of the ability to tell what is actually needed (compare Fast et al 2011). On the other hand if the decision was not made there would not have been any modernisation (case 1).

The detailed brief documentation help the decision maker to remember what has been discussed (success factor of the brief documentation was not realised in case 1). Even in a small project the briefing process and specified brief is important (case 3). Lack of briefing document can be seen as reason for sense of power and overconfidence of the knowledge of the head understanding of the needs (case 1).

The need to hurry can give a possibility to have fast decisions but the disadvantage can be the wish to jump to solutions without thinking the long term plans (case 1 and case 2).

The findings of the case studies suggest that successful project should contain following stages:
1. The vision of the facilities,
2. Specifying the functions e.g. how many persons use at the same time the space

3. What kind of requirements the functions have for the space
4. Checking what is possible to be realised with the given budget
5. Prioritising the needs: a long term plan.

The case studies used all possible sense modes:

1) based on single group power – in case 2 the university prioritised the projects and postponed the proposed project without properly negotiating with the other stakeholders.
2) based on two party deal – during case 1 the project scope was negotiated between department and facility management
3) based on multiparty alliance – during case 3 the process involved different stakeholder groups in extensive four day workshop.

This paper analysed briefing processes of three small renovation projects and found that an orderly process can help in finding the plans that are accepted. In addition, the written brief was not important for the powerful decision maker since it looked like the decision makers could use their own explanation for their decision. The hurry situation and lack of written brief resulted a situation where the decision makers used a lot power (case 1).

The decision makers were overconfident of understanding the needs and thus they were not willing to openly discuss their decisions. The overconfidence resulted a space that looks good but is not used like in case 1.

5. Conclusions

This paper analysed briefing processes of three small renovation projects and studied how power affects the decision making and how sense-making can be organised in order to reach better decisions. Though the project studied only three cases the results suggest the need to have an orderly briefing process where all relevant stakeholders are involved.

The facility managers and construction specialists should be aware that the overconfidence that is got when own memory is trusted can lead to reach faulty directions and the just renovated facilities need renovation soon. In future it should be studied alternative sense making processes in different situations. It would be interesting to study whether the sense-making based on multiparty alliance is always important.

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Key Enablers for Effective Management of BIM Implementation in Construction Firms

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Abstract

In recent years, Building Information Modeling (BIM) has been characterized as a promising tool and approach to tackle the traditional problems inherent in architecture, engineering and construction (AEC) industry. Several AEC firms around the world have deployed BIM to execute their projects. However, the full utilization of BIM has not been achieved yet in mainstream AEC firms and on construction projects. The implementation of BIM is a significant concern for many construction firms as it requires changes in existing business processes to occur. Given the huge financial commitment and multitude of other challenges that a BIM project entails as well as the potential benefits arising from its successful implementation, it is significant to understand what is needed to ensure a successful BIM implementation. Based on a literature review and by using an approach grounded in business process change management theory, this paper aims to provide a better understanding about the enablers of BIM implementation. An enhanced understanding of the BIM enablers could help the organizations to avoid costly errors and mistakes in the process of planning for BIM adoption and implementation and to increase the potential benefits of BIM.

Keywords: Building Information Modelling (BIM), innovation implementation, Construction Management

1. Introduction

The Architecture, Engineering and Construction (AEC) industry has long been criticized for its low productivity in comparison to other industries, and the industry is facing challenges to fulfil clients' expectations and remain competitive. Traditionally, for any construction project a set of design and construction documents are generated largely through 2D CAD-based applications. The result is that the contractor ends up with a pile of 2D drawings that have to be measured and calculated manually in order to get the quantity take off for the project. The on-site planning, assembling of different building components, and coordination of large number of different trades/subcontractors are all difficult tasks to perform with 2D-based workflows. The nature of construction projects is such that they involve a large number of stakeholders and organizations, which require a high degree of collaboration and communication. A smooth flow of information, materials and other key resources is crucial to shorten the lead time and reduce uncertainty. It is the key facilitator for increased team collaboration and providing better value to the client (Titus and Bröchner 2005).

In recent years, Building Information Modelling (BIM) has been considered as an innovative technology and approach to overcome the traditional problems inherent in the AEC industry. BIM is changing the way construction projects are executed. It offers several new opportunities for the optimization of whole construction supply chain through the reduction in reworks, design and construction errors, and by providing reliable and reusable digital information about a building's whole life cycle.

The adoption and implementation of BIM, however also comes with many inherent risks and uncertainties. It is in fact a complex business process for many construction firms to manage it. Some may consider BIM as a mere technological innovation, but it should be re-classified as an organizational innovation (Succar and Kassem 2015). Organizational innovation can be considered as "a means of changing an organization, whether as a response to changes in its internal or external environment" (Damanpour 1991). In other words, organizational innovation refers to a new organizational method for undertaking business practices and/or external relations.

Implementation of BIM as an organizational innovation involves adjustments to the firm's values and culture for its introduction. It also involves significant change in organizational structure and infrastructure. Most importantly, BIM implementation involves a high degree of difficulties because it deals with significant change management and resistance of individuals to embrace the change. Due to these associated difficulties, the full benefits of BIM have not been achieved yet in the mainstream construction projects and firms (Gu and London 2010).

BIM implementation requires a well-planned and coordinated approach with due consideration different aspects of innovation management and implementation (Smith and Tardif 2009). Given the associated difficulties and a huge amount of investment required, a better understanding about the key enablers during the process of BIM implementation is vital. Since BIM implementation involves changing the business processes of construction companies, the authors believe that business process change theory may provide a better understanding about the key enablers in the

BIM implementation. In the following section, the theory of business process change will be further explained.

2. Theory of business process change management

Business process change is defined as organizational initiative to design business processes to achieve significant improvement in performance through changes in the relationships between management, information technology, organizational structure, and people (Kettinger and Grover 1995). According to the theory developed by Kettinger and Grover (1995), "any significant business process change requires a strategic initiative where top managers act as leaders in defining and communicating a vision of change. The organizational environment with a ready culture, a willingness to share knowledge, balanced network relationships, and a capacity to learn, should facilitate the implementation of prescribed process management and change management practices". In the following sections, the different elements of this theory will be discussed in detail.

2.1 Strategic initiatives

Typically process change starts with strategic initiatives from the senior management team (Kotter 1995). These can happen as a result of reaction to a need or a proactive push to leverage potential opportunities (Earl 1994). Evidence also exists that strategic change, and arguably process change, is often incremental, informal, emergent, and is based on learning through small gains versus being revolutionary and radical. According to Shrivastava (1994), strategic initiatives can be forced on the organization through mandate or pushed through consensus within existing systems of the organization. Alternatively, champions of change could emerge to seek out creative ideas and make them tangible (Tushman and Nadler 1986). They engage in coalition building an information-intensive process of knowledge sharing and persuasion.

2.2 Cultural Readiness

Organizational culture governs how people inside an organization learn, share information, and make decisions. The significance of organizational culture can be best explained in terms of cultural beliefs, values, and norms (Schein 1984). At the highest level, an organization's beliefs symbolize the interactions between ideas and shape its interpretation of information and how it makes decisions. Value systems relate behaviours across units and levels of the organization, with values being shared by the organization as a whole or by distinct subunits. Values often exhibit a propensity to resist change because of their shared nature (Fitzgerald 1988). At the lowest level, norms are the unwritten and socially transmitted guides to behaviour. Norms that promote change include risk taking, openness, shared vision, respect and trust, high expectation for action, and a focus on quality (O'Reilly 1989). Norms that discourage change include risk avoidance, ambivalence, group think, and excessive competition (O'Reilly 1989). In short, cultural beliefs, values, and norms constitute an organization's cultural potency to influence behaviour. Thus, leadership that can identify and influence cultural readiness for change can be a requisite to an effective process initiative. Moreover, open communications and information sharing can promote a common culture and innovative behaviour among people inside an organization.

2.3 Learning Capacity

The major goal of learning is to provide positive outcomes through effective adaptation to environmental changes and improved efficiency in the process of learning. Adaptation involves making appropriate responses to technological changes and learning from other organizations that have achieved the best practices in the industry (Freeman and Perez 2000). Increased efficiency can also be obtained through "learning by doing" (Arrow 1962) and accumulation of knowledge through cross-functional interfaces (Adler 1990). Such knowledge accumulation is also called declarative knowledge (i.e., a body of organized information) and can facilitate learning in a collective manner (Corsini et al. 1996). Higher level learning occurs when members reflect on past learning experiences to discover new strategies for learning. Learning can also be brought about by scanning external information. This can come from organizational employees who constantly review the environment for new developments and opportunities (technology gatekeepers), consultants who span the boundary between the environment and the organization (boundary spanners) and from the end users.

2.4 IT Leveragability and Knowledge-Sharing Capability

IT is an organizational resource which enables the necessary means to accomplish knowledge processing and, hence, induce organizational change (Hammer and Champy 1993) . Evidence suggests that IT led projects often fail to capture the business and human dimensions of processes (Markus and Keil 1994). A case is often made for the socio-technical design approach which suggests a mutual, bidirectional relationship between IT and the organization. Such an approach recommends synergy between the business, human and IT dimensions of an organization and could be promoted through cross-functional teams.

Communication technologies have also been proven to facilitate learning and knowledge development through a process of coordinated interaction among individuals. The ability to share knowledge enhances an organization's tendency to change so that transparent data access empowers individuals and knowledge workers to reinforce one another's expertise (Nonaka 1991). Thus, information and communication infrastructure and the extent of knowledge sharing can create an environment that facilitates successful business process change.

2.5 Network Relationships

Research indicates that a successful change process requires leveraging of boundaries and relationships and balancing internal and external networks in terms of cooperation and competition(Nonaka 1991). Under most circumstances cooperative, interpersonal and group behaviour results in superior performance (Shaw 1958). However, it is possible that competitive controversy within generally competitive groups can result in greater openness, knowledge and understanding (Tjosvold and Deemer 1980). In terms of inter-organizational processes, research indicates the benefits of connection with external partners. Organizations that can manage these aspects of competition and cooperation continuously can benefit from employee incentives and to instil change more effectively.

2.6 Change Management Practice

Change management involves effectively balancing forces in favour of a change over forces of resistance (Strebel 1992). Organizations, groups, or individuals resist changes that they perceive as threatening them (Guha et al. 1997). It has been suggested that corporate transformation requires a general dissatisfaction with the status quo by employees who have to change (i.e. a readiness to change), a vision of the future, and a well-managed change process. The change management programme should address required cultural shifts in beliefs, values, and norms. Revolutionary and evolutionary change theorists propose contrasting tactics for accomplishing change which vary depending on the type of employee involvement, communication about the change, and leadership nature. Nevertheless, direct confrontation to forces of resistance will likely only increase resistance capacities. It is, therefore, suggested to use the theories of persuasion in changing attitudes to mitigate resistance and to understand “how” and “what” aspects and persuade the employees toward commitment and cultural assimilation (Melone 1995).

2.7 Process Management Practice

Process management is defined as a set of concepts and practices aimed at better stewardship of business processes (Davenport 1995). It combines methodological approaches with human resource management to improve the outcome of business process change. Successful process management uses process measurement (use of process metrics, process information capture, improvement feedback loop, and process audit), tools and techniques as well as documentation. Evidence also supports the use of team-based structures both for the implementing the project and for designing the new process (Guha et al. 1997).

3. Key enablers for effective management of BIM implementation

As discussed previously, BIM is an organizational innovation and a new approach in construction. The successful adoption and implementation of BIM requires a thorough analysis of different enablers. Based on the theories of business process change management, we have identified the key enablers associated with BIM implementation management which are summarized in Table 1.

Table 1: A summary of the BIM implementation management enablers

Constructs	*Enablers*	*Authors*
Strategic initiatives	Support from top management	(Arayici et al. 2011a)
	User's input	(Arayici et al. 2011b)
	Strategic vision	(Khosrowshahi and Arayici 2012)
	Strategic plan	(Arayici et al. 2011b)
	Stakeholder's analysis	(Arayici, Egbu and Coates 2012)
	Cost-benefit-risk analysis	(Mom and Hsieh 2012)
Change management	Rewards and recognition	(Peansupap and Walker 2005)
	User training and education	(Arayici et al. 2011b)
	Supportive supervisor	(Peansupap and Walker 2005)
	Management readiness for change	(Arayici et al. 2011a)
Cultural readiness	Existence of change agents	(Merschbrock and Munkvold 2014)
	Risk aversion	(Succar 2009)
	Early user involvement	(Miettinen and Paavola 2014)
	Open communication and information sharing	(Dossick and Neff 2009)
Learning orientation	Colleague's help	(Peansupap and Walker 2005)
	System expertise	(Eadie et al. 2013)
	Individual competency assessment	(Succar, Sher and Williams 2013)
	Learning-by-doing	(Arayici et al. 2011b)
	Community of practice	(Peansupap and Walker 2005)
	Learning from past experiences	(Arayici et al. 2011a)
Knowledge capability	Developing knowledge management system	(Arayici, Egbu and Coates 2012)
	Use of communication technologies	(Volk, Stengel and Schultmann 2014)
Network relationships	Inter-organizational linkage	(Homayouni, Neff and Dossick 2010)
	Cross-functional cooperation	(Cerovsek 2011)
Process Management	Setting benchmarking metrics	(Coates et al. 2010)
	Tracking benchmarks	(Giel and Issa 2012)
	BIM maturity assessment tools	(Succar, Sher and Williams 2012)

Strategic initiative enablers

Top management support is required throughout the implementation process. Top management must be committed and willingness and actively are involved in the process and allocate valuable resources to the implementation effort. This involves providing the required human resource for the implementation and allocation of sufficient time to get the job done.

Managers should legitimize new goals and objectives. A shared vision of the organization and the role of the new system and structures should be communicated to the employees. New organizational structures, roles and responsibilities should be established and approved and conflicts should be mediated. Policies should be set by top management to establish new systems in the company. Top management of the organization must understand and analyse the sources of resistance and must employ the appropriate set of strategies to counter them.

Moreover, a clear business plan and vision to steer the direction of the projects is required for BIM implementation. A business plan that outlines proposed strategic and tangible benefits, resources, costs, risks, and timeline is essential. This will help keep focusing on business benefits. There should be a clear business model of how the organization should operate behind the implementation effort and a justification for the investment. Goals and benefits should be identified and tracked. The business plan would make work easier and impact on work.

Cultural readiness enablers

Effective communication is critical to BIM implementation. Expectations vary at different levels, so they must be communicated. Management of communication, education and expectations is essential through the organization. User input should be managed in obtaining their requirements, comments, reactions and approval. Middle managers need to communicate importance of BIM implementation. Employees should be told in advance the scope, objectives, activities and updates, and admit change will occur.

A communication plan is important to involve the member with BIM initiative by showing them how it works, how it is related to their jobs and the benefits achieving from it. By doing so, resistant to change can be diminished. Moreover, it would be helpful to establish a communication program that can describe what should be communicated by whom and how often. It may help organizations to propagate their strategy. After implementation of BIM, it is best to publish the outcomes, but these should not be limited to success outcomes but also communication of drawbacks. It will help the future projects to avoid the same mistakes and from the past mistakes.

A champion is critical to drive consensus and to oversee the entire implementation process. They are the agents of change who should spread the BIM philosophy, benefits, as well as weaknesses throughout the organization. Someone should be placed in charge who has the power to set goals and legitimize change.

Knowledge and learning enablers

Knowledge sharing and communication play a pivotal role in alleviating resistance to change and reducing risk and uncertainty. IT tools can facilitate the knowledge sharing process. Another key issue is creating a learning environment through a set of interrelated practices and beliefs within an organisation that enable employees to develop their own skills and learning. In such an environment, employees do not feel constrained by fear of failure and willingly participate in experimentation and risk taking (Klein and Knight 2005). Through "learning by doing", members can learn how further efficiencies can be achieved through BIM implementation (Arayici et al. 2011b).

Network relationships enablers

Although the training courses provide a wealth of knowledge in BIM initiative, it may not reinforce all the new knowledge and skills required to sustain BIM implementation successful. Throughout the implementation process, companies need to look at external organizations who are successful and leader in BIM implementation and learned best practices and methods from them. Moreover, the organization implementing BIM should work well with external vendors and consultants and/or internal divisions such as R&D to resolve users and software problems. Altogether, these aspects help them to transform from a trained organization to a learning organization.

Change management enablers

Generally, when substantial change occurs inside an organization, the organizational members are afraid of the unknowns and might not realize the need for change. Some organizational cultures are fear based. Mistakes are not allowed, and employees are used to hiding errors. However, BIM as an innovation flourishes in an open and safe environment (Grilo and Jardim-Goncalves 2010) where mistakes are seen as improvement opportunities. Moreover, users must be trained, and concerns must be addressed through regular communication, working with change agents, leveraging corporate culture and identifying job aids for different users. As a part of the change management efforts, users should be involved in implementation processes, should be endowed by tangible or intangible rewards and should be provided with educational and training programs to improve their comfort zone. There should be extra training and on-the-job support for employees and managers during implementation. To meet users' needs after initial implementation, a support which can be provided either by an external organization such as help desk or internal colleagues is critical.

Process management enablers

Companies that adopt BIM must continuously improve their BIM performances and processes. Maturity assessment tools can be utilized to evaluate an enterprise's performance in BIM utilisation during the initial stages. Furthermore, process measurement metrics and tools enable them to perform benchmarking. The application of most maturity evaluation tools is to assess the level of BIM performance within an organisation during the initial stages, and benchmarking tools and metrics allow a comparison between one enterprise's BIM performance and that of their industry peers. These enable them to benefit from the lessons learned and best practices from other firms and use them for further improvement and modifications in the organisation.

4. Conclusion

The primary objective of this paper was to classify the BIM adoption and implementation enablers. The study identified that BIM is an organizational innovation and therefore needs organizational innovation principles to be taken into consideration. To this end, we believe the theory of business process change management may provide a better insight into the key enablers during the BIM implementation process. The results of this study should assist both practitioners and scholars and provide them with insights on how to better understand and prepare for BIM implementation. Specifically, this study tried to shed light on key facilitators of BIM implementation success that need to be focused for optimising the financial returns from BIM implementation. If any of these aspects are missing during the implementation of BIM, it would be the difference between a successful and unsuccessful implementation effort. However, the degree of influence of these factors may vary in different organizations. The key enablers identified in this study can serve as a checklist that covers the key success factors associated with BIM implementation for AEC firms.

During the BIM implementation process, an organization goes through a major transformation, and the management of this change must be carefully planned and meticulously implemented. We believe providing a conducive change environment supported by a set of change management as well as process management facilitators can help construction firms to better utilize from BIM workflows. Based on the theory of business process change management and through a review of literature, we identified a total of 27 BIM adoption and implementation enablers. The success of BIM implementation heavily hinges on the strong sustained commitment from the top management. An organizational culture where the employees share common values and goals and are receptive to change is most likely to succeed in BIM implementation. Moreover, user training, education and support should be available and highly encouraged. Change agents should also play a pivotal role in the implementation to facilitate change and to leverage the corporate culture. Maturity assessment tools can be utilized for process improvement.

In the next step of this research, we plan to assess the degree of significance of the key drivers identified in the literature and also compare a number of successful and unsuccessful BIM implementation. We are also interested in studying how the perceived importance of these drivers may differ across BIM implementation partners such as top executives, project team members, vendors and consultants. By having a better understanding of the key issues involved in BIM implementation, management and decision makers will be able to make critical decisions, better allocate resources and realize increased benefits from BIM implementation.

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Assessing BIM performance through self-assessed benchmarking

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Abstract

This paper describes research investigating what measures of performance of Building Information Modelling adoption can be standardised in creating an international benchmarking tool for self-assessment. By applying crowd-sourcing methodology to populating a prototype benchmarking tool, the research team aims to break down barriers of data and know-how ownership to encourage industry innovation to flow more freely. In particular, this research aims to answer the following questions: (i) Is self-assessed benchmarking a reasonable approach in assessing the performance of BIM at the project level?; (ii) Is crowd sourcing a valid method to populate the prototype? If so, how should the most appropriate metrics for benchmarking performance of BIM be selected?; (iii) What methods can be used to ensure the comparability, accuracy and consistency of the data input by users? The research described addresses these questions through an extensive literature review to build a foundation for future research combining the development and testing of a prototype tool with case studies and expert consultation in Australia and Sweden. This paper discusses key concepts used to develop the prototype and the requisite research being undertaken.

Keywords: BIM, performance, benchmarking, crowd-sourcing, self-assessment, selecting metrics, construction, capability, maturity

1. Introduction

Errors and omissions during design and construction phases in built environment projects are often the result of inefficient communication processes involving numerous stakeholders (Sebastian and van Berlo, 2010). These projects are characterised by being information intensive, putting pressure on enabling participants to have easy access to accurate and up-to-date information (Matthews et al., 2015). Hence, successful project delivery within the built environment industry requires accurate, effective and timely communication methods including inter-organisational communication and information exchange (Becerik and Pollaris, 2006). This pushes organisations to move away from traditional inter-organisational communication and delivery methods towards implementing more effective contemporary digital methods, such as Building Information Modelling (BIM).

BIM can be viewed as a socio-technical system that is expected to contribute to a vast and rapid change in the built environment industry similar to that experienced by the automotive industry when Information and Communication Technologies (ICT) were introduced (Sanchez et al., 2016). BIM is considered to take the entire Architecture, Engineering, Construction and Owner-operated (AECO) sector to a new era in integrating data and communication and is in that regard perceived to be the future methodology of the industry (Tuohy and Murphy, 2015). The industry-wide and organisational changes, required to implement BIM more effectively and broadly, have already required significant capital and time investments from early adopters. It will also, most certainly, pose a challenge to the whole sector, equivalent to the move from pens to Computer-Aided Design (CAD); from main frames to hand-held devices. These investments need to be justified by measuring organisational value-added Key Performance Indicators (KPIs) monitored in terms of the effectiveness of the chosen investment strategy.

Other sectors that have undergone a digital revolution in previous years, such as the finance and banking sector, have been successful in documenting efficiency improvement through benchmarking indicators (Tuohy and Murphy, 2014), an example being cost per transaction. However, the built environment industry has a high level of inter-organisational relationships, which are different to many other industries and provide industry-specific challenges and opportunities. Even though a collective goal may be defined within the context of a single project, actors contributing to it may have particular interests that are not shared with other stakeholders as well as diverting perspectives and internal organisational goals. It follows that within a single project, different stakeholders may have different approaches to implementing BIM and different ways of thinking about and measuring performance. However, implementing BIM effectively, requires a collaborative and integrated approach in order to maximise efficiencies across stakeholders and life-cycle phases (Sanchez et al., 2016). As noted by Sebastian and Berlo (2010); “BIM comprises collaboration frameworks and technologies for integrating process- and object-oriented information throughout the life cycle of the building in a multi-dimensional model”. Benefits expected from implementing BIM include more effective, efficient, fast and error-free collaborative processes (Sebastian and van Berlo, 2010). Nevertheless, implementation and value monitoring strategies that have not been well defined and optimised through evidence-based processes can quickly lead to efficiency losses and cost overruns.

One of the main reasons for ineffective implementation and monitoring strategies to happen is the lack of standard frameworks to assess and benchmark performance within and across organisations (Sebastian and van Berlo, 2010). Although this area is progressing quickly, there is often a lack of appropriate guidelines that help organisations and project teams identify and prioritise performance requirements (Succar, 2010). At the same time, while there is a market-driven pressure for organisations to invest in implementing these kinds of technologies and processes, they may not be able to access sufficient information to justify such investment and evaluate the effects of its implementation (Van Grembergen, 2002). Although organisational performance deriving from utilisation of BIM is important to justify investment, assessing the actual BIM performance at the project level is as important to understanding the effectiveness of the investment strategy. BIM performance is identified by Succar (2012) as being divided into BIM capability, the ability to generate deliverables and services, and BIM maturity, the extent, depth, quality, predictability and repeatability of the capabilities. Founded upon the above definition of BIM performance, this research proposes an internationally applicable open access system for project teams to develop internal BIM performance benchmarks while also providing the industry as a whole with cross-firm or industry benchmarks.

Research methodology

The research presented in this paper has been developed as a descriptive review of literature based on academic publications and therefore based on secondary data. As performance assessment within the AECO industry in general and BIM specifically are relatively under-developed, parallels to different sectors and their frameworks have been analysed and described. This study has been conducted with the aim of contributing to the development of a tool for benchmarking BIM performance. Future research on the topic will possibly include development of new data and methodological considerations necessary for developing an actual tool. This research aims to answer the following questions: (i) Is self-assessed benchmarking a reasonable approach in assessing the performance of BIM at the project level; (ii) Is crowd sourcing a valid and relevant method to populate the prototype? If so, how should the most appropriate metrics for benchmarking performance of the use of socio-technical systems such as BIM be selected?; (iii) What methods can be used to ensure the comparability, accuracy and consistency of the data input by users? Future research will include testing the prototype tool through case studies and expert consultation in Australia and Sweden. This will provide insight into the potential application across international markets with different economic and implementation contexts.

2. Assessment of BIM performance

According to Bassioni et al. (2005) the AECO industry has been noted by many for being complex, with high levels of conflict, underperforming, and characterised by low levels of productivity (Manderson et al., 2015). There is, seemingly, a need for developing ways of assessment that support improvement of BIM performance. Performance, a broad concept with, no widely accepted industry definition (Rankin et al., 2008), has different meanings between and even within sectoral contexts (Kouzmin et al., 1999). Performance in an organisational context has traditionally been measured through financial parameters such as return on investment (ROI) and is often criticised for providing a too narrow and one sided focus on organisational productivity and direct profit. In the AECO sector attempts at measuring performance in using BIM has mainly been focusing on measurable financial output in relation to time and quality at the organisational level (Bassioni et al., 2005). In doing so, it fails to take the total performance of BIM use into account with all aspects that contribute to a competitive advantage (Beatham et al., 2004), further it does not address the actual performance of using BIM. Liu et al. (2014) explain performance assessment as a process of quantifying and reporting the efficiency or outcome of an action that is performed in line with an organisation's goals and objectives. The soft values or benefits generated through the use of BIM such as improved communications between project participants has to be included into an assessment of performance in order to provide more accurate results.

A case study on the Canadian AECO industry showed that this industry has historically lagged in labour productivity growth when compared to the rest of the Canadian economy (Rankin et al., 2008). This study further points out that this observation does not necessarily mean that the productivity is lower in the AECO industry. Instead it is suggested that measuring performance is more complex than it is in most other major industries. Additionally, AECO actors often have a more complex output and more versatile and dynamic way of conducting their business than in other industries. This again supports the thesis that traditional KPIs are not necessarily suitable to accurately represent overall performance as they might do in other sectors. (Rankin et al., 2008). When assessing the performance of BIM performance measured only through the above-mentioned financial indicators and other organisational value measures, it presents an incomplete picture It requires abandoning some traditional methodologies and embracing more appropriate performance assessment to understand and develop business success (Liu et al., 2014). The use of traditional performance measurement indicators and frameworks can therefore be misleading and inaccurate when applied directly or partially to the assessment of BIM performance. A common understanding of how to define BIM performance assessment is necessary and has to be formalised.

In a project context BIM performance can be separated into capabilities and maturity. Assessment of BIM capability defines the minimum requirement for producing a task or delivering a service a project team possesses or is fulfilling. This can for example be the ability to produce a BIM model with a specific software. BIM maturity on the other hand distinguishes the project teams' quality, repeatability and degrees of excellence in which they perform the task or delivering service (Succar et al., 2012; Sebastian and van Berlo, 2010). This means that rather than determining what software is used, the BIM maturity determines how well it is used.

Identifying and collecting performance data is important in order to motivate and prove the efficiency that can be achieved by BIM implementation. However, many managers within the AECO industry may be reluctant to allow external parties to carry out this assessment. According to Costa et al. (2006), this unwillingness is a significant sign that AECO companies do not emphasise the importance of performance measures and benchmarks enough. This can be a reason why drive and development of BIM assessment is lacking. On the other hand, many organisations control and measure a wide range of other variables (Costa et al., 2006). Since performance data associated to BIM implementation processes and tools is infrequent, the most relevant metrics can be difficult to select when developing a framework for performance measurement. Having established what BIM performance is and why it is important, one has to identify what measures are already in use and how suitable they may be to assessing BIM performance in accordance with the performance definition.

2.1 Existing frameworks for BIM performance measuring and assessment

There are a number of models and frameworks that have been developed to measure BIM performance by assessing the capabilities and maturity of individuals, teams or organisations (Månsson and Lindahl, 2016). These have been developed in an ad-hoc fashion and are, if not organisation-specific, likely influenced by the context in which they were developed (Bassioni et al., 2005). Frameworks that have been identified include the Interactive Capability Maturity Model (I-CMM, 2009); BIM Proficiency Matrix (Indiana University, 2009); BIM Maturity Levels (Bew and Richards, 2010); BIM QuickScan (Sebastian and van Berlo, 2010); BIM Maturity Matrix (Succar, 2010); Vico BIM Score (Vico, 2011); CPIx-BIM Assessment Form (CPI, 2011); bimSCORE (bimSCORE, 2013); BIM Planning Guide for Facility Owners (CIC, 2013); and BIM Competency Assessment Tool (Giel and Issa, 2015). These frameworks for measuring performance are still evolving and are applied differently across the market. The development of some of them has been driven by the industry while others have been driven by government or academic actors. These create different areas of focus regarding metrics and methods used.

Bassioni et al. (2005) stress the importance of not relying on a single framework and the metrics it includes. Given the diversity of organisations and projects within the AECO industry, it is unlikely that all relevant metrics are included in one framework or that all metrics included in a specific framework are relevant to all organisations and projects. On the other hand, utilising several frameworks may require a significant investment of resources and there is a risk that the frameworks may not be compatible. Månsson and Lindahl (2016) suggest that the frameworks presented by Succar and Bew/Richards are among the more ambitious frameworks for assessing BIM performance. However, Bew/Richards iBIM model is overly simplistic and by that unsuitable for comprehensively assessing BIM performance. The model developed by Succar grants a way to assess BIM Maturity, however it is perhaps over complicated and too resource demanding to apply.

The methods and availability of data necessary to measure BIM capability and maturity in more depth also require additional development. Further, most of the existing frameworks are not open access tools; they either need to be internally developed based on general guidelines or require investing in a consultant to carry out the assessment. Furthermore, they do not offer the possibility for industry-wide benchmarks and thus limits inter-organisational and industry-wide data sharing.

3. BIM benchmarking

Among the main benefits of assessing performance through common criteria is the possibility to enable benchmarking. Within the context of this research and based on the general definition provided by Costa et al. (2006), BIM benchmarking is a systematic process of measuring and comparing organisational, project team and individual BIM performance with that of competitors or internally between projects; often with the objective to identify or determine best practices. In addition to assessing its own success internally, each organisation can use the lessons learned from competitors in order to improve its BIM performance and through this avoid common mistakes as well as unnecessary re-work (Costa et al., 2006). In order to be able to benchmark externally throughout the industry, an internal assessment has to be performed. Internal BIM benchmarking can also be performed as AECO organisations tend to benefit from comparing the performance of their own projects from each other. In that sense it is difficult to separate internal from external benchmarking since one depends on the other.

If developed from within, initially as a way to assess BIM performance across projects, the size of the organisation can be critical in deciding the capability to assess. Kouzmin et al. (1999) state that only large companies can afford to develop their own method of benchmarking and that smaller organisations have to rely on frameworks already developed by and specifically for their larger competitors. This can affect the relevance of the metrics involved and potentially lead to misleading performance benchmarking results. However, internally developed frameworks for internal assessment later transformed into external ones, will most likely differ from those developed by others. From this perspective, it would appear that externally developed un-biased method for assessing BIM performance is required to make such a tool relevant and applied more broadly throughout the industry. According to Costa et al. (2006) there has been an increasing number of initiatives focused on developing ways of assessing performance of BIM in the AECO sector.

Rankin et al. (2008) defines the process of developing benchmarking as following a step-by-step plan (Fig 1): (1) identification on what to measure, (2) selection of suitable metrics, (3) gathering of data, (4) identification of what can be improved and (5) adoption of best practice (Rankin et al., 2008). The search for valid indicators and methods of data collection are critical elements of this process and can "make or break" the whole process if sub-optimised or poorly executed. While the characteristics of organisations within the AECO industry vary greatly based on the type of business they conduct, it is important to apply unified, reliable and valid metrics that allow a uniform and accurate measurement and comparison of their BIM performance. Assessment of BIM performance will also need to report on how a project team actually benefits through the utilisation of BIM. Figure 1 illustrates that it is a key activity to identify valid metrics when developing frameworks or methods of assessing or benchmarking performance. But what are the suitable, valid, metrics for a BIM performance benchmark? Can there be a way of overcoming the challenges brought by the fact that sets of metrics will have different level of relevance when comparing organisations?

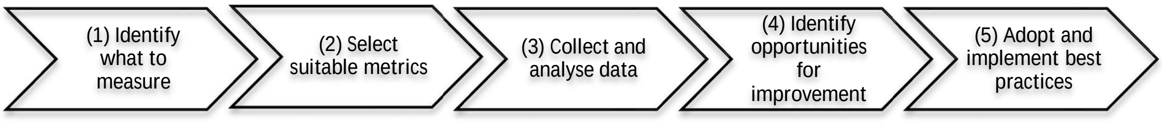

Figure 1: The process of benchmarking (Rankin et al., 2008)

3.1 Self–assessing

A common practice, in the process of assessing organisational performance, is that an external party, often a consultant, is both gathering and analysing the data. The main reason for this might be that organisations want a neutral party, or that it is required for accreditation, but also that the process and most frameworks are too complex for the organisation itself to manage and the challenge of providing knowledge from within. A likely effect of this is that organisations distance themselves from the act of measuring, as responsibility will be more concentrated in the hands of external parties. Through this process the sometimes sensitive information used for internal KPIs is exposed to external parties who are likely to have competitors as clients which in turn may be viewed as a business threat (Rankin et al., 2008).

Self-assessment of performance can help make the assessment process faster and less costly, and grow internal ‘ownership’. Pun et al. (1999) define organisational self-assessment as “a comprehensive and regular review of an organisation´s activities and results against a systematic model of business excellence”. Thus, it is proposed that applying a self-assessment methodology for performance benchmarks can save time and capital while at the same time build ownership. The assessment effort can also be ongoing, enabling continuous improvement processes in line with the dynamic and changing business climate in the AECO industry. Also, the continuous process of assessment and the continually-improving nature of the data may help increasing both the accuracy and the quality of the assessment. This is because parameters are up-to-date and updated as necessary and considered relevant by the users (Rankin et al., 2008).

3.2 Crowd sourcing

A significant barrier, when developing a framework for organisational BIM performance assessment, is that the needs of different AECO actors will vary significantly between organisations and even between projects within a single organisation. It is unlikely that there is universal set of metrics for evaluating the BIM performance that is relevant to all actors in all scenarios. By allowing the user to select their own metrics from a default dataset, and add non-existing metrics where needed, the framework can grow organically, continually improving. This approach and methodology is in a way a type of crowd sourcing; here understood as a growing, efficient way of collecting data and by that building multi-variable datasets (Pierce and Fung, 2013; Amsterdamer and Milo, 2014). Therefore, a framework for self-assessed BIM performance constructed through crowd-sourced data gathering is proposed to be a valid way of developing a BIM performance benchmarking system suitable for the diverse and protective AECO industry.

3.3 Selecting valid metrics

Developing a series of BIM performance metrics is a prerequisite and a paramount cornerstone in the process of creating a method for assessing BIM performance (Sebastian and van Berlo, 2010). Crowd sourcing a database of measures means it will grow organically to a certain extent. However, a generic framework with key metrics has to be provided initially to drive and support use. It is of great importance to build this first set in collaboration and consensus with industry actors from different disciplines within the AECO industry (Rankin et al., 2008). Metrics need to be (1) valid, (relevant, appropriate and justifiable) (2) quantifiable and (3) realistic (Fang et al., 2004). After the first dataset is created, early users can start selecting the most relevant metrics from the dataset that represents their view of key indicators of the BIM performance within their core business. In addition, they can request metrics that do not exist in the dataset to be included.

Through this process less used metrics can be removed, or at least valued lower and thus the framework will become more relevant.

To reduce the risk of having deceptive data affecting the tool through the self-assessed benchmarking affecting the dataset, the metrics have to be regulated to some extent and, as noted above, be anchored among the participating industry actors (Rankin et al., 2008). Some administrative control has therefore to be included in a potential tool. Fang and Wong (2015) developed a model for selecting metrics for assessing organisational resilience. Their model, here

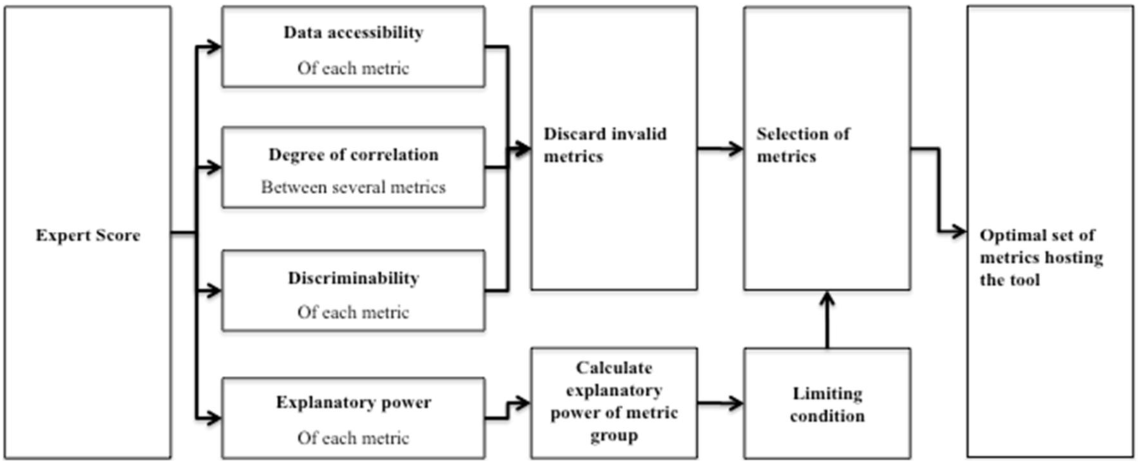

Figure 2: Process for selecting metrics for hosting the benchmarking tool- altered version (Fang and Wong, 2015)

provided with some minor alterations (Fig. 2), is also applicable for the process of selecting metrics for hosting a self-assessment BIM performance benchmarking tool. This implies that even if the user can add new metrics, there needs to be a managing entity that will validate it in accordance with the process provided in Figure 2. Further, the hierarchy of the importance or value of the metrics as well as whether they are fixed or changeable, has to be established.

4. Discussion

There are many metrics identified as appropriate and valid when scrutinising methods of measuring BIM performance. However, since the AECO industry consists of actors from many different fields, using BIM in sometimes different ways, it is impractical aiming to select an ultimate series of these metrics to serve as valid for all actors within the industry. Established frameworks and models for assessing BIM performance is either too simplistic (e.g. iBIM) or overly detailed (e.g. BIM Maturity Matrix) and therefore somewhat ill-suited for self-assessment. The self-assessed benchmarking approach instead enables an easy, accessible, dynamic and customised set of metrics for performance measurement to be developed. This will enable a “relevant only” approach for measuring. The crowd sourcing approach will eventually enable the development of dataset groups and categories, what Succar et al. (2012) refers to as filters that will incrementally guide validation and valuation of metrics.

By this we argue that self-assessed crowd sourcing methodology will contribute to the gathering of relevant data; organisations select what is relevant to them for internal benchmarking purposes.

More users successively will lead to a better database, with more valid metrics and more precise measurements which will benefit all users. Furthermore, this approach to benchmarking BIM performance will reduce the risk of leaking sensitive information to a third party since data considered sensitive is regulated in its exposure. Existing frameworks applicable for measuring BIM performance, as mentioned earlier, will either require help from expert consultants or the development of possibly costly in-house know-how and thus are more cumbersome to get started with.

An obstacle to overcome, when applying this methodology of assessment over the whole AECO industry, is the probability for some metrics being easier to score high or fulfil than others. This since there is a risk that the performance of actors in a certain sector will be shown, or indicated, as more mature than others as a result of what metrics are closer, and thus more likely to be used, to the core business and the characteristics for this type of organisation. Hence, it seems reasonable that this methodology and approach to developing BIM performance benchmarks may be a way forward. As a tool for comparing organisations with different abilities and focus throughout the whole industry however, it is unlikely to be applicable in the same way. Rather, it can be used to give a rough estimation, an indication, between the fields which in the long run can provide valuable information about how well a sector is performing BIM in industry context.

As the system is used more, the database will grow in terms of additional new metrics and get more refined and precise as the users automatically validate the metrics. Early adopters or pilot organisations risk suffering inaccurate measuring results as the dataset is developing. This is likely to create barriers to developing the database and pose a threat towards convincing industry actors to adopt it. However, setting up a tool with relevant and versatile default metrics developed through case studies and expert consultation will reduce the chance of this occurring.

5. Conclusions

Development of a framework for self-assessed benchmarking of project based BIM performance with utilisation of crowd sourcing as a method for populating the tool is proposed to be an accessible and cost effective way of evaluating BIM performance. This methodology may reduce unnecessary cost and lead-time as well as avoid sensitive information being exposed to third parties. It can also serve as an efficient tool for comparison between projects given that they will have similar ways of conducting their business and thereby are using similar key metrics. As a method for comparing organisations in varying fields within the AECO industry however, it seems more likely to provide a rough comparison which can be valuable for pin-pointing the weakest capabilities in terms of BIM performance throughout the AECO industry.

To reduce or remove misguiding user influence, the tool has to be developed on the foundation of some default metrics. Also, there has to be a certain amount of administrative control in order to adjust eventual misguiding data. The dataset hosting the tool is suggested to be developed in accordance with the structure shown in Figure 2.

6. Future research

For this methodology to be efficient in procurement situations more research has to be conducted on a foundation of industry case studies. As mentioned earlier in this paper, a starting point and platform of BIM performance default metrics is needed. In order to be useful for the AECO industry as well as internationally applicable, these will be developed through case studies with diverse sectorial as well as regional participants. Another challenge is to define if and by that how weighting of the metrics should be considered. A metric or factor frequently used or assessed might be less important than one of lesser frequency.

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Leveraging Customer Satisfaction Using BIM: House Builders' Perspective

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Abstract

The UK housing industry is growing from the recent recovery of global and the UK economy. More homes are currently required to be built putting a strain on resources. Over the last fourteen years customer satisfaction has been a key performance indicator for the UK government and industry bodies to determine the quality and service that is being provided by house builders. As a result, house builders and professional bodies over these years have strived to improve the level of after sales customer satisfaction. This has led to increased customer satisfaction during the recession. However recent drive for increased productivity levels have reduced customer satisfaction levels; suggesting that the industry needs to use innovation to provide higher levels of customer satisfaction while maintaining productivity. BIM is a new way of working that enables digital representations of the physical and functional characteristics of a facility. BIM intends to supply usable information throughout the lifecycle of a project. The housing industry is beginning to utilise BIM in certain aspects within the business. The implementation of BIM into customer care departments could be the innovation the industry so desperately needs to enhance customer satisfaction. This paper explores how after sale customer satisfaction is evaluated by the UK house builders and their opinion on how BIM can be used to enhance customer satisfaction.

Keywords: BIM, Customer Satisfaction, After Sale Customer Care, Volume House Builders, Housing Industry

1. Introduction

In 2004, the Barker review was published with a view of globally examining the current Housing Industry. Areas such as economic stability and growth, to environmental considerations were reviewed and the report identified thirty five recommendations in order to develop the current housing industry with the aim of improving customer confidence which was the mechanism to drive house builders to improve customer satisfaction. Further proposal by Callcutt review team (2007) recommends that house builders must achieve customer satisfaction standards within the next two years. However, the Office of Fair Trading (OFT) (2008) points out that even within this broadly competitive sector, many homebuyers experience faults or delays, which includes but not limited to postponements to initial moving in date and faults in new homes. On 1st of April 2010, Consumer Code for Home Builders was made mandatory in the UK and was implemented by the industry's main warranty providers – National House Building Council (NHBC), Premier Guarantee and Local Authority Building Control (LABC). Any house builders using the aforementioned institutions are now required to implement the Consumer Code into their business approach. The code provides guidance to house builders and entails requirements for suitable systems and procedures to ensure it can reliably and accurately meet the commitments on service, procedures and information (Consumer Code for Home Builders, 2010).

From 2006 onwards, there have been extensive market studies that illustrate continuous improvement by house builders relating to customer satisfaction. In a market survey carried out by OFT between 2006 and 2008, an average of 75% of the customer recommended their builder to other potential buyers (OFT, 2008). In March 2015, National Builders Federation (NBF) published further findings based on the 'National New Home Customer Satisfaction Survey'. In comparison, between 2011 and 2012 a 91% of the customers recommended their builder. This suggests that housing developers are striving to improve customer's satisfaction throughout the process. Transparency to the customer through communication and involvement during the construction is now an integral part of the majority of house builders. As such several house builders are starting to offer fundamental customer communication tools to provide them with information on their acquisition from inception to final completion. Conversely many purchasers can still find the process both ambiguous and confusing.

Building Information Modelling (BIM) and related technologies provide an opportunity to improve communication between builder and customers and therefore reduce customer complaints and improve customer confidence. However, many working within house-building do not yet have an awareness of its potential benefits of BIM (NBS, 2013). In order for BIM implementation to be a viable option, house builders must increase their own knowledge and understanding of BIM throughout their business with a view to successfully improve the limited awareness of the potential customers. Therefore a sustainable BIM platform with a user friendly interface for the customer to access during the construction, handover and operation is essential to develop confidence and heighten customer satisfaction. This paper explores how after sale customer services are provided by house builders and the use of Building Information Modelling (BIM) to enhance customer satisfaction.

2. Literature review

In 2014 the Lyons housing review was published by the UK Housing Commission. The basis of the report is to determine how best to increase new build units entering the market. Lyons (2014) suggests building at least 243,000 homes a year to keep up with an ever increasing demand from the growing population (see Figure 1). Statistics published by the DCLG indicate that the building industry from 2012-2013 produced 118,540 new builds, which is less than half the recommended units detailed in Lyon's report. Currently the housing market would seem to be on the mend from an incredibly difficult period of its long history. Annual housing starts totalled 137,780 in the 12 months to June 2014, an increase of 22% compared to the year before (Sleight, 2014). Currently developers producing between 500 and 2000+ units yearly contribute to the majority of the overall new build completions yearly figures (Lyons, 2014).

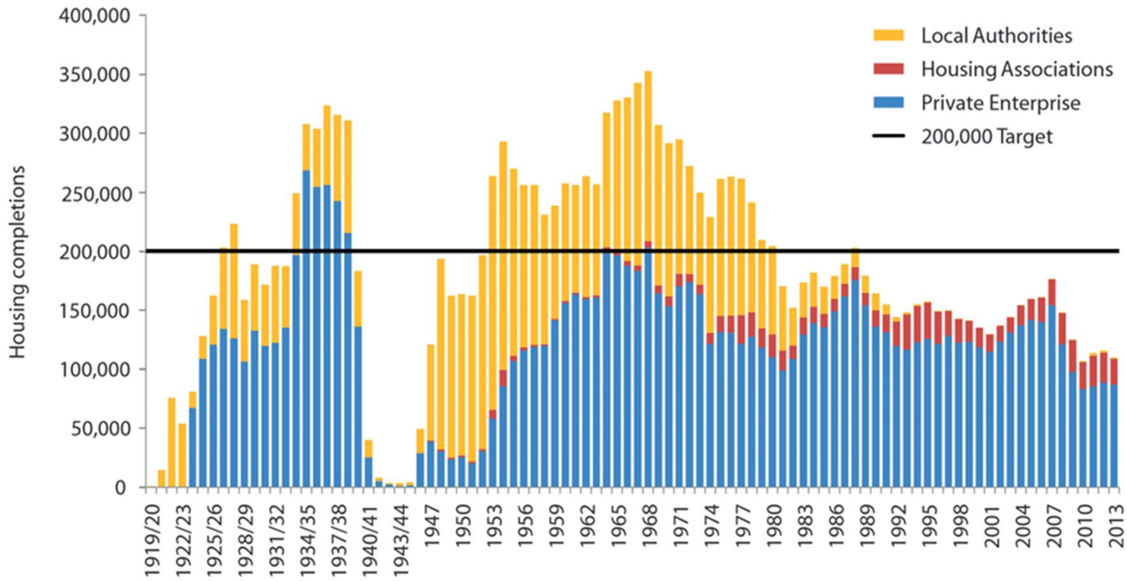


Figure 1: Historic housing completions in the UK (Lyons, 2014)

2.1 Customer Satisfaction in Housing

The Latham report recognised the customer as being at the core of the construction process (Latham, 1994). Hayes (2008) suggest that customer satisfaction and perception of quality are labels used to summarise a set of observable actions related to the product or service. A further definition of satisfaction presented by Kotler and Keller (2006) outlining satisfaction as *"person's feeling of pleasure or disappointment which resulted from comparing a product's perceived performance or outcome against his/ her expectations"*. Rai (2008) and Churcher (2003) draws the basic formula of customer satisfaction as: *"Customer satisfaction = Customer Perception of the Service Received – Customer Expectation of Customer Service"*. A house is one of the biggest purchases many people will make in their lifetime. Ozaki (2010) argues that *"house builders have increasingly been searching for ways to be more customer focused"* and thus the level of expectation when buying a home and the advertised level of service a house builder provides will elevate the customers' expectations even higher. Whilst Oliver (1993) considers customer satisfaction in housing as being a comparison between the customer's pre-purchase expectations and their after purchase perceptions.

The national housing output requirements show that housebuilders need to build more houses every year. The volume of new build unit requirements to meet public demand by house builders will need to rise by half their current output. Therefore challenges set upon the house builders business to achieve these targets such as resource restrictions, availability of material, lack of suitable labour, increasing land values and increase in the requirement to build on brown field developments. This increase in output, could have a potential effect on the customer experience and overall satisfaction of the product. Customer satisfaction of an end product is seen as a direct and reliable indicator of a business' future performance. Cronin and Taylor (1992) suggest customer satisfaction to be important means of obtaining competitive advantage in the market place. Therefore is important for of housebuilders' business growth to improve and maintain customer satisfaction.

Since 2006, Home Builders Federation (HBF) has measured customer satisfaction in the UK which records results from new home customer satisfaction surveys. The surveys were implemented in response to recommendation 32 of the Barker review of housing supply (2004) which stated that the house building industry must demonstrate increased levels of customer satisfaction. In response to the new homes customer satisfaction survey volume house builders have now dedicated customer care teams across their business offices each providing a direct link of information to the customer and responding to all customer complaints to ensure a positive outcome.

To improve customer satisfaction, house builders need to innovate and develop systems to streamline and energise the after sales experience both for the customer and the internal customer care team and therefore to improve follow-ups on incomplete items. According to CA Design services (2001) *"customer satisfaction comes from exceeding expectations, that means not just meeting the basic need for a building, but also providing services that meet and exceed their specific individual requirements, as a result delivering something extra"*. There are anecdotal evidence that suggests BIM as an approach to improving customer satisfaction. For this the industry needs a systemic change rather than a visualisation tool. Hence, it is important to understand what BIM and its potential use.

2.2 What is BIM?

Building Information Modelling, BIM is set to modernise the construction industry. According to Gardiner (2013) BIM is a way of working that allows virtual 3D models of buildings to be created by designers and contractors that can be shared with an entire project team. Information about objects and products that goes into constructing and maintaining a building can also be added to the model. NHBC (2013) suggests that *"BIM is a process that improves the efficiency of organising and distributing information - or data - that is generated during the design and construction of buildings and infrastructure"*.

RIBA proclaims BIM to be the, *"the process of generating and managing data about the building during its lifecycle"*. (RIBA insight, 2014). Which suggests BIM offers increased productivity in design and construction from the data in produces and holds. It delivers value through creation, collation and exchange of shared models and corresponding intelligent structured data. BIM can assist to close the gap between stages with shared data sets while allowing transparency. From these BIM can be understood as a different way of thinking and working by sharing, and effectively working on, a common information pool. BIM involves building a digital prototype of the model and simulating it in a digital world. This suggest that BIM must be promoted as a delivery system to produce an intelligent model that can hold physical attributes that could be used for overall design decision making.

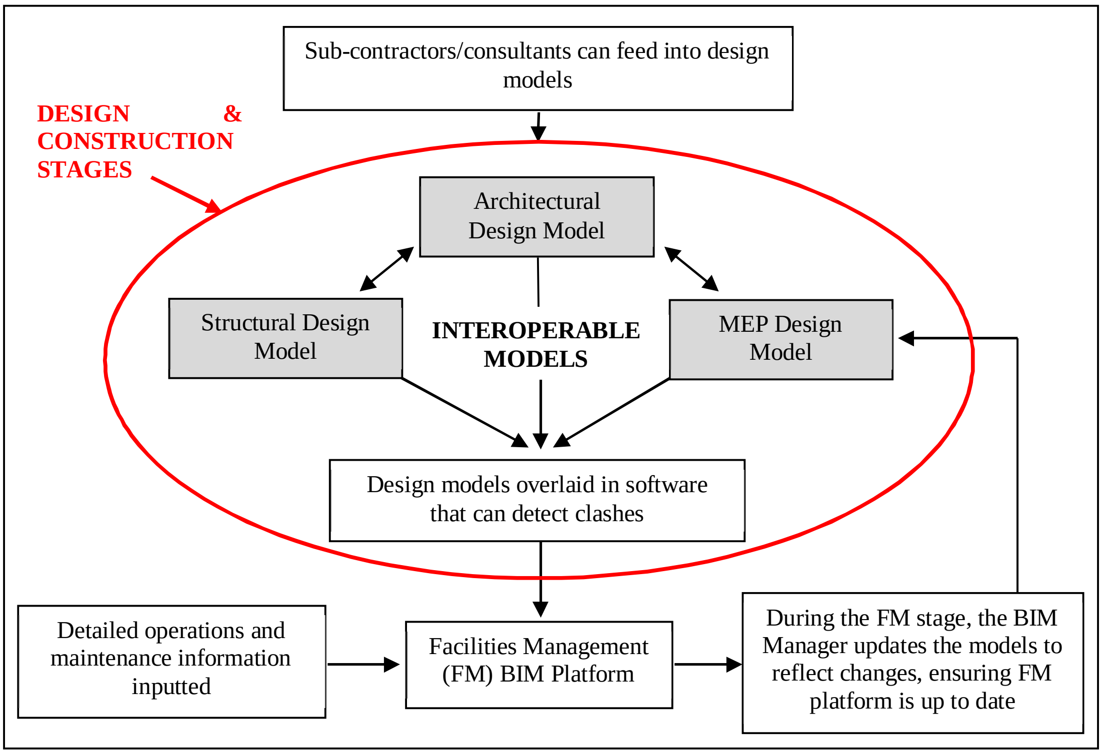


Figure 2: Interoperable BIM Process

The introduction of BIM has been brought about due to a requirement for increased sustainability and productivity within the construction industry (BIS, 2011). As stated by BIS (2011) there are four levels of BIM adoption, from 0-3, depending on how models are managed and the collaborative working practices are adopted. Level 2 essentially requires teams to be working collaboratively with 3D BIM (see Figure 2), however with no obligation for the 4D programme, 5D cost and operation elements to be incorporated within the model (Isikdag, Underwood, & Kuruoglu, 2012).

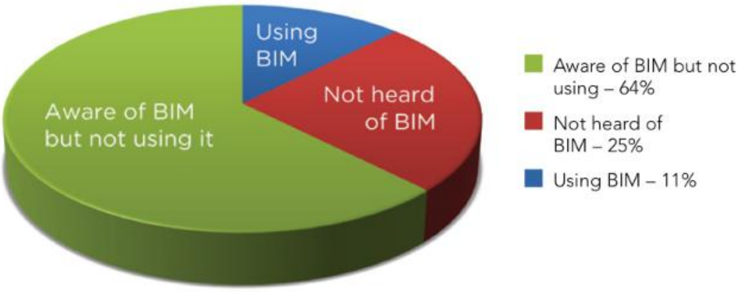
2.3 House Builder's and BIM

As suggested by Saxon (2013) *"The arrival of BIM since the early 2000s has been USA- led"*. A study by National Building Specification (NBS), has made yearly information available since 2011. The reports suggest improvement in awareness and use of BIM across the industry.

However, a recent report by the NHBC indicates that the majority of the major house builders in the UK are currently not engaged in BIM (NHBC, 2013) (see figure 3). This would suggest that due to the amount of awareness in the industry, it does not seem to potentially be in House Builders' vision for the foreseeable future.

Furthermore, the benefits that BIM can provide to house builders are not adequately researched. There are challenges that come hand in hand with the implementation of BIM as an integral part of a business including technological and business process integration, as with any enhancement. The effect of making a momentous step when resources are at their most stretched as demand is out weighing supply both from a materials and customers point of view.

Figure 3: House builders' engagement with BIM (NHBC, 2013)



Organisations are cautiously starting to move forward and upscale operations from the recent recession. BIM is seen as similar to move to drafting on tracing paper to using 2D. As proclaimed by CA Design services (2011), "BIM by its nature is client-centric" and can, used well, deliver better services. Including:

- Provide accurate documents.
- Improve communication between the customer and the house builder.
- Reduce errors and coordination issues leading to cost saving to the house builder.
- Inform clients with visual aids and represent the final product to avoid any unwanted features.
- Produce a product that is less defective and thus increases the satisfaction of the customer.

Over the last 15 years customer satisfaction has been a major factor for a house builder and has been increasing year on year. However the house builder approaches a potential tipping point and will require systems of innovation in place that can manage to ease pressure on personnel and resources to allow them to get on with building houses to a high standard.

BIM could be that revolutionary system by:

- Providing real time information to customer on build completion date.
- Storing of information in one place including house designs from wall construction to boiler type to tile manufacturer. Information includes contracts, Warranties and itemise details of what parts of house is under warranty and terms, from reservation to after sales care.

- Storing relevant underlying data (e.g., material, dimension, cost, energy performance, and even product availability) that allow builders, designers, and buyers to make informed decisions (See figure 2).
- Allowing access to site production team and update model house types where clashes have occurred in design.
- Allowing customers to pinpoint defects to ensure the right after sale support and relevant trade visits to complete the work.
- Providing the customer the option to improve design and / or functionality that can be passed to architect for review of current customer living needs and requirements.

Briefing documents	Costing/supplier enquiries
General correspondence	Quotations
Feasibility studies	Requests For Information (RFIs)
Utilities and infrastructure reports	Tender/contract documents
Site surveys	Commissioning sheets
Ecology studies	Working drawings
Design drawings	O&M manuals
Specifications	Statutory certificates
Schedules	Local authority submissions and approvals
Programmes	Financial management

Figure 4: Information types for house builders (NHBC, 2013)

These points are by no means exhaustive; for implementation a clear delineation is essential to appreciate what is needed and to consequently support a strategy for operation. BIM entails an adjustment to a collaborative and autonomous way of managerial philosophy to essentially enrich the corporate benefits previously detailed. Suggesting BIM is more than just an enhancement of an existing software package but more of a sophisticated computer software creating a virtual model that can benefit all professionals in the lifecycle process. With BIM customer care departments can potentially lead to increased customer satisfaction and transparency.

3. Research methodology

Research methodology refers to the overall approach to the design process from the theoretical underpinnings to the collection and analysis of the data (Collins and Hussey, 2003). For this research, fourteen semi structured interviews were conducted with customer care professionals working in Volume House Builder organisations to gather qualitative data. Interview questions were divided into two sections, a) to understand the current process of after sales customer care b) potential influence of BIM on customer satisfaction. Initial pilot studies prompted further research into a software package that was used by many respondents. It was identified that the current after sales system providers were developing BIM for integration into their current software. During the interviews open questions were used. These open questions allowed the development of an open forum, in order to capture the opinion of the interviewees and to develop a meaningful understanding of how current systems work within the organisation and as discussed above, how BIM would be an added benefit rather than a system overhaul.

4. Findings and Discussion

Customer care ratings produced by the NHBC/HBF are very significant to how potential customers perceive them and how well developments sell. Most of the interviewees indicated that house builders currently have business objectives in place to improve after sales customer satisfaction. Plumbing, drainage, electrical issues and painting were suggested as the main complaints/issues received after sale. Most of the interviewees confirmed that a similar system is currently used within the customer care department. Interviewee 1 stated that the current *'system is very good and is used universally by all of our regions'*. This links all departments under one umbrella from land acquisition, feasibility studies, design, procurement, build programme, payments, sales, and customer service and after care. *'It's a company package that we bolt on to and not just specific to our department'* as interviewee 3 proclaimed.

This customer care system starts when a customer advisor receives a call/text/email from the customer. Then the customer care advisor contacts the customer and discusses the issue. From the information provided, the advisor can find the property address and identify a contractor to complete that work. A defect report is then sent to the contractor and the system keeps a log of initial customer contact. The contractor is normally given three days to contact the customer and arrange an appointment with the customer to complete the work. The contractor then updates the advisor who then contacts the customer to ensure that they are satisfied with the ongoing process.

All interviewees discussed the complex communication lines between four or more parties when dealing with issues. It was a common theme from the interviews that communications become very diverse as all parties can talk to each other at different times, agreeing different arrangements. All interviewees confirmed that arrangements between two parties are very rarely communicated effectively to all other parties. This leads to a very complicated and chaotic approach, and parties can be left unsure of what is required of them and when. This needs a better communication system incorporated into the customer care process. Interviews also advocated for increased support from subcontractors and a better user friendly system to improve after sale services.

The interviewees recognised the use of BIM to avoid errors in communication and help support the customer care department in trying to bring everyone together. House builders are starting to develop large 1000 unit parcels of land. To speed up the development of these parcels and to spread risk, multiple developers work together as a consortium. With this in mind, house builders need to implement a system that not only allows communication between participants during the construction stage but also for after sales operations. This means house builders need a systemic change to their operations. BIM can improve communication between the clients and house builders and can reduce number of snags (defects). BIM models hold information such as who installed the building element, supplier details, warranties, insurances and all building components operating user manuals about a specific property. Interviewees suggested that the system with the 3D user interface could provide diagnostic tools to enable users to resolve the issues themselves with step by step guides. These models could provide a maintenance plan for the owner providing updates on when maintenance is required such as boiler check and electric test. This would enable more efficient fault detection and reduce customer complains. Most of the interviewees suggested that BIM could help to decrease delivery time as they can communicate with customers, contractors and suppliers more efficiently. BIM makes it possible to integrate information from different disciplines in different phases of the building process enabling a central location for communication links between all departments within the business as well as the customer. Current systems and processes are not equipped to deal with the increased requirements of the industry. BIM could be utilised to drive and improve customer satisfaction across the business. A strong company brand with efficient processes through the business can lead to increased employee satisfaction while being able to attract the best talent in the market further increasing the quality and satisfaction the customer receive.

The significant barrier is the implementation of BIM into current house builder software infrastructure. As the majority of volume house builders use a similar system it would be difficult to change and introduce a new one. Findings suggests that BIM is being designed into the current system and therefore would not be an onerous or difficult process to integrate. This would be beneficial to the customer care department as the current system is not designed specifically for efficient work processes.

5. Conclusion

The research has attempted to establish an understanding of what customer satisfaction means to a house builder and the current systems they have in place to be able to satisfy their customers. House builders are pushed to produce more houses across the nation. However this could affect customer satisfaction levels in the industry. There is significant need for innovation and improved systems to centralise asset data and provide customers with services that exceeds their expectations to improve and maintain customer satisfaction. BIM could be the innovative tool providing real-time information to the clients and to streamline aftersales operations.

Findings suggest that housebuilders are reluctant to change their current aftersales systems. However there is an overwhelming suggestion to integrate BIM as part of the current aftersales system, especially with the provision of online 3D model based graphical user interface to improve communication. This means house builders need to integrate BIM across the organisation and ensure the use of BIM throughout the lifecycle of a building. However, further research is required in understanding how the existing system and BIM can be effectively integrated throughout the lifecycle of a building to improve customer satisfaction.

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Towards a Framework to Understand Multidisciplinarity in BIM Context - Education to Teamwork

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Abstract

Construction projects by their very nature, have always involved the cooperation of various disciplines. Typically, construction projects are unique and large, comprising of many phases, requiring major investment and activities that are spread amongst multiple disciplines. Active collaboration and effective teamwork between project participants is thus considered central and critical. Multidisciplinarity in construction projects however requires careful investigation of team selection that is based upon individual skills and competences. The industry today is inclining towards the adaptive use of model-based processes and technologies namely building information modelling (BIM), and there is a need of BIM competent workforce to support these ongoing changes. Study of the impact what different levels of BIM skills and competences an individual has in multidisciplinary team selection and how the multidisciplinarity of the BIM team works is a relatively new area of interest for researchers in academia and industry alike. This paper thus proposes a conceptual framework for assessing multidisciplinarity in BIM context.

Keywords: Add up to five keywords here, separated by commas

1. Introduction

Construction projects are unique by nature and include a wide variety of disciplines, individuals and organizations working towards a common goal. Traditional methods of construction project planning, designing and execution have been fragmented across multiple firms and disciplines. Effective and efficient collaboration amongst the project participants is seen as critical and beneficial for projects, leading to greater efficiency, quality, and hence, increased productivity for the construction industry as a whole. Today, we see different methods, processes and technologies being actively implemented to support collaborative ways of working, such as building information modelling (BIM).

BIM is considered a disruptive technology that provides a new way of managing the design and construction of projects with wide support for collaboration (Eastman et al., 2008; Gu et al., 2008; Hardin, 2009; Arayici, Egbu, & Coates, 2012, Yalcinkaya & Singh, 2015). BIM processes and technologies are increasingly being implemented at varying levels across the world. There is currently a rapid growth in BIM adoption and implementations in construction projects of different scales and nature. According to the literature, there has been 21% increase in BIM adoption from 2007 to 2009 in North America (McGraw Hill, 2009); 12% increase from 2009 to 2010 in Europe (McGraw Hill, 2010); 41% increase from 2010 to 2014 in UK (NBS, 2015).

One of the basic constituents of successful BIM implementation is efficient collaboration amongst project participants and the multidisciplinarity of the team involved. While multidisciplinary teams are considered important, there has been very little conceptual and methodological support (1) to objectively assess and compare multidisciplinarity of two or more individuals or teams, (2) to measure the impact of individual expertise on multidisciplinary teams, and (3) to define which of the many combinations of multidisciplinary skills is suited to a given context. Thus this paper aims to present a conceptual framework that could be further developed to understand multidisciplinarity in BIM context.

2. Background

2.1 Multidisciplinarity approach

Creating teams made up of varying disciplines, in general, facilitates the resolution of complex problems by generating new and creative solutions. The Oxford dictionary defines the term "multidisciplinary" as "combining or involving several academic disciplines or professional specializations in an approach to a topic or problem." Various sources in literature identify the importance of multidisciplinarity in teamwork. Choi & Pak (2006) define the objective of multidisciplinary approach as "to resolve real world or complex problems (...and) to provide different perspectives on problems". Similarly, Cross (2004) highlights the importance of multidisciplinarity as an approach to increase the possible generation of creative solutions through interconnection of interdisciplinary knowledge of participants.

Multidisciplinary teams, on one hand are required and beneficial for solving critically important and complex problems, while on other hand can also provide new dimensions towards innovative knowledge generation and creation. Individual expertise, skills and competencies have direct impact on dynamics of multidisciplinarity in teamwork and so a balanced synthesis amongst required fields is important for effective multidisciplinary team building. Given the complexity of social, technical and process variables when working as part of a team in a construction project, it is important to gain an understanding of what multidisciplinarity means in the specific context of AEC industry. This understanding is particularly necessary given the traditionally silo mentality that exists between the engineering disciplines.

2.2 Multidisciplinarity in construction projects

Construction projects by their very nature, have always involved the cooperation of various disciplines. Typically, construction projects are unique and large, comprising of many phases and requiring major investment. Output of a construction project is a collective effort and goal of multiple disciplines involved. Due to the fragmented nature of activities, active collaboration and teamwork is being considered as essential today in construction projects.

A significant factor accounting for the fragmentation of the AEC industry is organizational divisions due to the fact that the industry is made up almost entirely of SMEs (small to medium enterprises) many of these acting in a single discipline. The annual report on SMEs by the European Commission concluded that between 2012 and 2013, 90 % of total people employed in the European construction sector work in SMEs and furthermore SMEs contributed €400 billion to the construction sector out of the €485 billion total value added production (Gagliardi et al., 2013). Given that such a large percentage of the industry is made up of small to medium organizations, many of which are mono-disciplinary, it becomes imperative that exchange of information and skills between organizations be explored in greater depth to gain an understanding of multidisciplinarity.

Various tools, processes and technologies have been developed and implemented to facilitate, support and enhance multidisciplinary collaboration. Contractual models such as PPP (Private Public Partnerships), IPD (Integrated Project Delivery), Alliance contracts and partnering encourage shared interest in project success by giving the participants a vested interest/ownership. Further to the development of integrated contractual arrangements to encourage multidisciplinary collaboration and partnering, various tools and methods have been developed to improve the capabilities of the organizations involved. Building Information Modelling (BIM), BIG room (BR) and Knotworking (KW) are amongst a number of which have been developed to facilitate collaboration in multidisciplinary projects. However, all these approaches are enablers to create multi-disciplinary environments, but they by themselves do not provide any decision support on how to compose a balanced multi-disciplinary team.

2.3 BIM and multidisciplinarity

BIM is widely accepted as a revolutionary technology, and potentially revolutionary socio-technical approach for collaboration in construction projects. BIM adoption, implementations and its benefits for construction projects has been widely discussed and researched. Active collaboration between the project participants and smooth data exchange between the tools they utilize is considered a key to successful BIM implementation. Thus, adaptive use of BIM not only requires but also supports multidisciplinarity.

2.3.1 How BIM influences/ supports multidisciplinarity

BIM support multidisciplinarity at individual as well as team level. Some of the aspects of BIM supporting multidisciplinarity are listed as follows:

- **BIM and multidisciplinary communication -** Koutsikouri et al., (2006) state that "success in a multidisciplinary practice depends on (...) the quality of interactions between team members". Recognizing that a BIM approach facilitates better quality interactions between team members it surmises that BIM adoption is ultimately positive as a multidisciplinary team.
- **3D coordination -** The majority of interest and focus (with regard to BIM approach) is in the area of 3D coordination. According to Jung and Lee (2015) 85% of AEC companies surveyed considered this to be the most important utilization of BIM today.
- **Common data environment** - Single file concept of integrated BIM for multidisciplinary data exchange.
- **BIM as a knowledge creation and exchange platform** - integrated domain specific knowledge.
- **BIM as a tool for multidisciplinarity input -** BIM applications as knowledge-based systems have a lot of integrated interdisciplinary and organizational knowledge. An architect with limited experience in energy modeling can still run preliminary energy simulations to know how his/her design is performing with regard to energy.
- **Design authoring -** Integrated teamwork possibilities within domain specific BIM environments for informed decision making.

2.3.2 How BIM requires multidisciplinarity

As discussed earlier, BIM technologies, their adoption and implementation requires collaborative teamwork and processes. Development of new roles and need of new competencies for disciplines suggest new approaches and requirements for multidisciplinary collaboration amongst the project participants. As an example, the job of BIM coordinator/BIM manager has become a common role only in the past approx. 5-10 years to support coordination and management of multidisciplinary team and activities spread among different disciplines. Therefore, BIM requires multidisciplinary skills and knowledge both at individual and team level.

- Individuals not only need to know about their own discipline but also need to have BIM skills and knowledge. i.e. domain knowledge as well as BIM knowledge; and
- The team as a whole not only needs to know about the domain areas, but also needs to know how to work together and collaborate in a BIM project, i.e. task knowledge as well as teamwork knowledge, including teamwork in the context of BIM.

Therefore, it is desirable to understand the balance of domain vs BIM knowledge that is required at individual levels, and similarly, what is the balance of task vs team knowledge needed at team level. Currently, there are no methodological approaches to assess or understand these requirements.

2.4 Need for a common framework for multidisciplinarity assessment

With increase in BIM adoption and implementations, the need of multidisciplinarity in teams has been highlighted as a core element in BIM based projects. There is a need for processes and methods to assess multidisciplinarity both at individual and team level, for smooth BIM transition and to support the technological changes brought about by BIM. We furthermore highlight the need of a common framework for multidisciplinarity assessment for the following reasons at individual level and team level:

2.4.1 Individual level:

There is lack of BIM capability assessment criteria, standards or standardized accreditation. As diverse BIM tools and technologies are present, there is not yet any common system for assessing individual BIM competencies and guidelines to support the level of BIM expertise needed. There is much variance in individual BIM competences dependent upon level of BIM knowledge, BIM skills and the level of expertise required for a project of differing types. Assessment of individual BIM tool competences can be seen emerging for specific BIM applications conducted primarily by private industry such as software vendors. These individual level of competences are important, however, requirements vary according to the project type, location and diversity of BIM tool utilization. No system defining these levels or competences has yet been developed.

2.4.2 Team level:

The level of BIM application competences in accordance with the level of domain expertise have several possible combinations and thus have direct impact on the level of team competence and multidisciplinarity in teams. Not only is the individual BIM competence assessment (individual BIM competent profile) missing, a system for selecting a BIM competent team based on the skills required for a project, does not exist (Multidisciplinary team profile).

We see that a common framework for understanding multidisciplinarity at individual and team level would be able to assist in the composition of multidisciplinary project teams. It is the view of the authors that developing a common framework to measure and compare multidisciplinarity levels in the AEC industry both at individual and team level could provide a tool, method and system for team selection. The core concept of development towards a framework to understand multidisciplinarity in BIM context is thus discussed and presented. Furthermore, we see an opportunity for utilizing the framework for various purposes and needs in different fields such as recruiting and employment (comparison of candidates), development of BIM educational activities and programs (aligned to industry requirements of graduates) as well as to facilitate team selection criteria for BIM based projects.

3. Conceptual outline for the multidisciplinarity framework

Different maturity matrix models have been developed over time that claim to precisely quantify BIM maturities of people (individual and team level), processes (organizational level) and product (project level). Amongst the present BIM maturity toolsets, organizational and project level maturity are much more focused; whereas only "BIMe" is present for assessing individual as well as team maturity as shown in Figure 1.

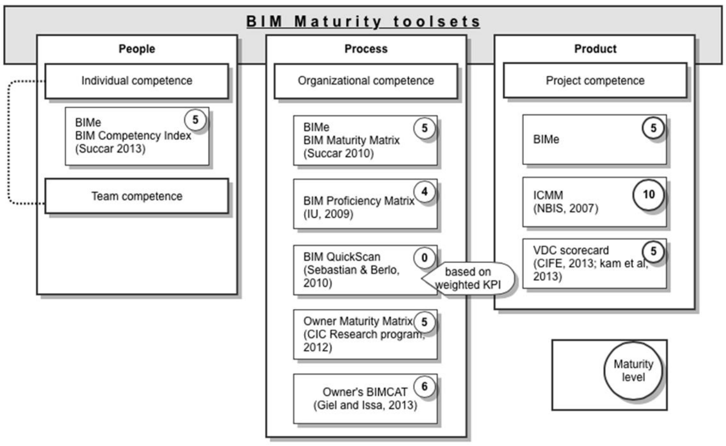

Figure 1: BIM maturity tool comparison (adopted from Geil and McCuen, 2014)

Our conceptual focus goes beyond assessing the maturity levels to understanding the BIM competence combinations and the varying level of combination possibilities that would help in optimizing multidisciplinary team formation and see its impact on the possible team compositions. Thus, rather than focusing only on assessing a team's maturity, we also intend to develop methodologies of profiling so that we can understand the desirable composition. That is, out of the numerous permutations and combinations possible for skills and expertise levels, which combinations are desirable and suitable to a specific context is needed, Figure 2.

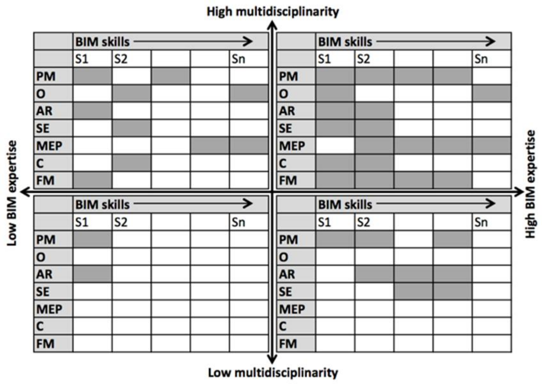

Figure 2: Individual and team profiles as a combination of disciplines and expertise levels aligned with BIM skills (Adopted from Singh and Casakin 2015)

As an analogy, you do not get the best football team by putting together a team of all the best players in different positions. A good team has a balance of top class players, good players and promising rookies, who can still collaborate to potentially give the best result. How do we achieve the same level of team management in BIM projects? How do we profile the team members and team for their various competences, and identify areas for improvement at both the individual and team levels?

3.1 Individual profile - Individual BIM competent discipline

Project participants today require adequate BIM knowledge and skills of tools and processes along with the discipline specific knowledge and processes. We term the disciplines as "individual BIM competent discipline" (in generalized form "Dn"). This integrated BIM competent discipline profile has different variances (D1a, D1b,...D1n as represented in Figure 3) depending upon the level of expertise and knowledge an individual has both in their own disciplinary field as well as with BIM.

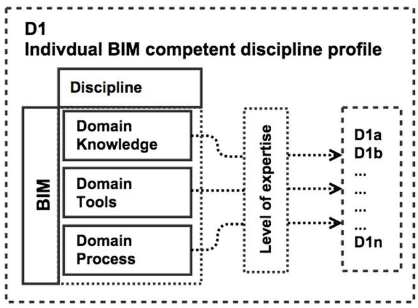

Figure. 3 – Individual BIM competent discipline profile formation

As the use of BIM varies with project type and scope, primary and secondary BIM uses from Kreider et al (2010) (Appendix 1)has been followed and defined as the 25 BIM skill set in this paper. Common BIM requirements (CoBIM, 2012) series has been extensively followed in this paper to develop the project participants and the roles needed for a BIM project. The identified roles and responsibilities in a typical BIM project are listed as seven disciplines, namely - project manager (PM), owner (O), Architect (AR), Structural engineer (SE), Mechanical electrical and plumbing engineer (MEP), Contractor (C) and Facility manager (FM). We are aware of emerging new roles of BIM coordinator/manager (Lehtinen, 2010), however for this study we include it as a role conducted by a project manager.

Different maturity matrices use a range of 4-10 maturity level as presented in Figure 1. To make it simple at this conceptual stage, we follow the approach of Succar & Kassem (2015) and adopt five level of maturity levels represented as level 1: low, level 2: medium-low, level 3: medium, level 4: medium-high, and level 5: high. A baseline standard thus could be easily adopted in an individual, organizational as well as national level to support and define the minimum BIM competence required. For example, if a standard baseline of a PM is set as of minimum requirement of level 4, presented scenario in Figure 4, would have a direct approach for the preferable PM with level 4 competence.

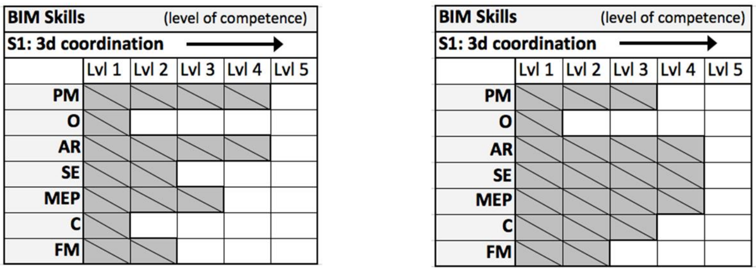

Figure 4 - Possible individual BIM skill profile depicting a possible multidisciplinary team composition for 3d coordination skill

3.2 Multidisciplinarity and BIM expertise - Team profile

The variance of individual BIM competent discipline profile provides the possibilities of generating different combinations of multidisciplinary teams. The teams thus generated could be compared with benchmarked profile of a multidisciplinary team to depict the best possible solution based on the project as presented in Figure 5.

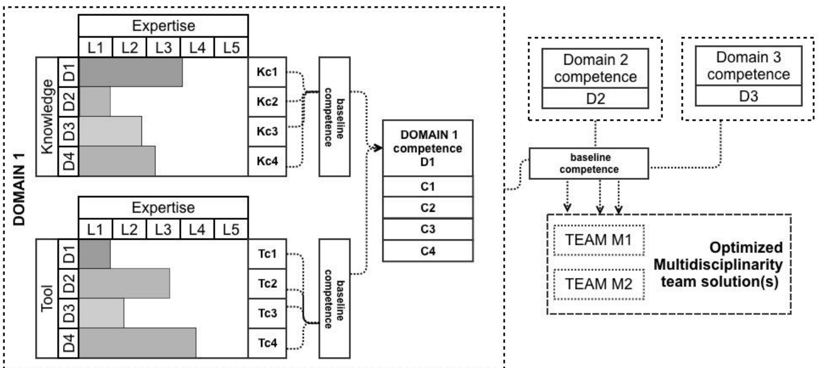

Figure 5: Optimized multidisciplinary team solutions

Thus, the possible combinations of multidisciplinarity and levels of BIM expertise is large and so there is very rare evidence about how the multidisciplinarity of team and individual BIM competences influence the team performance.

4. Future work / Discussion

The authors in near future aim to implement the presented conceptual framework for various scenarios ranging from education to teamwork in AEC projects that will help in validating and giving more rigorous results in practical scenarios. BIM skills identified will be filtered for the various planned case projects and thus applied to validate its usefulness.

4.1 Mapping individual skills and profiles

Multiple approaches to creating and validating the multidisciplinary assessment framework will be applied. Building on the existing research and industry surveys conducted in various parts of the world (e.g. McGraw Hill, 2009, 2010; Kreider et al., 2010; Finne et al., 2013; NBS 2015), this research will collect further data within classroom settings, offices and recruitment agencies. The questionnaires for collecting data will begin with an open ended structure, where respondents will be asked to identify the skills they deem most important for their role. In the next phase, a list of skills will be given for respondents to choose from and rank in order of their importance. In the final phase, for each of the shortlisted skills ranked high by the participants, they will be required to use a Likert scale (varying level of scales will be implemented based upon the case projects) to mark the level of expertise desirable in that skill set. Thus, the questionnaire will create a matrix of the number of skills and the level of expertise in each of the skill sets. In addition, experimental set-ups with simulated BIM projects will be used to test the applicability of the framework.

4.2 Validate the mapping of skills and profiles

In order to validate the proposed conceptual framework, future work may test the framework in a multidisciplinary setting, observing skills as they are acquired and measuring the effects on the profile of the group and, of course, its performance at the given task. Therefore, the authors will implement it in a workshop bringing together design students from various backgrounds to simulate a BIM based construction project scenario. The students will simulate their roles resembling a real construction project. The workshop has been planned as a small structure that should, for its completion, bring together a number of trades and construction methods. The team will utilize BIM for the design and construction of the structure. In order to simulate roles more accurately, BIM dimensions focused includes digital project controlling in order to track and analyze progress of the construction activities and phases.

Based on the conceptual framework presented, Figure 6 shows the baseline for required project participants and the BIM skills focusing the planned construction workshop. The framework suits the type of project and group of disciplines. The BIM competences are rated out in Likert scale of range 1-5 to generate the baseline profile for the team.

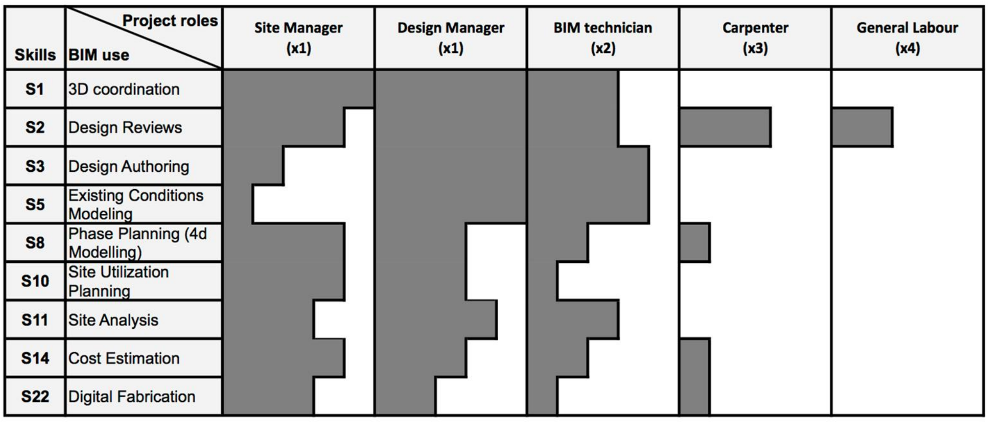

Figure 6 - BIM skills required of workshop participants

As a method of benchmarking, the framework prepared is planned to be distributed within industry as questionnaires for further validation of the BIM competences specific to Finnish requirements. Respondents would be instructed to fill out the framework with the desired range and level of BIM skills needed for the team and project. Having these industry requirements as a benchmark, the data collection will be aligned with the participants of the workshop. The participants during the workshop will fill in their skills into the framework at two levels - before the workshop to map expectations and understandings of the participants and after the commencement of the workshop to validate the usefulness of implementation. With the perceived usefulness of the implementation, authors seek to furthermore assess the impact in BIM learning. Furthermore, we hypothesize that these types of collaborative approaches of working in a multidisciplinary environment generates new skills and assist in learning from each other while simultaneously completing the project more effectively.

5. Conclusion

It is agreed in the literature that multidisciplinary collaboration in projects leads to the generation of creative solutions for complex problems. Global increase in BIM adoption and its diversified implementations have shown that BIM is here to stay and will be a de-facto attribute for the professionals. Various researches and industry implementations suggest that success of BIM based projects require integrated multidisciplinary team and active collaboration amongst the individuals. However, the level of BIM competencies and its impact on the multidisciplinary team formation and its effectiveness is still a very young research area. Authors believe that the framework presented will help in assessing BIM competences at individual as well as team level. It will furthermore guide towards development of systems and method to both assess and support on how to compose a balanced multi-disciplinary team.

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Appendix 1 *- BIM skills based upon BIM use frequency and benefit with respect to rank order from Kreider, et al., (2010)*

Skills	*BIM use*	*Description*	*Discipline*
S1	*3D coordination*	*A process in which Clash Detection software is used during the coordination process to determine field conflicts by comparing 3D models of building systems.*	*PM, AR, SE, MEP, C*
S2	*Design Reviews*	*A process in which stakeholders view a 3D model and provide their feedbacks to validate multiple design aspects.*	*PM, AR, SE, MEP, C*
S3	*Design Authoring*	*A process in which 3D software is used to develop a Building Information Model based on criteria that is important to the translation of the building's design.*	*PM, AR, SE, MEP, C*
S4	*Construction System Design*	*A process in which 3D System Design Software is used to design and analyze the construction of a complex building system (e.g. form work, glazing, tie-backs, etc.) in order to increase planning.*	*PM, O, AR, SE, MEP, C*
S5	*Existing Conditions Modeling*	*A process in which a project team develops a 3D model of the existing conditions for a site, facilities on a site, or a specific area within a facility.*	*PM, AR*
S6	*3D control and Planning*	*A process that utilizes an information model to layout facility assemblies or automate control of equipment's movement and location.*	*PM, C, FM*
S7	*Programming*	*A process in which a spatial program is used to efficiently and accurately assess design performance in regard to spatial requirements.*	*PM, O, AR*
S8	*Phase Planning (4d Modelling)*	*A process in which a 4D model (3D models with the added dimension of time) is utilized to effectively plan the phased occupancy in a renovation, retrofit, addition, or to show the construction sequence and space requirements on a building site.*	*PM, AR, SE, MEP, C*
S9	*Record Modelling*	*Record Modeling is the process used to depict an accurate representation of the physical conditions, environment, and assets of a facility. The record model should, at a minimum, contain information relating to the main architectural, structural, and MEP elements.*	*PM, FM*
S10	*Site Utilization Planning*	*A process in which BIM is used to graphically represent both permanent and temporary facilities on site during multiple phases of the construction process. It may also be linked with the construction activity schedule to convey space and sequencing requirements.*	*PM, AR, C*
S11	*Site Analysis*	*A process in which BIM/GIS tools are used to evaluate properties in a given area to determine the most optimal site location for a future project.*	*AR*

S12	*Structural Analysis*	*A process in which analytical modeling software utilizes the BIM design authoring model so to determine the behavior of a given structural system.*	*SE*
S13	*Energy Analysis*	*The BIM Use of Facility Energy Analysis is a process in the facility design phase which one or more building energy simulation programs use a properly adjusted BIM model to conduct energy assessments for the current building design.*	*MEP*
S14	*Cost Estimation*	*A process in which BIM can be used to assist in the generation of accurate quantity take-offs and cost estimates throughout the lifecycle of a project.*	*AR, SE, MEP, C, FM*
S15	*Sustainability LEED Evaluation*	*A process in which a BIM project is evaluated based on LEED or other sustainable criteria.*	*AR, MEP*
S16	*Building Systems Analysis*	*A process that measures how a building's performance compares to the specified design. This includes how the mechanical system operates and how much energy a building uses.*	*MEP*
S17	*Space management/tracking*	*A process in which BIM is utilized to effectively distribute, manage, and track appropriate spaces and related resources within a facility.*	*PM, AR, FM*
S18	*Mechanical Analysis*	*A process in which intelligent modeling software uses the BIM model to determine the most effective engineering method based on design specifications.*	*MEP*
S19	*Code Validation*	*A process in which code validation software is utilized to check the model parameters against project specific codes.*	*PM, AR*
S20	*Lighting Analysis*	*A process in which intelligent modeling software uses the BIM model to determine the most effective engineering method based on design specifications.*	*MEP*
S21	*Other Engineering Analysis*	*A process in which intelligent modeling software uses the BIM model to determine the most effective engineering method based on design specifications.*	*AR, SE, MEP*
S22	*Digital Fabrication*	*A process that uses digitized information to facilitate the fabrication of construction materials or assemblies. Some uses of digital fabrication can be seen in sheet metal fabrication, structural steel fabrication, pipe cutting, prototyping for design intent reviews etc.*	*AR, SE, C*
S23	*Asset Management*	*A process in which an organized management system is bi-directionally linked to a record model to efficiently aid in the maintenance and operation of a facility and its assets.*	*O, FM*
S24	*Building Maintenance Scheduling*	*A process in which the functionality of the building structure (walls, floors, roof, etc.) and equipment serving the building (mechanical, electrical, plumbing, etc.) are maintained over the operational life of a facility.*	*FM*

S25	*Disaster Planning*	*A process in which emergency responders would have access to critical building information in the form of a model and information system.*	*AR, FM*

Is the lack of a common BIM vision between clients and contractors a cause for concern?

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ABSTRACT

A post-positivist methodology is employed to answer the question posed as to whether or not the lack of a common vision about BIM poses a problem for adoption in the built environment. The context is set by reviewing both the established benefits of BIM and the collaborative and other benefits it fosters. A sample of nine recent adopters of level 2 BIM were interviewed, including clients, architects, designers, first and second tier contractors. Their responses provided qualitative data for examination and interrogation. The population was asked about their definition of BIM, the positives and drawbacks they perceive over a series of questions. In this way, and through the examination of comments from the respondents, it was possible to examine the divergent views on what BIM represents to the UK construction industry in 2015. The key finding is that complimentary views existed notwithstanding the different emphasis placed on BIM by the respondents.

Keywords: Building Information Modelling, Collaboration, Early Contractor Involvement, Partnering.

1. INTRODUCTION

If Building Information Modelling (BIM) is to succeed then the take up amongst all stakeholders at all levels must be accelerated. The University of the West of England has experimented with achieving improved take up by encouraging best practice by embedding the knowledge and learning derived from academic institutions within commercial organisations. In this context, collaborative placements were arranged in 2015 whereby Masters Students on the BIM master's programme were able to assess and align the business case and needs of the participants and elucidate the same in a BIM Execution Plan.

The notion behind the placements was that the students would become "BIM champions" for the firms taking them. The students acted act as a focal point for BIM implementation and were able to deliver any projects set for them by the business owners. The students were also present to listen as a sounding board for any observations about BIM obstacles and drawbacks being experienced. Their time at the placement culminated in their interviewing of key staff which

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has provided the data for this paper. Views were gathered on. the wider context of BIM adoption and the perceived barriers to entry and thoughts for the future. These views became the main data set on which this paper is based.

2. CONTEXT

In the United Kingdom, many commentators have adopted the definition coined by Keith Snook former RIBA director of research; "*Building Information Modelling is a digital representation of physical and functional characteristics of a facility creating a shared knowledge resource for information about it forming a reliable basis for decisions during its life cycle, from earliest conception to demolition.*" It requires, therefore, contractors, sub-contractors, lead designers, architects, project managers and designers to work together and share information.

BIM maturity and adoption varies between industry sectors and countries. More contractors are using BIM than architects (McGraw-Hill Construction, 2012). 37% of engineers in Western Europe use BIM, versus 42% in North America, 48% of architects who use BIM consider themselves advanced or expert (McGraw-Hill, 2010). Notwithstanding these statistics, a recent study concluded that there is a great lack of well-educated and trained BIM professionals (Wong & Fan, 2013).

The UK Cabinet Office has published a construction strategy article that requires the submission of a fully collaborative 3D BIM (with all project and asset information, documentation and data being electronic) as a minimum by 2016 (BIS, 2011). Successful implementation of these systems requires an appreciation of how BIM resources (including hardware, software, as well as the technical and management skill of staff) need to evolve in harmony with each other (Succar, et al., 2012).

BIM adoption involves a discussion of the levels which reflect the progress towards a fully collaborative process being achieved. Level 2 BIM is a managed 3D environment created from models/information produced separately by members of the project team and managed by a BIM Coordinator (also known as the BIM Information Manager), who is the central control point for the 3D environment which stores shared data and information. There is therefore a series of domain specific models. The BIM Co-ordinator builds a 3D model from the separate 3D inputs from the design teams and makes sure that each piece of data is inserted from the same origin. The BIM Co-ordinator also ensures that drawing and layer conventions are maintained in order to validate the individual inputs and they will then lead the clash detection and design reviews of the 3D combined model.

The Government has set a target of 2016 for all major Government projects to get to Level 2 BIM – this only affects public sector projects.

Level 3 BIM maximizes the potential of BIM. All the data is stored on a single integrated Project Information Model (PIM) system which can be accessed by all members of the project team to create a completely open design process. Each contributor adds its own specific information to the model on an ongoing basis and tracks any changes made. The model can be used to take account of changes and determine impact on time and cost of the programme can be used to plan procurement of materials. There is only one model. Designers go in and develop the scheme from a single source. It is frozen at periodic (pre-agreed) intervals so that iterative design progress can be recorded.

Since the Government publication of a BIM Protocol (BIM Task Group, 2013) for use at Level 2, designed to accompany standard forms of contract, the industry has (in theory) the tools it needs to deliver the government's ambitions. The survey shows that 68% of the industry believes that BIM is all about real time collaboration (NBS, 2013), and forty per cent felt that when they use BIM, they need to do so within a collaborative project suggesting that a significant number of people feel that if the project is not collaborative, then it is not BIM (NBS, 2013).

It has been claimed that BIM delivers project cost reductions, reduced build time, reduced claims and less project change costs (Bryde D, 2013). In his recent Construction Industry Council report 'Growth through BIM', Richard Saxon CBE made some important observations about the relationship between BIM, partnering and collaborative forms of contract. He suggested that *"What partnering needed to succeed was BIM"* (Saxon, 2013).

3. METHODOLOGY

The collaborative and participative placements were run over an average of a six month period involving a minimum of ten contact points between the consultant and the organisations. Twelve placements were undertaken. The organisations were a mixture of large clients, architects and first and second tier contractors. As such, this represents a representative cross-sample of BIM stakeholders notwithstanding the small sample size. The views expressed by these respondents are therefore capable of generalisability within the limitations of the research. The limitations were the limited time and resources in which to conduct the study alongside the wider objectives of the placements. Interviews were used to seek the views and interpretations of practitioners (Bourg, 1989). Individuals tasked with introducing BIM into the firms were interviewed and their views recorded. The individuals approached were concerned with delivering change to their organisations in the form of the BIM execution plan. The views and experiences of these opinion formers were therefore extremely relevant to the discussion around BIM adoption.

The research interviews on which the dataset collected is based were conducted after the completion of the placement within four months of the exercise.

This paper adopts a post-positivism philosophy which aims to mirror scientific method whilst remaining realistic to the data in context. An interdisciplinary methodology is introduced given its references to external factors and context. The epistemological nature of the research is that of external enquiry examining a social entity. Interdisciplinary research broadens discourse in terms of its theoretical and conceptual framework which guides the direction of the studies and its specific research methodologies are able to generate empirical evidence to answer research questions (McConville, 2007).

4. MAIN FINDINGS AND DISCUSSION

The findings are presented in three sections which deal with the definitions, positive elements and uncertainties detectable within the interview transcripts. Taking these in turn:

Definitions

The respondents were asked to give their definition of BIM. The following views were recorded and have been grouped together by membership of either the client side respondents or supply side. The emphasis placed by the respondents on the BIM feature they identified reflects their place in the construction process. Essentially, the clients accentuating the importance of the data flow whilst the supply side is more concerned with the key deliverables. The definitions identifying the importance of data were as follows:

BIM is a process; a new method of storing and transmitting information in a digital format. (Type: Client, Occupier, User, and Facility Management)

BIM is assembling supplier information in a 3D model with intelligent information behind which generates schedules, graphical information and a collaborative network of bringing those all together through a common data environment. (Type: Client)

I see BIM as an expansion of graphical data to include more informative data around other data as part of a wider building data base. (Type: Client, Operator, Facility Management)

BIM being the graphical and information and data representation of a physical building or yet to be built building. (Type: Client, Occupier, User, and Facility Management)

The model is built up of intelligent elements used for CAPEX and OPEX (Type: Client, Occupier, User, and Facility Management)

The clients have a global view on BIM and the legacy of the data involved the process. The last comment shows the financial importance of the information and how it can lead to the savings promoted by the government.

Other definitions identified the importance of collaborative behavior. These respondents were from the supply side as Tier 1 and Tier 2 respondents. Their perspective and viewpoints were more concerned with collaboration and improvement in their working processes. The opportunity to work in a smarter way is a major attraction for these participants. The need and the desire for collaborative practice is writ large here.

I see it as a sort of very social and behavioural [tool] aligning interests of various stakeholders, operator, maintainer, end user. (Type: Contractor)

BIM is the bringing together of different design teams to collaborate on a project bringing about a cost effective well engineered project (Type: Sub-Contractor)

It is notable that stakeholders in BIM find a definition of the benefits which work best for them and resonate with that person's perception. It is therefore a healthy outcome that the different aspects of BIM at level 2 are stressed and different parts of its appeal are highlighted by the individuals targeted. SMES are therefore all about the collaboration but also need to be aware of the other elements in the definition to access the whole range of BIM benefits.

Positive Elements

The respondents were asked to identify positives in relation to BIM. The client and supply side can be differentiated by the focus of their comments:

The main benefit for us is the reduction in capital investment (gov't target 20%) and reduction in the number of conflicts if instructed properly (Type: Client, Occupier, User, and Facility Management)

What's in it for the client? 20% saving cost certainty and you can sleep at night the builders on time on budget to quality. What's in it for the user? He gets a BIM model and can integrate the model into FM BMS (Type: Client, Occupier, User, and Facility Management)

These two comments re-iterate the importance of the end game for the client and the translation of data management into financial savings.

The supply side focus is on the key deliverables in term of benefits to the Contractor.

BIM is trying to keep the information that the client eventually has on his building as something useful rather than gathering dust on a shelf in multiple folders. (*Type: Sub-Contractor)*

The idea of begin able to feed into something, a system that's going to persist that will carry our information on to an entity and having that pass through into the management of the asset is right up our street. (*Type: Sub-Contractor)*

What we rarely see are other professionals interested in what we do. (*Type: Sub-Contractor)*

The respondents are imagining BIM for themselves and see the benefits of terms of improvement to working process and offering a better service to their clients. The massive potential to work collaboratively and end a silo-based approach is evident. The vision is clearly to have a means of transcending adversarialism and a desire for a more straightforward and manageable process where supply side views are respected and sought.

Comments demonstrating uncertainty

The comments point at change and flux in the guidance as it has been disseminated from the government. The feelings of being overwhelmed and uncertain are evident from the comments.

The information on BIM out in the real world is really quite daunting for us (*Type: Sub-Contractor)*

It is still a moving goalpost but we are improving (*Type: Sub-Contractor)*

We all end up following people who we think they know what they're doing and they might not (*Type: Sub-Contractor)*

There are a lot of companies who know a little and everybody seems to be saying yeah we do BIM level 2 and then keeping their head down and hoping they do not get caught out. (*Type: Sub-Contractor)*

These comments are indicative of current exposure to BIM processes which are still in their infancy. All of these comments are from the supply side which shows that they are concerned with the deliverable aspects of BIM. This might be explained by the focus to date by the PAS 1192, 1193 and 1195 documentation suite, which approached adoption from the construction process side rather than putting the emphasis on client articulation of their BIM brief through the BIM execution plan. The wisdom of preparing the ground with the supply side makes sense in terms of creating a receptive environment capable of offering BIM services to the eventual users. The downside of this approach is that it is only relatively late in the adoption process that the clients can actually express their needs. Once the process is established the clients will be able to state their needs more clearly. There is uncertainty amongst the supply side insofar as this eventual pronouncement differs from the predicted use.

There is additional reservation as to procurement process with the future UK government BIM Level 3 aspirations in the publication of Digital Built Britain – Level 3 Building Information Modelling Strategic Plan

5. CONCLUSION

It is evident from this study that BIM is viewed positively by both client and supply side in terms of being a welcome development for the built environment. There is clear divergence between the two groups in the views as to how BIM should be defined and the different benefits it delivers. Ultimately, this is not thought to be an issue. The multi-faceted nature of BIM means that there are many different aspects on which respondents may focus. All of the BIM potential benefits are equally valid and provide long term improvement and progress on from existing practices. The scope and encouragement BIM delivers to practices wishing to make a difference regardless of their position is a tangible result of this research. The perception of the respondents pointed to their excitement that that they are right now at the forefront of the market and have competitive advantage and an energized workforce as a result.

The views of the client and contractor side are congruent in that they are complimentary and mutually supportive. The emergence of BIM as a genuine panacea for the ills of the industry is therefore appreciable.

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BIM for Parametric Stadia Design: Do Designers Really Need Visual Programming?

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Abstract

This research seeks to address complex issues related to stadia design, with a particular focus on parametric terrace modelling. Using advanced Building Information Modelling (BIM) processes and techniques, a dynamic 3D model is developed which automates c-value and capacity calculations, improving efficiency and quality within design firms. The scope of this research has been confined to the activity area, terrace, seating, barriers and gangways. These design areas, particularly terraces', provide constant headaches for designers due to strict regulations. Simplifying this process enables designers to spend more time designing and less time modelling based on meticulous calculations. All aspects of this research have been developed directly within native BIM software to determine if designers really need visual programming to facilitate parametric stadia design. A mixed method approach has been adopted, using quantitative analysis for capturing design formulas and associated parameters, and qualitative discussion addressing problematic and successful aspects of parametric design. It soon became apparent that one parametric family would not be capable of providing designers with the flexibility to meet the significant number of variables associated with stadia design. As such, several families were created using different templates and tools, then federated using a four level nesting methodology. Other findings highlighted that shared parameters are essential to automate data flow to schedules, whilst the incorporation of 3D seats within the terrace family dramatically slows design iterations. That being said, a 20,000 capacity stadium with seats was created in under an hour using the parametric stadia models developed during this research. Conclusions drawn from this research show that complex parametric stadia design can be achieved without the need for third party visual programming software. The process is by no means straightforward and an in depth knowledge of parameters and formulas is paramount for its success.

Keywords: BIM, parametric, modelling, design, stadia

1. Introduction

Sporting events have attracted crowds in excess of 50,000 since the Colosseum was constructed in the first century AD. Even then there was a basic understanding of crowd safety with the inclusion of 80 entrances/exits (Elliott & Smith, 1993). Stadia design is still a particularly important and complex aspect within the modern day sports and leisure sector. Regulatory bodies have been setting strict design requirements to ensure spectators have a comfortable and most importantly, a safe experience when visiting sporting venues, especially in light of disasters such as Hillsborough, Ohene Djan and the Kathmandu Stadium, to name a few. These disasters, along with many others have claimed the lives of between 1280 and 1645 innocent spectators, with the number of injuries reaching 10,000. Most of these disasters are a direct result of 'complex space', poorly designed spaces which fail to cater for ever increasing crowd sizes (Hoskin, 2004).

As such, designers around the global are trying to eliminate spectator incidents by striving to meet stringent design requirements. The most common method is the use of complex mathematical equations which are performed manually. This is not only inefficient, but promotes costly errors and increases the risk of incidents. Design data such as the stadium holding capacity, appropriate density, c-values, terrace rake, seating info, etc, are being manually entered into schedules and resulting values fed in to drawing packages. This fragmented approach presents endless complications as the design changes, especially on large scale, multiple tiered stadiums. Whilst an inherent problem in stadia design, it presents opportunities within the industry to automate design and information processes through parametric modelling, enabling informed decisions to be made based on accurate geometry and associated data, during design and construction, through to facilities management. These benefits can be realised through Building Information Modelling (BIM).

The importance of parametric modelling within the Architecture, Engineering and Construction (AEC) industry has gained momentum with companies striving to increase productivity, improve quality and create added value. Parametric modelling can be described as creating flexible design and information parameters that can be dynamically altered within a project to quickly adjust 3D geometry and associated information which is automatically mapped to schedules. The advantage of using parametric BIM software is that changes in parameters are generated within minutes to deliver complete and accurate models for use by all disciplines, making it possible to adjust the design until the very last minute (Hubers, 2010). However, this process demands a forward thinking attitude when setting up a project as there are a significant number of design variables to be contemplated, one design element cannot be considered in isolation.

The emergence of visual programming is growing at a steady rate. Visual programming is a graphical algorithm editor which bridges the gap between Application Program Interface (API) and standard software tools and techniques. Free open source software such as Dynamo present designers with the opportunity to use custom nodes, systems and interoperability workflows, which aren't available in native BIM software packages. The problem lies in the complexity of the program. Users need to have a firm understanding of parameters, formulas and node based design to achieve the desired outcome.

2. Research Methodology

Following a few intense years specialising in the development of parametric BIM models based on manufactures products and specifications, a new challenge was sought. It was during this time where it became apparent that these specialist skills could have a far greater impact if the same principles were applied to the design of complex buildings, rather than the fixtures and fittings which adorn them. Now working as a BIM Coordinator in a company specialising in stadia design, the problems faced by the industry and the potential solution soon became clear.

This research uses 'Pragmatism' knowledge claim position, seeking to address complex challenges relating to stadia terrace design to increase real-world practice orientated efficiency and improve quality. The scope is confined to five key design elements; activity area, terrace, gangways, barriers and automated scheduling. The key challenge will be achieving the desired outcomes whilst restricted to using 'Out-of-the-Box' BIM software. The idea being that if flexible stadia design can be achieved without the need for additional and complex visual programming software, it opens the door for widespread application. The design software selection for this research is Autodesk Revit Architecture, but other relative BIM compliant software have similar tools and techniques which can achieve comparable results.

A literature review of previous stadia related studies along with industry design standards is made to form a solid foundation on which to develop a parametric stadia component that can be utilised during conceptual design through to detailed design and construction phase. Pragmatism is not committed to any one system of philosophy and reality (Creswell, 2003). This research approach facilitates the best outcomes through a mixed method technique which is ideally suited to a practical, parameter based study. Inquiries are drawn liberally from quantitative analysis for capturing design formulas and associated parameters, and qualitative discussion addressing problematic and successful aspects of parametric design within a native Revit environment.

3. Literature Review

Firstly, when studying stadia design it is important to get a complete overview of the many standards and guidelines which dictate how architects design stadiums to provide a comfortable and safe environment for spectators. The documents highlighted in Table 1 provide an invaluable source of information to help shape the methodology from which a parametric stadia model, applicable within the United Kingdom (UK) and internationally, can be developed. DCMS, 2008 provide a zonal planning diagram which divides stadia design into 5 key zones; 1 - activity area, 2 - viewing accommodation, 3 – internal concourse, 4 – outer circulation area, and 5 – outside sports ground. This research focuses on zones 1 and 2, designing from the central zone outwards.

Table 1: Important Stadia Design Literature

Code	*Document Title*	*Issuer, Year*	*Doc. Type*	*Application*
01	*FA National Ground Grading A-H*	*FA, 2011*	*Standard*	*United Kingdom*
02	*FA National Ground Grading Step 1-7*	*FA, 2015*	*Standard*	*United Kingdom*
03	*UEFA Stadium Infrastructure Regulations: Edition 2006*	*UEFA, 2006*	*Standard*	*International*
04	*Accessible Stadia*	*FSIF & FLA, 2003*	*Guide*	*United Kingdom*
05	*BS EN 13200 Spectator facilities – Part 3: Separating elements - Requirements*	*BS EN, 2005*	*Standard*	*International*
06	*FSIF Data Sheet 5: Services and Support Facilities*	*FSIF, 2004*	*Guide*	*United Kingdom*

07	*Guidance on designing for crowds – an integrated approach*	*CIRIA, 2008*	*Guide*	*United Kingdom*
08	*Pavilions and Clubhouses*	*Sport England, 1999*	*Guide*	*United Kingdom*
09	*Sports Halls: Sizes and Layouts*	*Sport England, 2000*	*Guide*	*United Kingdom*
10	*Stadia: A design and development guide – Fourth Edition*	*Geraint, Sheard & Vickery, 2007*	*Guide*	*International*
11	*Guide to Safety at Sports Grounds – Fifth Edition*	*DCMS, 2008*	*Guide*	*International*

There have been previous studies into parametric stadia design such as Hudson, et al., 2011 who documented the parametric design of the Aviva Stadium with a focus on its form and façade detailing; Miller, 2009 study covereing all angles of stadia design using a multitude of software programmes; and BIM Troublemaker, 2010 who spent 13 months developing a native revit parametric stadia model. There is however one commonality between all studies, they each fail to provide a useful insight into how their models have been created from a technical perspective. Shared knowledge is an essential factor in helping the industry to innovate and something which this paper seeks to address.

3.1 Activity Area

Firstly, it's important to start design in the central zone (Zone 1 – Activity Area) and work outwards towards the terrace and concourse areas. The activity areas were created using the 'Generic Model' family but could also have been developed using the 'Generic Model Adaptive' family category. It was important to create each activity area as an individual family, but using the same Shared Parameters for the pitch length, depth, perimeter offset, material, etc (see

Figure 1). The reason for this is that when the individual activity area families are nested into the master activity area family the parameters remain consistent when mapped.

The main aspect that designers require is flexibility. This needs to be considered and built into the activity area family so that the model is applicable to a wide variety of sports. Another key consideration is the visibility settings for each activity area family. This should be tackled directly within the master activity area family so that each activity area (football, tennis, cricket, etc) can be turned off as necessary. Once all families were nested into the master activity area family, parameters mapped and new visibility parameters created, the master family was loaded and placed within a new or existing project.

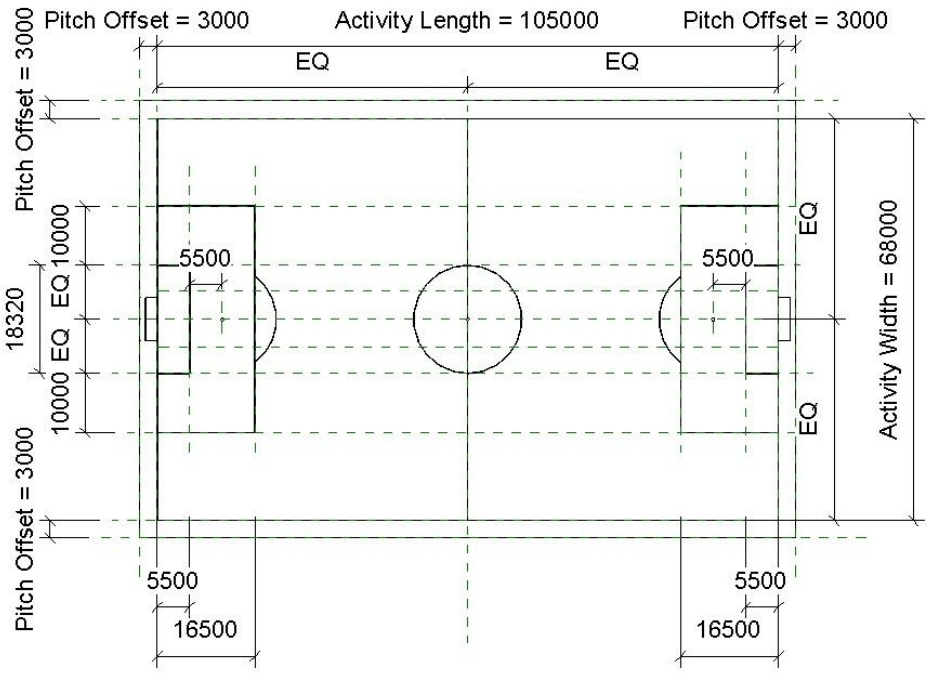

Figure 1: Activity Area Parametric Layout

3.2 Terrace

Terrace design is the most complex challenge when designing any new stadium. There are substantial variables which need to be considered. As such, it cannot be a 'one family fits all' process as this would severely limit the flexibility of the model for the end user. A better approach is to identify the key areas and design flexible models for each, which can then be used in conjunction with each other to perform complex design proposals. Aspects of terrace design which need to change dynamically include terrace riser height, depth, thickness, length, material, etc. Not only that, specific formulas need to be embedded which reference parametric values in order to extract c-value and capacity statistics on the fly (see Figure 2).

The complexity of creating a parametric terrace model provokes the need for a four-layer nesting system which covers all eventualities. The process starts with the creation of a single terrace sweep as a 'Generic Model' family with built in parameters. The terrace riser needs to have an offset which is linked to the terrace thickness parameter so that once arrayed, the row behind sits nicely on top with the correct terrace height and the join line disguised by the terrace seats in front.

This family was then nested into a separate ‘Generic Model’ family to create the terrace array which needed to be aligned and locked to specific reference planes. Parameters were mapped to enable the model to function based on input values. This nesting process simplifies the development and application of parametric design, and in some cases parametric design would not be possible without it. Once the terrace had been arrayed, an additional parameter needed to be added which allows the end user to specify the desired number of rows. The problem faced here is that an arrayed integer parameter doesn’t allow an input value of ‘1’. To bypass this an additional parameter and formula was developed to show a single terrace family and hide the arrayed terrace if the user entered a number <2. It was also important to lock the second arrayed terrace to the top and rear of the first terrace row. Failing to do this causes the arrayed terrace rows to malfunction once the terrace height, depth or thickness parameter is adjusted.

This family was then nested into a new ‘Generic Model Adaptive’ family where the process of mapping parameters was repeated prior to setting the formulas to generate c-value and capacity data. Once mapped, an adaptive node was placed which will act as the insertion point when the family is loaded into the project. This node was aligned and locked to the activity area touchline so that c-value data is generated. A model line was then drawn in the family spanning from the first row to the rear row with a divided path linked to the number of rows parameter. A lined can then be placed from the adaptive node to the first node of the divided line and arrayed to create the spectator sightlines using the ‘Repeating Detail’ command. Parameters also needed to be formed for the horizontal distance of the first row from the touchline and the vertical offset of the first row from the touchline. Additional ‘Reporting Parameters’ were created for ‘R-Vertical height of sightline from the Point of Focus (POF)’ and ‘D-Horizontal distance of sightline from the POF’ which could be referenced when calculating the c-value. These measurements needed to be taken from the rear terrace spectator to represent the minimum c-value achieved by each terrace. The capacity was then calculated by creating a formula based on the Terrace Length*No. Rows/Seat Width. To take this calculation one step further, a desired terrace length parameter was added which drives the actual terrace length parameter, rounding the length up to the nearest seat width. This formula enables the capacity to be viewed and scheduled without the need for memory intensive 3D seating. However, the idea is to have a basic terrace family with no seating to be used during iterative design and easily swapped out for a more detailed family during document production and visualisation.

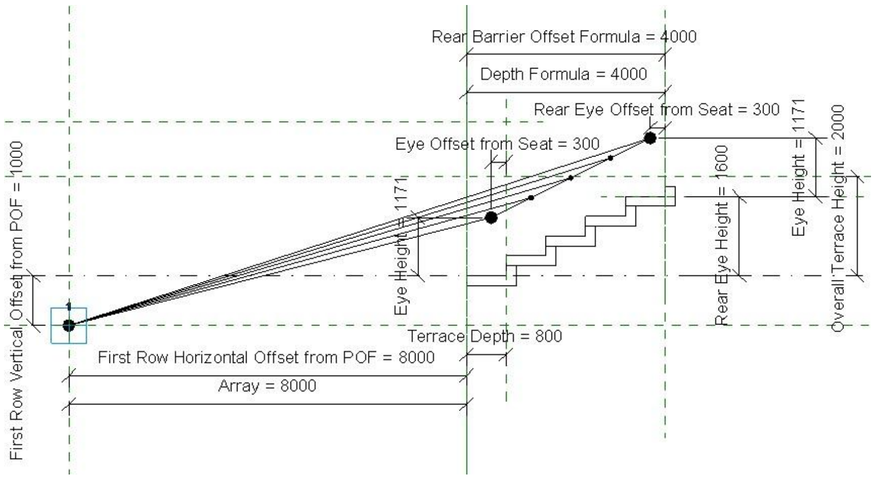

Figure 2: Master Basic C-Value Parametric Layout

3.3 Barriers and Gangways

Lateral gangways tend to be formed in front of the front row and behind the rear terrace row so it makes sense to build these in as a design option. In doing so it is important to create these as an option which can be turned on and off as required using visibility parameters.

The barrier design commenced as a 'Generic Model' family with built in parameters to control its thickness, length and material. This family was then nested and mapped to a separate 'Generic Model' family for the front gangway extension whose length and material parameters correspond to the shared parameters used in the terrace families. An additional parameter was then added to adjust the gangway depth. This model is then nested and mapped to the c-value family where it is aligned and locked to the front row terrace (see Figure 3). Depending on which side of the reference planes the family is created on will impact upon which way it flexes once the depth value is adjusted, so it's important to get this correct or the alignment will break and the parameters fail.

This family can also be used for the rear gangway, however the gangway family needs to be situated on the opposite side of the reference plane so that the gangway depth increases from the barrier outwards. This family is aligned and locked to the rear terrace riser. Separate visibility parameters need applying to the front and rear barrier/gangway families so they can be turned on and off individually. Because of the '1' integer array issue, an 'if statement' formula needed applying to the rear barrier/gangway family to turn it off if the No. Rows <2. This means a separate barrier and terrace infill family needed placing at the rear of the first row with the reverse 'if statement', not (No. Rows > 1).

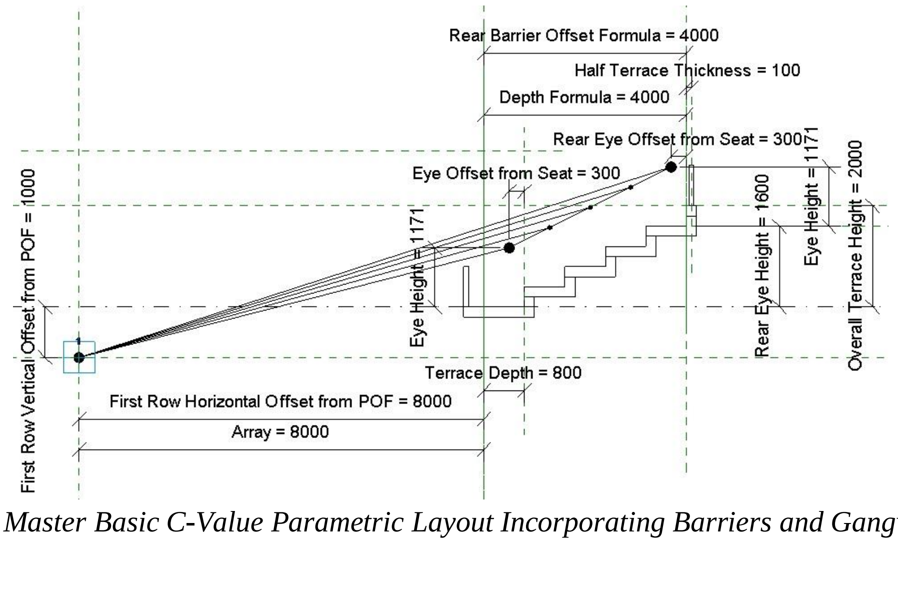

Figure 3: Master Basic C-Value Parametric Layout Incorporating Barriers and Gangways

3.4 Seating

Again, similar to the terrace family process, a new ‘Generic Model’ family was created to model the individual stadia seat. The Level of Development (LOD) can vary dependent on the end users requirements, but in this instance, parameters have been created for seating height, seat height, seat depth, seat width, armrest height, armrest length, armrest thickness, clearance, etc. Other visibility and material parameters were applied to the armrest and seat.

Once satisfied with the individual seat family, this needed to be nested into a copy of the single terrace family, parameters mapped and arrayed along the length of the terrace. The array required a parameter for the number of seats which is driven by a ‘Terrace Length/Seat Width’ formula. When the model has been flexed to determine if the parameters function correctly, the family was nested into a copy of the arrayed terrace and the existing family swapped out for the new seating terrace. During this process some of the parameters break and need to be re-applied. Once all the parameters have been mapped, the seats fill the terrace and adapt to changes in terrace length and number of rows.

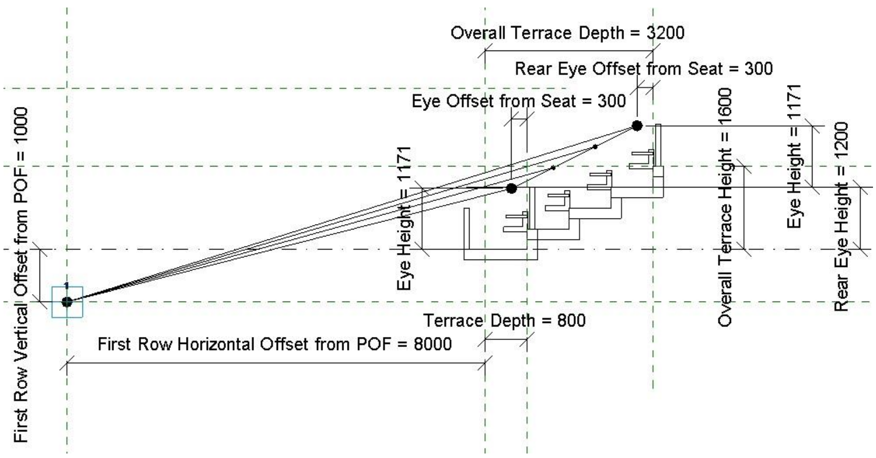

Figure 4: Master C-Value Parametric Layout Incorporating Barriers, Gangways and Seats

This family can then be nested and mapped into a copy of the c-value adaptive terrace family, again resolving any broken parameters affected during the process (see Figure 4). We now have a basic family for quick design iterations and a heavier family incorporating 3D seats for document production and visualisation.

4. Parameters

As discussed, there are a substantial number of parameters (55) required to not only make the terrace function correctly, but provided the required flexibility to make it applicable to industry (see Table 2). With this quantity of parameters to manage, it is essential to use ‘Shared Parameters’ to add consistency and to think carefully about the naming and categorising of the parameters. The naming is important as the parameters will be sorted in alphabetical order, so to make things easy to find, the best method is to start the name with all the same identification word e.g. terrace, seat, barrier, etc, followed by a differentiator to group interrelated parameters. The categorisation is equally important to also separate and group parameters within the project. The method used here is to place the parameters which are dormant/formula driven within a category lower down the alphabetical list to keep them out of the way and prevent unnecessary scrolling.

Table 2: Master C-Value Terrace Family Parameters

Parameter	Value	Formula
Text		
Stand Name (default)		=
Terrace Name (default)		=
Tier (default)		=
Materials and Finishes		
Armrest Material	Armrest Material	=
Barrier Material	<By Category>	=
Seat Material (default)	Seat Material	=
Terrace Material	<By Category>	=
Dimensions		
Barrier Height (default)	800.0	=
Barrier Offset Left (default)	0.0	=
Barrier Offset Right (default)	0.0	=
Barrier Return Length (default)	1000.0	=
Barrier Thickness (default)	100.0	=
C - C Value (default)	152.6	= D * ((Terrace Height + R) / (D + Terrace Depth)) - R
Capacity (default)	40.000000	= Terrace Length * No. Rows / Seat Width
D (default)	10100.0	= First Row Horizontal Offset from POF + ((No. Rows - 1) * Terrace Depth) - Eye Offset
Eye Height	1171.0	=
... Offset from Seat	300.0	=
... Offset from POF (default)	8000.0	=
...	1000.0	=
		...
		...errace Length / Seat Width
		... * No. Rows
		...
		...2) * Terrace Height) + Eye Height

4.1 Scheduling

Shared Parameters were the key to successful automated stadia scheduling as these allowed any parameter created during the development of the stadia families to be mapped to an ‘in-project’ schedule (see Table 3). The columns of data were automatically updated as the stadium was being designed, providing critical, up to date information as the design progressed. These parameters show only a fraction of the information which could be utilised if required. Each independent terrace family has an ‘Instance’ parameter for the ‘Stand Name’, ‘Terrace Name’ and ‘Tier’, that way each and every terrace element could easily be referenced and the schedule filtered depending on the designers’ requirements. In this case the schedule rows have been grouped based on ‘Stand Name’ and the ‘Itemise Every Instance’ turned off, just showing the total capacity per ‘Tier’ of each stand.

Table 3: Automated Zone 2 – Viewing Accommodation Schedule

Zone 2 - Viewing Accommodation											
Terrace	Tier	T - Terrace Depth	N - Terrace Height	Terrace Length	Terrace Thickness	Overall Terrace Depth	Overall Terrace Height	No. Rows	Seat Width	C - C Value	Capacity
Stand A											
A-1	Ground	800	500	30000	200	13600	8500	17	500	84	3,060
A-2	First	800	600	10000	200	8000	6000	10	500	82	1,400
											4,460
Stand B											
B-1	Ground	800	400	20000	200	12800	6400	16	500	81	6,400
B-2	First	800	600	15000	200	9600	7200	12	500	78	2,520
											8,920
Stand C											
C-1	Ground	800	400	10500	200	8800	4400	11	500	149	1,848
C-2	First	800	600	20000	200	9600	7200	12	500	139	2,880
											4,728
Stand D											
D-1	Ground	800	500	10500	200	13600	8500	17	500	84	2,142
D-2	First	800	600	10000	200	9600	7200	12	500	78	1,680
											3,822
Grand total											21,930

5. Parametric Stadia Design

5.1 Parametric Design Framework

The overall parametric design framework adopted during this research is highlighted in Figure **5**. This demonstrates the four layered nesting system and link with the project environment. There are several design areas which needed to be addressed so it was important to separate these into sections, then the sections placed within zones. The complexity of the nesting system is clearly evident, even though this research is confined to just the activity area and viewing accommodation. There are lots more areas and zones which could be incorporated into the framework moving forward so it’s essential to have a structured system to creating content. This strategy prevents developers from getting caught up in the labyrinth of complications inherent with multi-layer nesting and provides the basis for a scalable and repeatable approach.

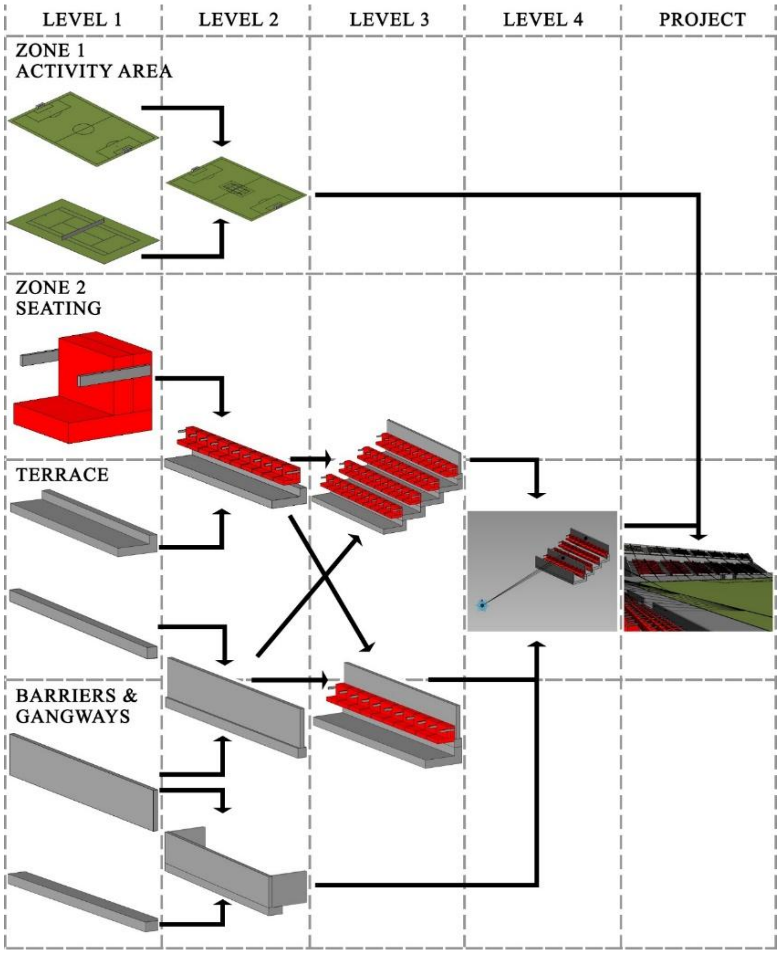

Figure 5: Overall Parametric Design Framework

6. Discussion

Autodesk Revit being the design software of choice has over 80 family categories which offers flexibility as they each have their own tools and functionality. However, this can also provoke problematic issue with template selection as this cannot be changed in most cases once design work commences. Only two family categories were used in the parametric development of the stadia model, 'Generic Model' and 'Generic Model Adaptive'. The 'Generic Model' family is great for constructing general objects such as the terrace, seats, gangways and barriers, but the complex c-value calculations could only be realised using the 'Generic Model Adaptive' family for its inherent adaptive tools.

Formulas are a fundamental aspect of parametric modelling, but a developer also needs to understand how formulas are used to drive 3D model parameters and associated data in order for it to function correctly. In many instances the development hit roadblocks which prevented progression via the use of standard parameters. Additional parameters were used as a workaround with attached formulas to bypass these roadblocks. It was also essential to create a 'Shared Parameter' file which is used consistently across all families to improve efficiency and enable the data to automatically populate the stadia schedule. 'Project Parameters' created during family development will not be mapped to the 'in project' stadia schedule.

As anticipated, the c-value calculations proved the most complex challenge due to the sightlines, variables and formulas involved. The c-value adapts dynamically to changes in both horizontal and vertical distance to the POF, terrace height and depth, and eye height and eye offset. The c-value is taken from the rear terrace row which has the worst sightlines which guarantees the minimum c-value per terrace. Ideally this can be taken further so that the end user can input a required c-value which then generates a unique terrace height for each row, forming a parabolic curve and consistent c-values throughout the terrace. It would also be advantageous for the data of each row to automatically populate the schedule. Another serious problem encountered was the inclusion of 3D seats to the terrace family. Whilst this rapidly speeds up the process through automation, it dramatically slowed design iterations with each change in parameter taking approximately 8 seconds to generate. This was mitigated by developing a duplicate terrace family without the seating to be used during design and swapped out for the terrace seating family once finalised. This methodology meant design changes are instant.

The benefits of the parametric model are already being realised with the 3D terrace design, including seating, of a 20,000 capacity stadium being achieved in under one hour. This also included a fully populated schedule of terrace related data. Once created it is a simple case of manually incorporating the concourse areas, stairs and roof structure based on the clients' requirements and site specific constraints to complete the design.

7. Future Research

This research merely scratches the surface of potential issues which could be tackled through parametric design. There are five key areas which would benefit this research and enhance the stadia design process through automation. These areas include:-

1. Automated C-Values Data Per Row – where the designer inputs the desired c-value and this figure is used to drive the terrace height of each row, forming the optimum spectator sightlines through a parabolic curve.
2. Stairs and Railings – derived and constrained by industry regulations and standards.
3. Roof Canopy – which to be used for quick iterations using parametric design options.
4. Structural Support– integrated into the parametric terrace family with parametric options for column and truss design.
5. Concourse Areas – which can be used to form internal and external concourse areas.

8. Conclusions

The primary objective of this research was to determine whether it is possible to develop a parametric stadia family, without the need for visual programming, which could be used by designers to increase efficiency and improve quality. Whilst the answer to the question is yes, the process is by no means straightforward. A high level understanding of complex formulas and parametric modelling techniques is essential to construct a robust functioning model. That being said, the process is more straightforward than a visual programming methodology as this would require an in depth understanding of parameters and formulas, but also nodal design.

Whilst the objective has been met in the broadest sense, the path to arrive there deviated slightly from the original plan. The key reason for this was that upon initial development it quickly became apparent that a single parametric family would severely limit the designers' flexibility due to substantial design variations. There are so many complex factors which needed to be considered such as the terrace, seating, barriers, gangway and activity area, which all have strict requirements and unique variables. Thus, it was essential to develop these key aspects as individual parametric families which can be used and function in unison. This method was found to be the most manageable from a development perspective, yet dynamic and user-friendly for the designer.

The shear amount of variables involved in stadia design presented endless complications. Limitations include the inability to automate data per terrace row and lack of integration of additional elements such as stairs and railings, roofs, structure, concourses, etc. The process to create a flexible model needed to be rethought over and over again, but the framework is now in place from which a robust parametric stadia model can be further refined. This framework and associated model provides an efficient system which can be used by sports and leisure designers to increase efficiency whilst improving quality.

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Approaches for Assessing BIM Adoption in Countries: a Comparative Study within Qatar

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Abstract

The adoption of Building Information Modelling (BIM) is now examined at different scales ranging from organisations, through supply chains, and across whole countries and markets. For the assessment of BIM adoption at country and market scale, two main approaches are being utilised. The first traditional approach utilises a survey of industry stakeholders operating within a defined market/country to assess BIM diffusion. The second emerging approach adopts specialised macro BIM adoption models and metrics. In this paper, we aim to apply and compare these two approaches for investigating BIM adoption within Qatar.

In the implementation of the survey approach, we selected key client, contractor and consultant organisations and conducted 28 face-to-face interviews in an attempt to overcome some of typical limitations that might occur in traditional survey-based approaches (e.g. unknown and biased population). The obtained results included: BIM is increasingly specified by clients on large construction projects; BIM experience has become part of the pre-qualification criteria; traditional Design Bid & Build (DBB) is the predominant procurement route with an increasing use of the Design & Build (DB); lack of national BIM standards or guidelines and adoption of a combination of UK and US standards. Although these results provide a general understanding of the BIM landscape in Qatar, they remain qualitative and not actionable for policy makers, e.g. for developing BIM adoption strategies. Then, we applied two specialised macro BIM adoption models – i.e. Diffusion Areas model and Macro-Maturity component model developed by Succar and Kassem (2015). This second approach was capable of providing a rating of the different areas of BIM diffusion and a holistic discovery assessment of the country BIM maturity. Using the same approach, the results from Qatar can be benchmarked against those of a target country and can be utilised to inform a Qatari-specific BIM adoption policy. Based on this result, the research concluded that new approaches such as the macro BIM maturity approaches should be increasingly encouraged and used to complement the traditional market BIM surveys.

Keywords: BIM, Diffusion Areas, Macro BIM adoption, Macro Maturity Components.

1. Introduction

Building Information Modelling is now widely acknowledged as a revolutionary change in the technologies, processes and policies underlying the Design, Construction and Operation (DCO) industry. BIM transformative impact on the DCO industry includes a technological and procedural shift (Succar, 2009; Eastman et al., 2011). It is also considered a disruptive impact forcing the industry to rethink deliverables, roles and relationships (Eastman et al., 2008; Smith and Tardiff, 2009).

Following years of escalating connotation and impact of BIM, industry associations, governmental bodies and academic communities across several countries are increasingly releasing a wide variety of Noteworthy BIM Publications (NBPs) (Kassem et al., 2015). One of the NBP types are the BIM surveys that aim to assess BIM diffusion – defined as the spread of innovation adoption within a given population (Rogers et al., 2005) – within a defined market for a single discipline or across all disciplines. For example, a nationwide survey of architects, engineers, contractors, owners, manufacturers and others (facility managers, software vendors, and project managers) has been conducted in Australia (BEIIC, 2010). Similarly in the UK, the National Building Specification (NBS) conducts annual surveys of Architecture, Engineering and Construction (AEC) professionals (NBS, 2015). In North America, a survey of 582 professional was performed by McGraw-Hill Construction (2012) to assess BIM diffusion rates. These surveys often lack the support of a theoretical framework and may involve an unknown population.

This paper aims to compare the findings from two approaches for assessing market-wide BIM adoption. The first approach is the traditional survey-based approach with enhancement – selection of a known and representative sample and inclusion of all BIM fields namely, process, policy, technology and people (Vukovic et al., 2015; Kassem et al., 2013).

The second approach involves the utilisation of emerging models for assessing macro BIM adoption within a defined market. In recent years, several countries have launched their BIM adoption strategies and national initiatives. Research has responded to this need by developing specialised models that can be used to assess the market wide BIM adoption. One of the earliest studies in this domain is the one proposed by Succar and Kassem (2015). This study has developed five macro BIM adoption models, namely, these are Model A: diffusion areas, Model B: macro-maturity components, Model C: macro-diffusion dynamics; Model D: policy actions, and Model

E: macro-diffusion responsibilities. This research will implement '*Model A: Diffusion Areas'* and '*Model B: macro-maturity components'* and their accompanying metrics to assess BIM adoption in Qatar.

The implementation and results from both approaches, i.e. (a) the survey-based approach and (b) the specialised models for macro BIM adoption, are respectively described in the subsequent two sections.

2. Market-wide BIM Adoption: Survey-based Approach

The interviewees included stakeholders from Client (N=9; 32%), Contractor (N=5; 18%) and Consultant (N=14; 50%) organizations working on several ongoing projects in Qatar. The interviews covered four domains of interest: Policy, People, Process and Technology (Grys and Westhorpe, 2011; Kassem et al., 2014), containing a total of 18 questions/discussion topics with 36 subtopics.

The policy section of the interviews investigated project delivery methods and types of contracts used in Qatar. The people section investigated professional BIM related roles and the challenges around the availability of BIM skills and knowledge and the corresponding learning and training opportunities within the Qatari construction industry. The process section aimed to analyse topics such as the BIM requirements, availability and use of BIM execution plans, standard project phases or plan of work, the adopted Levels of Detail (LoD), and the roles and responsibilities of different stakeholders towards such process related topics. Finally, the technology section aimed to survey the BIM tools used across the project lifecycle in Qatar. The following sections highlight the results in each of the four domains of interest.

2.1 Policy

The common two project delivery methods utilised in Qatar are Design and Build (68%)[1] and the Design-Bid-Build (75%). The predominantly used contract types are FIDIC (International Federation of Consulting Engineers) contracts (68%) and American Institute of Architects (AIA) contracts (18%). Other contracts included the New Engineering Contract (NEC) (4%), Public Works Authority contracts (7%) and professional service agreements with consultants.

BIM standards are required on the majority of projects (68%) and 75% of interviewees think that BIM should be enforced on projects. The BS 1192: 2007 is the most widely used standard on projects in Qatar (61%) followed by the PAS 1192-2: 2013 (39%). Other BIM related standards identified with a lower frequency include: AEC (UK) CAD standards (AEC, 2012), AIA Integrated project delivery BIM protocol exhibit (AIA, 2008), National BIM standard (NIBS, 2012), Singapore BIM guide (BCA, 2012), BIM project execution planning by Penn State University (PSU, 2010), and the Global Sustainability Assessment System (GORD, 2014). The

[1] Values in brackets refer to the percentage of respondents.

majority of respondents (89%) believed that the government should be developing the required BIM standards for the industry with the participation of educational institutions and private organisations.

2.2 People

The BIM related roles identified within the Qatar construction industry according to the interviewees are summarised in Figure 1. Under ‘other’, roles including BIM project managers and BIM interface managers were mentioned by 30% of respondents. As to the sourcing and skilling up of individuals playing these BIM roles, 75% mentioned in-house training complemented with the hiring of external BIM construction in 36% of cases. The majority of respondents (96%) complained about the lack of BIM skilled professionals in their supply chains and highlighted the need for training. At the same time, 46% of respondents reported challenges facing their organisations in the development of BIM professionals – i.e. difficulty in convincing people to enrol on training courses and the availability of appropriate BIM training and learning opportunities.

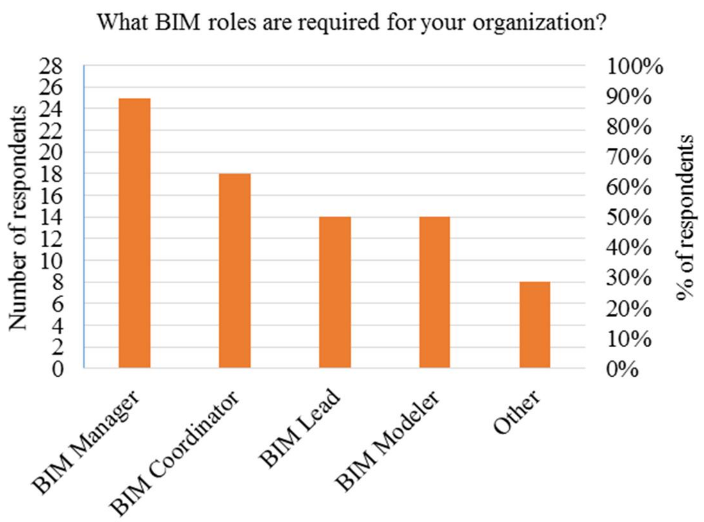

Figure 1: BIM-specific roles in Qatar

2.3 Process

There was a unanimous agreement among all interviewees (28) that BIM is used on projects in Qatar when it is required by clients and 70% of respondents highlighted the increasing inclusion of BIM related assessment in the tender prequalification and selection process. The prevalent use of BIM, according to 75% of respondents, is the federated BIM in common data environment. The most frequently required (indicated by 64% of respondents) Level of Development (LOD) is the LOD 300. Other LOD required are LOD 100 (7%), LOD200 (18%), LOD 400 (32%) and LOD 500 (11%).

Several types and labels for the BIM documents used on project to help manage the process were identified: BIM execution plan (68%), BIM implementation plan (46%), BIM strategy (39%), modelling guidelines (36%) and ‘other’ documents – i.e. BIM manual, owner’s guide and CAD manual - (7%). The responsibility for defining the LOD is attributed to the client (71%), the designer (29%) or the contractor (7%).

A wide variety of project stages or plan of works is adopted in Qatar including the RIBA Plan of Work (29%) and the AIA five phase of design (14%), the CIC Scope of Services and the PMI project management processes (7%). ‘Other’ plan of works such the BSRIA Design Framework for Building Services and client specific project phases was reported by 46% of respondents. As a consequence of these multiple project stages, interviewees reported issues such as the misinterpretation and the lack of adherence to project stages. They concurred about the need for developing standard project stages and BIM process maps for Qatar’s construction industry and the joint responsibilities of government bodies, educational institutions and the private sector in this task.

2.4 Technology

This part of the interview aimed to identify the technologies used across all phases of the project lifecycle in Qatar. A summary of the result is depicted in Figure 1. It is clear from Figure 1 that for each of the four project purposes, there is a technology that is predominantly used. This exercise was intended to inform the development of lifecycle BIM information flow which is one of the overarching goals of the funded research project. Hence, in addition to identifying the technologies used on projects, this interview part aimed to capture information about the used file exchange formats. Predominantly used exchange formats include: IFC (68%), 3D PDF (25%), COBie (21%), NWC/NWD (50%) and ‘other’ proprietary file formats (57%).

3. Market-wide BIM Adoption: Specialised Models

Six experts and practitioners operating in Qatar were invited to apply the two models (i.e. Model A and Model B). The experts were selected using the snowball sampling procedure. The snowball sampling procedure occurs when the researcher accesses participants through contact information that is provided by other participants (Noy, 2008). The initial subjects serve as ‘seeds’ through which wave 1 subjects are recruited; wave 1 subjects in turn recruit wave 2 subjects, etc. (Heckathorn, 2015). The snowball effect enabled the implementation of a non-probabilistic sampling approach. This enabled the research to start with an exploratory sample – not a representative one – that could lead to generalizable results through either (a) cumulative approach (further identification and participation of experts until data saturation, convergence or statistical validity is achieved) or (b) Delphi technique to achieve consensus about the results. In this case, the generalisation was achieved using a mini Delphi approach (a single round) where the mean, excluding the most deviating ratings from it, was circulated to all experts to achieve consensus about the measurement. The two models and the results from their applications within Qatar are described and analysed in the subsequent two sections.

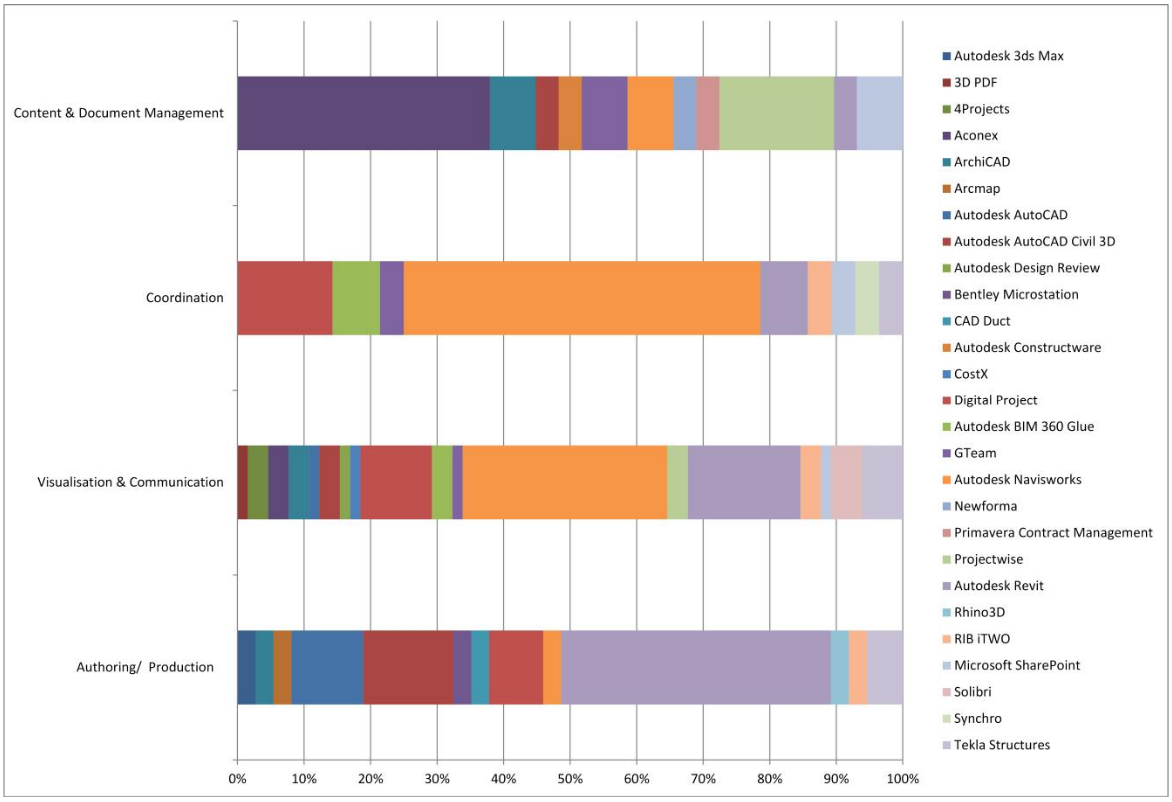

Figure 2: Technologies used on construction projects in Qatar

3.1 Assessing the Areas of Diffusion in Qatar

The Diffusion Areas model establishes nine areas for targeted BIM diffusion analysis and planning which can be assessed independently or collectively. These nine areas of diffusion are the result of overlaying the three BIM field types (technology, process and policy) and three BIM capability stages (modelling, collaboration and integration). This model can be used to assess the extent of BIM diffusion within organisations and across markets. The six experts were asked to rate the level of each BIM diffusion area according to a five-level scale: [0] low; [1] medium-low; [2] medium; [3] medium–high; and [4] high.

Figure 3 (upper part) displays the mean for the levels of diffusion of the nine areas. The results show that all areas of diffusions, with the exception of modelling technologies, are rated below medium. This is a reasonable outcome as modelling technologies are considered one of the capability sets (software step) required to move into the first BIM capability stage – i.e. modelling stage (Succar, 2009). This result is complemented with the results obtained from the survey-based approach (Figure 2) where the spread of modelling technologies was found to be prevalent in Qatar's construction industry. This result can be better understood in the lower part of Figure 4, which aggregates the score of the three fields (i.e. policy, process, technology) for each capability stage. It shows that the highest concentration of BIM diffusion rates is in low-level modelling capabilities followed respectively by lower mid-level collaboration capabilities and high-level integration capabilities.

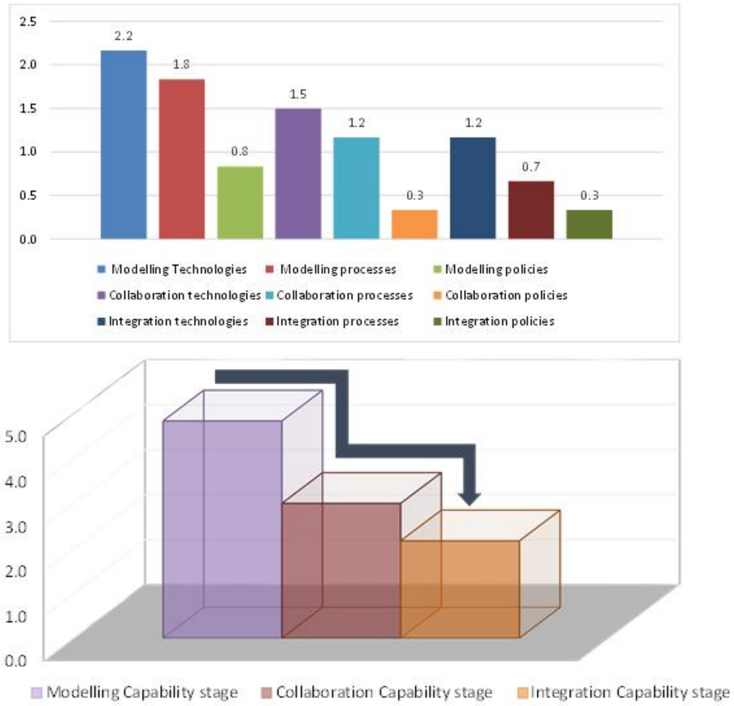

Figure 3: Assessment of BIM Diffusion Areas in Qatar

The levels of diffusion of three areas of policy (i.e. modelling policies, collaboration policies, and integration policies) are all rated below medium-low. The integration policy area has the lowest diffusion. This area refers to e.g. the rate of adoption of integrated supply-chain standards, protocols and contractual agreements; rate of proliferation of interdisciplinary educational programmes. Analysing the level of diffusion obtained for this area in conjunction with the survey results for the policy domain (Section 2.1), the result can be considered reasonable and complementary. Indeed, the survey showed the lack of Qatari specific collaboration protocols and the simultaneous coexistence of several standards and protocols within Qatar leading to misapprehension among organisations of the supply chain. Similarly, the results for the three process related areas of diffusions (i.e. modelling processes, collaboration processes and integration processes) are complementary and congruent between the survey and the Diffusion Area model.

There are key differences between the two approaches. Despite the adequate design and structuring of the survey into topics (i.e. people, process, policy and technology), the survey results can be used only for a general understanding or a situational analysis of a market. Indeed, they do not differentiate or recognise the different BIM capabilities that coexist within a market as demonstrated by the Diffusion Areas model and consequently, they are unable to provide a corresponding assessment of such areas. Moreover, the results from the survey are not actionable by policy makers interested in targeting a specific BIM diffusion area (e.g. achieve a high diffusion level in collaborative technologies). The Diffusion Areas model provides such capabilities through the generation of targeted ratings for comparative market analysis.

3.2 Assessing the Macro-BIM Maturity of Qatar

The second model (Model B: Macro-maturity components) identifies eight components that must be measured and compared in order to establish the BIM maturity of a market (Figure 4). These eight components are: 1. Objectives, stages and milestones, 2. Champions and drivers, 3. Regulatory framework, 4. Noteworthy publications, 5. Learning and education, 6. Measurements and benchmarks, 7. Standardised parts and deliverables, and 8. Technology infrastructure. These components are assessed using the BIM Maturity Index (BIMMI) which includes five maturity levels: [a] Ad-hoc or low maturity (0); [b] Defined or medium–low maturity (1); [c] Managed or medium maturity (2); [d] Integrated or medium–high maturity (3); and [e] Optimised or high maturity (5) (Succar, 2010). The assessment can be made holistically (low detail discovery assessment) or granularly (higher detail evaluation assessment). The discovery assessment is beneficial for comparing the relative maturity for each macro-component against the other seven components; while ‘evaluation’ assessment enable the detailed analysis of each component using specialised metrics applicable to that component only (Succar and Kassem, 2015).

Figure 6 reports the assessment result for the eight components. The maturity of all macro components in Qatar, with the exception of the ‘technology infrastructure’, falls within the interval ‘low’ and ‘medium-low’. ‘Learning and Education’ and ‘Measurements and Benchmarks’ have the lowest maturity rating. While the survey did not provide distinct components and metrics for their assessment, some of its qualitative results (e.g. limited training and learning opportunities, lack of country specific standards and protocols) support the assessment conducted using the macro maturity component. From the comparison of the application and results from both approaches (i.e. survey based and Macro-Maturity Components model), key advantages that can be attributed to the macro maturity model are: (a) it identifies and measures eight distinct but complementary components underpinning the BIM maturity of a market; (b) Improvement targets, in terms of maturity level, can be set for each of the eight components, and (c) Can promote learning in policy development and implementation for each of the eight components. For example, targets can be established against the other markets when new markets are added to the assessment and benchmark (e.g. benchmark countries 1 and 2 in Figure 5). Countries 1 and 2 in Figure 6 are two hypothetical markets that are used as a benchmark for Qatar. Using this outcome, Qatar can set performance targets across the eight components and learn from countries that achieved relatively high maturities in such components compared to the others (e.g. noteworthy Publications form Country 2, Regulatory Framework from Country 1).

4. Conclusions

This research aimed to apply and compare two approaches for the analysis of market-wide BIM adoption: (a) the traditional survey based approach, and (b) specialised macro BIM adoption models. Both approaches were successfully implemented but the obtained results enable different understanding of market wide BIM adoption and have different practical implications.

Figure 4: Macro-Maturity Components model (Succar and Kassem, 2015)

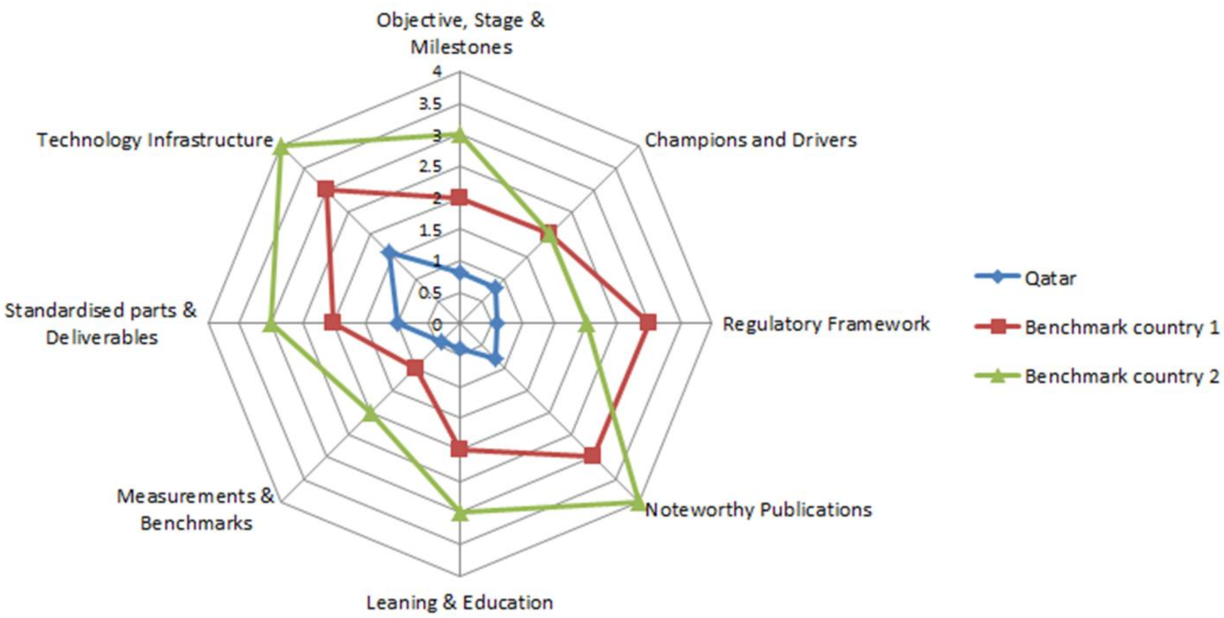

Figure 5: Rating of the eight maturity components in Qatar

The results from the survey/interview enabled an adequate general understanding of BIM adoption in Qatar. However, despite the improved structure (subdivision into topics: Technology, People, Process and Policy) and sampling methods (use of known sample of experts from key organisations operating in Qatar) of the survey/interview, the results remained descriptive and qualitative. For example, the results identified: the different BIM technologies used in Qatar; the key issues in policy domain such as the lack of country-specific standards and protocols; the limited BIM learning and training opportunities within Qatar, among others.

The application of two macro BIM adoption models – i.e. Diffusion Areas model and Macro-Maturity component model – both enabled a more informative assessment of BIM adoption in Qatar and provided results that could inform policy actions. This is the result of using specialised models, each with a specific purpose – one model to assess diffusion areas and another model to assess the macro-maturity components – and corresponding metrics. Using these models, the macro BIM adoption can be benchmarked between two or more markets. One market can set specific improvement targets corresponding to the high performance achieved within another market, hence, promoting the learning process in BIM policy development across markets.

Finally, the two approaches can be considered complementary. The results from the traditional BIM survey-based approach can be used to explain or justify the rating obtained from specialised macro BIM adoption models.

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Future of the multidimensional digital built environment

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Abstract

The stakeholders of a built environment can attain several benefits by digitalizing the existing built environment. To highlight these benefits, this article presents a prototype of a digitalized built environment using 3D Internet technologies. To utilize existing data reserves and various measuring techniques, models of different levels of detail and accuracy must be combined, including existing location-based data, geographic information, building models, regional information, and infrastructure models. This raises a number of questions concerning novel types of GIS data, data integration and big data, interfaces, and availability and ownership of data. These questions bind the topic to the development of 3D Internet technologies. Finally, a smart city application architecture is proposed to enable the application development and increase the transferability of presented solutions.

Keywords: City model, digitalization, built environment, smart city, 3D map

1. Introduction

By using digital multidimensional models, many design and engineering tasks can thereby be performed in the digital domain. Three-dimensional (3D) models can be applied for various simulations and analyses. The underlying potential of this has led to the development of a megatrend within engineering. The built environment is likewise increasingly digitalized, both on the level of individual buildings and entire urban environments. Several drivers for digitalization in urban environments currently exist; simulations of different scenarios are required for increasing resilience. The limited existing resources for these call for new, more efficient ways of working. Finally, the smart city paradigm, with the emergence of 3D/4D city models is promoting digitalization (Hyyppä et al., 2014a, Hyyppä et al., 2014b).

Inside the building, the digitalization offers considerable benefits, such as improved quality assurance of construction, and utilization of integrated sensors to produce smart buildings (Firner et al., 2011). As the digital city models start to include more detailed models of buildings which include the exteriors, infrastructure, and surroundings, the realms of building and city modeling eventually intersect. Indeed, the first pilots are already being conducted where city models are updated to include the BIM models of buildings.

For larger urban areas, the digitalization of existing built environments is facilitated by 3D measurement techniques that make it possible to measure outdoor and indoor locations efficiently. For instance, depth cameras can be applied for indoor measurements (Du et al., 2011). Emerging measuring methods, such as laser scanning mounted on a person (Kukko et al., 2012) or unmanned aerial vehicle (UAV) (Lin et al., 2012), produce comprehensive 3D data sets from both the indoor and outdoor environments. In addition, the amount of data available from the environment is increasing due to the open data movement (Virtanen et al., 2015a). A third data flow is volunteered geo-information, enabled by mobile devices equipped with camera, GPS and Internet connection (Goodchild, 2007). For structures designed with building information modeling (BIM), the existing 3D models can be applied (Lang & Sittler, 2013).

As the data acquisition methods have developed, more emphasis is being put on automated processing of large data sets. Several algorithms have been developed for object detection from point clouds (e.g. Lehtomäki et al., 2010; Pu et al., 2011), classification (e.g. Antonarakis et al., 2008), and finally, automated modelling of the environment (Zhu et al., 2015). It is also possible to develop hybrid methods, which utilize both measurement data and existing data (Zhu et al., 2015). In addition, data from other sources can be combined to the city model to allow additional analyses (Hamilton et al., 2005).

To create a 3D model one can choose from multiple approaches and platforms, depending on one's needs and availability of data. There are nearly hundred different 3D modelling software to choose (some commercial ones like Esri's CityEngine, or Autodesk Revit but also freeware like Blender or freemium options like SketchUp).

After being created, the 3D models of the built environment can be applied to urban planning, architecture, and decision making in the urban environment (Döllner et al., 2006, Virtanen et al., 2015b). 3D city models can become a portal used to access urban information, the user interface to the digital city (Prandi et al., 2014). One of the applications for accurate 3D models of urban environments is the 3D cadastre (Rahman et al., 2011). The development of applications that utilize detailed models of the environment is stimulated by several technologies. Mobile devices have turned city models into a navigation tool and information portal (Burigat & Chittaro, 2005; Nurminen, 2006). Virtual reality technology is increasingly used for immersive applications (Beimler et al., 2013; Woodward & Sukittanon, 2015), also with city models (Engel et al., 2012). Virtual worlds and game engines are being used in development of various applications, including education (Potkonjak et al., 2016) and planning (Bishop & Stock, 2010).

When combined, the digitalization of the built environment creates a significant application potential, operating as a platform for new business models and value chains (e.g. Suwal et al., 2013, Underwood et al., 2010). The term "regional information modeling" can be used to describe this combination of expansive area models, accurate building models, and other data. The first phase in regional information modeling is the integration of existing location-based data, geographic information, building models, regional information, and infrastructure models with modern measuring technology and virtual elements (Hyyppä et al., 2015). Figure 1 summarizes the aspects of future digital built environment; measurement techniques and data sources, processing methods, platforms and applications.

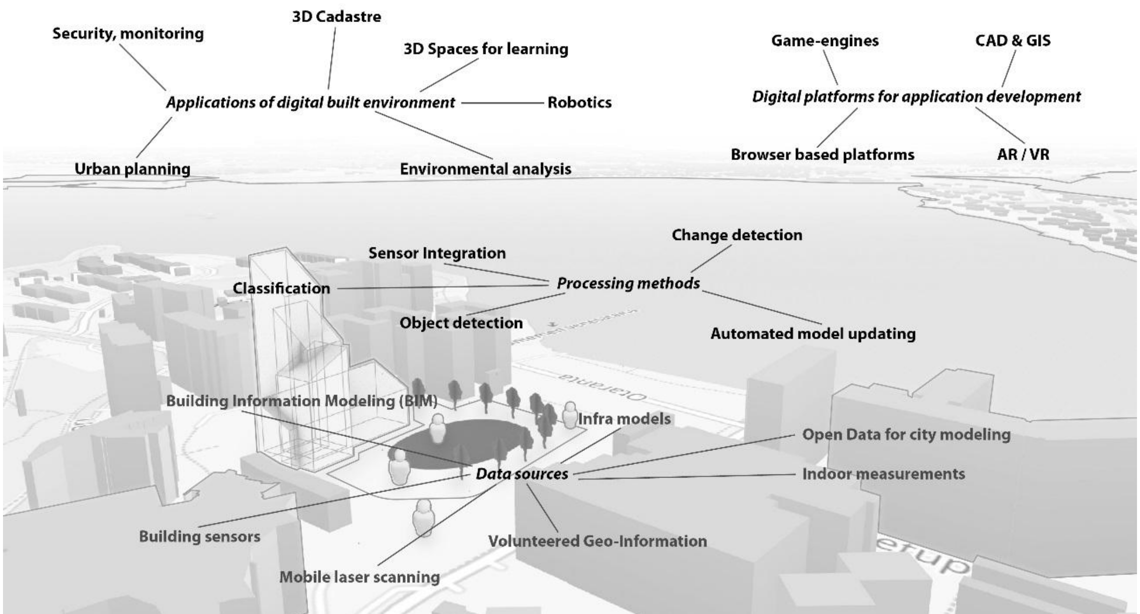

Figure 1: Aspects of the future digital built environment

Applications are a central component in value creation of digital models. In the context of digital built environment, platforms are required that support large city models and detailed building models while simultaneously allowing for application development. 3D application development platforms provide a beneficial starting point for this.

Our aim is to explore the concept of future digital built environment, by developing a prototype that combines the use of several different data sets on a 3D application development platform. There are several 3D modelling platforms and approaches, as mentioned earlier in the Introduction. For the purpose of this exploratory prototype we have chosen some typical set of data, including statistical data of a city and different types of building models, and a platform allowing the development of browser based 3D map applications. This article presents the results achieved.

2. Materials and methods

2.1 3D Internet application development platform

Meshmoon, a commercial development platform for virtual world applications, is based on open-source realXtend technology. The realXtend architecture is presented in earlier research by Alatalo (2011). Meshmoon and realXtend technology have been utilized to develop educational applications (Mattila et al., 2012), 3D cartographic applications (Virtanen et al., 2015a), and virtual city applications (Hyyppä et al., 2014b). To access Meshmoon scenes, it is possible to employ either a standalone or browser-based client.

The background maps and simple building models were obtained by using the Meshmoon Geo plugin (later commercialized as MapGets). The plugin obtains a simple terrain model with a set of alternative textures (eg. aerial image, properties map, and background map) and Level of Detail 1 (LOD1) building models over the WFS interface from the city data sources.

2.2 Espoo regional planning data

A set of regional planning data from the City of Espoo was converted to 3D and uploaded to the platform. The original data was in the Map Info format. For point data, columns were created to visualize the table values. For polygons, corresponding mesh models were built in the Rhinoceros 3D modeling suite (Figure 2). Thereafter, a small application was written for the Meshmoon platform to change the heights of the mesh models to visualize statistical data related to regions.

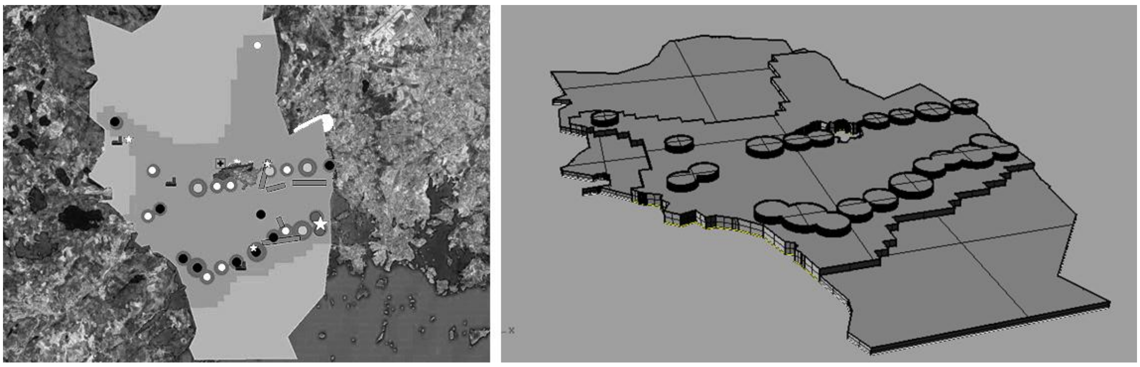

Figure 2: Original data and the resulting 3D equivalent

2.3 Keilaniemi area models

Two area models depicting the Keilaniemi area in Espoo were used in the experiment. ALS data from the Keilaniemi region was applied to produce a LOD 2 model of the area (Figure 3). A digital terrain model (DTM) of the area was textured with aerial images. In addition, building models were produced by automatic building vectorization. Tree parameters for the area were extracted from ALS data, and utilized to produce a visualization of the trees in the area by duplicating the same simplified tree model.

To produce a more detailed model from a part of the Keilaniemi shore, a set of commercial high-rise buildings was modeled using both aerial and mobile laser scanning data sets as a reference. The goal of this was to produce a near-photorealistic representation of the area. The results of the automated building vectorization were employed as the starting point for more detailed modeling. Typical methods from the computer gaming industry were utilized to create content. For example, materials included in the models use tileable bitmaps, and material properties have been added to surface through other bitmaps, such as specularity, surface normals, and reflectance. The subsequent measurements performed with MLS were completed in only a few hours, after which some additional time was required for processing the data. However, the modeling work required several weeks of working time from an experienced modeler. Originally, the scene was built using the Unity game engine, and the models were crafted in 3ds Max. The completed model was then transferred to the Meshmoon environment (Figure 3).

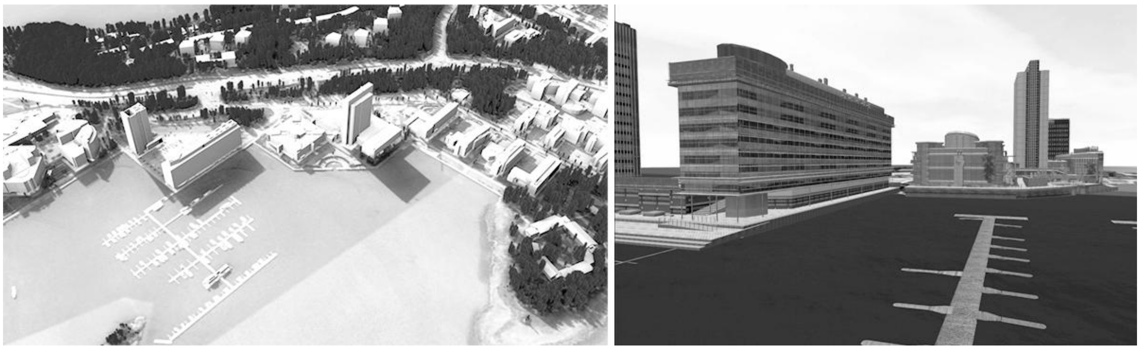

Figure 3: Virtual Keilaniemi shore, showing the LOD 2 model (left) and the near-photorealistic model (right)

2.4 Building models

A model of the Keilaniemi Towers project was used as an example of a 3D CAD model. The model was converted from its original SketchUp format and uploaded to the platform. The position of the model was solved from the regional plan provided with the model. The model contained the simplified exterior of the proposed project, as it was envisioned in the early planning phase of the area (Figure 3).

In addition, a depth camera-based indoor measuring device, Matterport (2015), was utilized to produce a detailed and textured 3D model of a small office space in Espoo, Finland. To achieve this, several camera positions were employed to measure the space; the resulting measurements were performed in less than an hour. The time required for the automated modeling was not recorded; however, the model was available on the day following the measurement. The automatically produced mesh model was transferred to Meshmoon via the Unity platform (Figure 4).

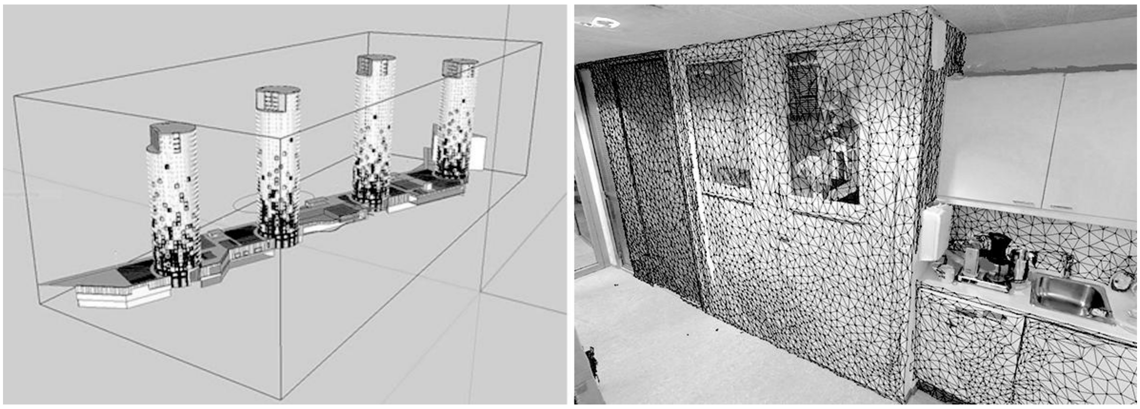

Figure 4: The building model of Keilaniemi Towers (left) and a detailed model of an office environment (right)

3. Results

By using the developed processing methods, it is possible to visualize all of the previously described data sets on the same virtual 3D map. The models have been divided into components that can be separately toggled on or off. For example, the vectorized building models from the ALS data set can be used with or without the textured terrain model. The building model from the Keilaniemi Towers project can be studied either on a properties map, typical background map, or a DTM textured with aerial images (Figure 5). The regional planning data from the city can then be visualized on top of these models.

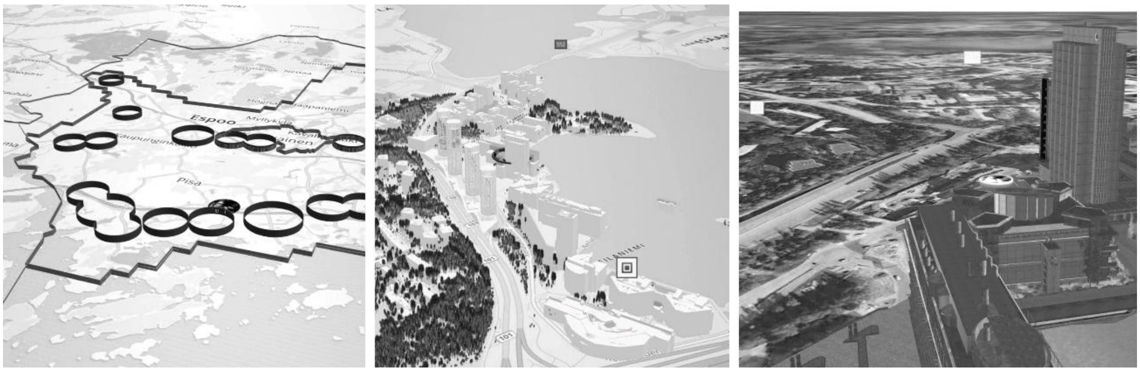

Figure 5: Regional data (left), LOD 2 model (middle) and fotorealistic model (right) rendered in Meshmoon on top of the 3D map

3.1 Future smart city architecture

Figure 1 presents a set of aspects of the future digital built environment, including the measuring methods utilized to obtain the data, models produced, and finally applications of these models. As stated in the introduction, the emerging measurement methods, such as mobile laser scanning and UAV-based laser scanning, are able to produce comprehensive data sets from the existing built environment. For efficient utilization of these techniques, it is necessary to implement automated modeling workflows. By combining efficient measurements with automated modeling, the detailed 3D city model can be produced to operate as the starting point for smart city applications. After this, other data sources must be integrated into the model. This includes data from various sensors and other city data systems. Finally, the model can be transferred to an application development platform for use in applications. However, if the measuring and modeling pipeline is repeated for each application, the amount of redundant work becomes too high. To increase the cost effectiveness of applications operating in the digital built environment, an architecture is required that allows for the transfer of applications from one area to another. Additionally, to detach specific applications from the data sources, homogenous models have to be produced from varying sets of starting data.

To overcome these challenges, this article proposes an architecture for application development in the future digital built environment. In this, an intermediate smart city platform layer is added between the data sources and 3D application authoring platform (Figure 6). The proposed smart city application layer consists of the following components: an automated modeling pipeline, data integration, and model authoring. In the automated modeling pipeline, 3D models of the environment are created from the source data. Data from other systems, such as city GIS, is combined with these 3D models in the data integration stage. Finally, a model compatible with 3D application development platforms is exported in the model authoring step. Following this architecture, the existing 3D application development platforms can be employed to produce the specific smart city applications. This serves two purposes: firstly, it enables the use of generic 3D platforms (e.g. Unity) for creating and publishing smart city applications and secondly, it creates distinct boundaries between the source data, model, and application. This increases the transferability of produced solutions to all regions from which suitable source data is available. This permits an easier transfer of solutions, and lowers the threshold for wider adoption of solutions piloted in test regions, thus supporting pioneering activities (Markkula & Kune, 2015, Virtanen et al., 2014).

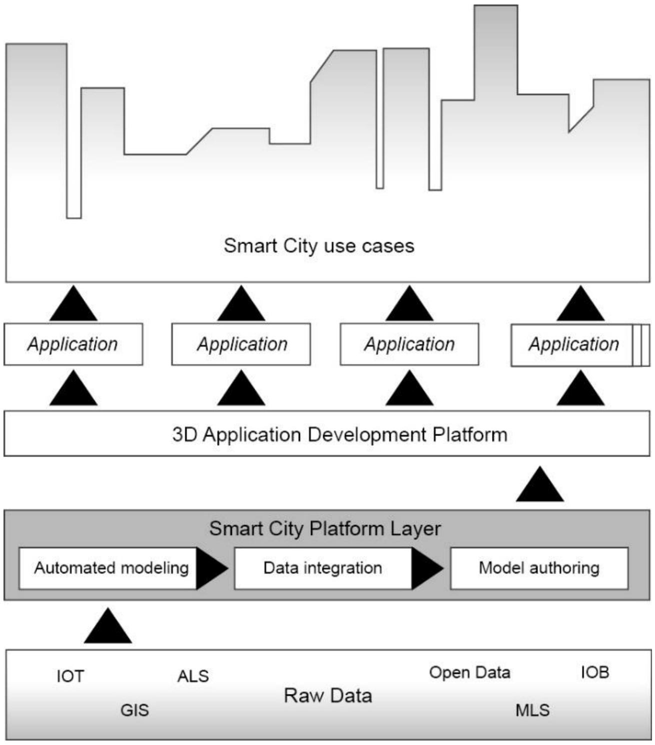

Figure 6: The future smart city architecture

4. Discussion

With current technologies, it is possible to create digital equivalents of built environments that can be applied to a variety of tasks, such as urban planning. To reach the benefits described in the introduction, the digitalization of the built environment must be carried out with a wider scope. 3D digital models can be produced by measuring the existing physical environment, for example with aerial laser scanning (ALS). Moreover, the development of automation in 3D modeling is accelerating digitalization and reducing costs. For the new urban areas under development, this 3D data is readily available as a result of BIM. Furthermore, 3D GIS are needed for analysis of energy consumption, solar energy potential, accessibility, visibility and 3D position of apartments in high rise construction, for example.

With the currently available tools, generating a simple 3D map can be largely automated, if suitable data sources are available. In the Finnish context, the open data repositories enable the generation of DTM from open ALS data. However, the degree of automation decreases when the data types start to vary from cartographic entities (such as building footprints and road contours) to statistical data, which may or may not contain physical areas defined as polygons. In this case, the workflows must be adapted to each data set. Nevertheless, as long as the statistical data is bound to a known coordinate system, the processes can in theory be automated. For models that do not contain information of their location and orientation in a known coordinate system, the only remaining alternative is to perform an interactive orientation. This concerns both building models that are in an unknown local coordinate system, and indoor models that cannot be easily georeferenced with GPS for example.

The computational requirements of the system increase with the amount of data. With the described models, the visualization system remained operational in a web browser (Google Chrome) with a high performance laptop (Intel Core i7, 2.7 GHz, 16 GB ram). Thus, optimization methods must be applied to enable improvements to the detail level of the models or the modeling of larger areas.

In the presented demonstration, all the data was uploaded to the server by a single user. In this research project, the ownership and publicity of the data sets did not cause any conflicts. However, if the presented system is to be used by more stakeholders, there is a need to address these potential ownership issues. In addition, if the data originates from several providers, some quality assurance methods have to be applied. Another issue encountered in the presented demo is the merging of several overlapping data sets of different detail levels and accuracies. Therefore, methods should be applied that allow for the intelligent integration of these data sets. These issues become most pronounced when an individual building is represented in several data sources. In such cases, it would be beneficial to identify the building from all data sets and define several LODs for its model.

It should be noted that there are alternatives to the utilization of 3D models in an urban context. Firstly, linked and georeferenced panoramic images have been used in previous research (Nebiker et al., 2010). A well-known commercial example of this type of "modeling" is Google Street View. A second possibility is the utilization of dense, colored point clouds. This can be considered to be an alternative paradigm to modeling: instead of building models based on points, edges, and surfaces, the system focuses on segmenting the point clouds and combining the semantic information directly to them. The notion of building virtual environments from point clouds has been previously presented by Nebiker et al. (2010). However, breaking away from the paradigm of modeling would be a significant change of direction in the city model discussion and would make existing modeling workflows and model formats obsolete.

5. Conclusions

By adopting an existing application development platform, it is thereby possible to merge different models and study their subsequent combinations. For example, a 3D map of the area with buildings of an ALS or MLS-based model can be combined with a CAD model of a building being planned. These combined models can thus already be applied to decision making and visualization.

By using 3D application development platforms, multi-user visualizations that operate in a web browser can be built from these diverse data sets. Commercial platforms (MapGets) have already been released that can automatically produce a background map for such applications. By applying these, such visualizations can be achieved more efficiently than by just applying them with a game engine. These technologies are the key to a wide area of potential applications that can be developed in the future.

The development and prototyping of digital 3D platforms that simultaneously support large area models and detailed building models pave the way for the future merger of 3D Internet technologies, BIM, civil engineering, urban planning, and volunteered location-based information.

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Innovative Industrialised Buildings: Performance, Perceptions, and Barriers to Financing associated with Building Manufacturing

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Abstract

Most buildings are still constructed one brick or timber at a time, over lengthy periods on-site, much like ancient civilisations. This paper poses the question of whether the manufacture of buildings using digital and production line techniques from advanced manufacture can transform building to be less wasteful, quicker, more affordable, and more sustainable. This is an important question as the innovative industrialisation of buildings presents a significant opportunity for the building and construction sectors worldwide. Findings suggest that between 2011 and 2012 the economic output from the industrialised manufacture of buildings globally increased by a staggering 50% to just over US$90 billion, with nearly half of this manufactured in the Asia-Pacific region. The paper points out that there is great potential for the manufacture of buildings to be harnessed to significantly strengthen both the building and manufacturing sectors. The research suggests that domestic building industries around the world will face strong international competition in the near future, especially as the quality of imported prefabricated and manufactured building offerings is increasing and the price is decreasing. However the transition to manufactured buildings must be undertaken in such a way as to harness a nations existing pool of skills and trades so as to allow workforce transitioning in a manner that strengthens industry. The paper highlights a number of challenges to upscaling building manufacture related to finance, insurance, and warranty structures, and presents potential options for overcoming such barriers. This paper presents findings of research undertaken as part of a Sustainable Built Environment National Research Centre (SBEnrc) in Australia in collaboration with the Cooperative Research Centre (CRC) for Low Carbon Living

Keywords: Manufactured Buildings, Innovation,

1. Introduction

There are numerous economic, social, and environmental benefits associated with building manufacture or offsite construction. This presents a lucrative opportunity for the construction and advanced manufacturing industries. According to research by the Australian Sustainable Built Environment National Research Centre (SBEnrc, 2014), new approaches to design, materials, and expanding the use of modular techniques can take advantage of faster fabrication times, lower costs, less waste, high quality standards, and shorter onsite construction periods. According to the research benefits of shifting to an offsite construction and fabrication model include:

- *Reduced Costs*: Faster construction times together with reduced delays from delivery, coordination, and inclement weather lead to reductions in project cost, including: cost of finance, insurances, hire equipment, plant and equipment fuel, and staffing costs, also reducing homebuyers need to pay rent.

- *Increased Safety*: Significantly improved workplace occupational health and safety by bringing the majority of building construction indoors and providing 24 hour lighting and climate control. Easy use of platforms, mini-cranes, wheeled scaffolds, and harnesses.

- *Materials Benefits*: A central facility allows for 24 hour receipt of bulk orders with secure storage which will reduce costs and delays. Materials can easily be reused which can reduce waste by 30-40%, reducing wasted materials and dumping costs - some 40% of landfill in Australia is derived from construction waste.

- *Access to Services*: A central facility allows for line-side services such as scaffolding hire, materials stores, tool shops, building component manufacture (such as window frames), and access to fixed cutting and fabricating equipment (rather than on-site handheld equipment).

In Australia, the construction of buildings offsite for onsite assembly dates back to the first set of portable iron clad homes constructed in the UK and shipped to Melbourne in the 1850's. Decades later the aftermath of World War II created conditions of abundant building materials and an urgent need for rapid rebuilding, leading a number of countries to turn to prefabrication of buildings. The first housing manufacturing plant was created in the United States in 1926, followed by the UK, and Japan in 1955.

However despite such benefits and the early uptake of building manufacturing processes the current level of offsite construction and prefabrication of buildings in Australia is low, representing some 3 percent of the value created by the Australian construction industry. This low level of uptake not only forgoes associated benefits but also opens up business to the threat of imports from the region, with Australian imports of buildings anticipated to reach a value of $30 billion by 2025, displacing around 75,000 jobs nationally. In 2012 the economic output from the manufacture of buildings globally was estimated at just over US$90 billion, up from $60 billion in 2011. In 2014 the largest regional market was Asia-Pacific valued at US$44.4 billion, followed by Europe at US$31.5 billion, and North America at US$10.2 billion (Research and Markets, 2014). The growing number of case studies and examples of manufacturing buildings provides quantifiable data that can inform efforts to capture the opportunities by providing strong evidence to developers, investors, and homebuyers.

However the transition to manufactured buildings must be undertaken in such a way as to harness the existing pool of skills and trades so as to allow workforce transitioning in a manner that strengthens industry. Further a number of challenges will need to be faced such as issues related to finance, insurance, and warranty structures. For instance, until recently the Queensland Home Warranty Scheme that protects consumers and builders excluded '*offsite prefabrication in a factory of the whole of a building*' (BSA, 2011). There are a number of barriers to finance that need to be overcome, namely:

- *Progress Payments:* In order to provide the access to capital needed to significantly upscale building manufacture, and capture the associated benefits, long standing financing structures need to be rearranged in the building sector that are on progress payments at different stages of onsite construction rather than being able to support factory style construction prior to transportation to site of completed product for erection. Issues related to the lack of a standardised quality assessment process for offsite construction along with gaps in current building standards and codes complicate matters.

- *Completion Risk:* There is also uncertainty around managing completion risk, such that the building is in the possession of the manufacturer up until delivery and may not be able to be easily completed should the manufacture halt operations (this may be affected by issues related to intellectual property of manufacturing methods hindering a shift in manufacturer if required). This also presents a risk to the builder or manufacturer as clients many not provide purchase confirmation until the building is delivered and able to be used for collateral for loans, leaving open the potential to withdraw part-way through the offsite construction or not being able to secure a loan at time of delivery.

- *Warrantees and Defect Rectification*: There is a need for a clear and accountable process for the rectification of defects, especially when sourcing building modules from overseas, along with insurance and warrantee structures that support offsite construction and onsite erection. The allocation of responsibility for defects is complicated by the nature of the offsite delivery model in that it can require multiple contractors to undertake offsite construction, module transportation, and onsite preparation and assembly, with each stage able to identify defects and warranty issues.

This paper investigates if the performance of manufactured buildings is superior to onsite construction methods, and considers ways to overcome barriers to financing in an Australian context.

2. Why does building manufacture present an opportunity?

2.1 Benefits of offsite construction

The shift to the manufacture of buildings stands to reduce a number of impacts including economic (reducing the time homebuyers rent while their home is constructed), social (significantly improving workplace occupational health and safety by bringing the majority of building construction indoors), and environmentally (through reduced materials wastage, reduced materials transportation, greater inclusion of energy and water efficient elements, and the potential for greater use of recycled materials). Research by the Australian Sustainable Built Environment National Research Centre (SBEnrc, 2014) has shown that building manufacture allows for cost savings, faster delivery times, and the reduction of a number of impacts associated with on-site building construction methods, such as:

1. *Cost Savings*: The shift to prefabrication of buildings stands to deliver a range of cost savings to developers, builders, and owners. The greatest cost benefits are achievable in projects where replicable structures are used, such as apartments, housing developments, hotels, student accommodation, classrooms, prisons, and mining accommodations. Direct costs savings are achieved from the faster delivery of buildings using prefabrication methods, along with reductions in construction waste both from design and higher reuse of materials, weather damage of materials, damage caused from onsite handling in often restricted sites with multiple trades, and the elimination of vandalism and site theft during construction. The potential for such savings opens up the opportunity for the greater provision of affordable and social housing along with the provision of a higher level of quality and non-standard inclusions in residential and commercial buildings. In particular it would make 'sustainability' related inclusions that can deliver lower operating costs to occupants and owners more economically feasible at the construction stage (especially energy related inclusions). Not only is there significant potential for cost savings it is likely that due to a manufacturing approach being taken that rewards reducing variations that the initial price of the building is close to the final price, whereas onsite construction enjoys the ability to incur variations that add to the cost of the project.
2. *Faster Delivery*: The shift to the manufacture of buildings stands to significantly reduce construction times, along with reducing onsite delays often caused by waiting for materials delivery, coordinating service providers and subcontractors, and from inclement weather. Reducing construction times can lead to a range of benefits such as reducing the cost of fees on land taxes, equipment hire, fuel bills, and staff on-costs. The shift will also allow a greater volume of buildings to be delivered as not only is the construction time shorter it can be carried out at the same time as site preparation (i.e. footings, retaining walls, and landscaping). This is important as the shift is likely to reduce the labour requirement of individual buildings so it will be important to compensate with a growth in building output.
3. *Improved Work Place Conditions*: The shift to the manufacture of buildings in dedicated facilities will provide a number of improvements to workplace conditions, including:
   - Protection from weather and other hazards for both workers and materials, along with the provision of appropriate lighting levels 24 hours a day,

- Provision for use of central power tool facilities rather than the reliance on hand tools or portable power tools onsite, and
- Greater ability to provide elevated platforms, mini cranes, roped harnesses, and other safety equipment due to construction undertaken in a fixed facility with flat floors and overhead beams.

Furthermore, the shift to a centralised facility leads to a number of benefits such as greater flexibility in supplier choice as materials can be stockpiled rather than being needed on demand at multiple sites across a city or region, a regular delivery location with dedicated loading bay facilities reducing transportation costs of supplies, and the assurance that there will be someone to sign for materials at the facility.

2.2 What is needed to accelerate building manufacture in Australia?

Despite the opportunities there are a number of challenges to overcome, both real and perceived, in order to mainstream building manufacture, especially in Australia. For instance there are lingering miss-perceptions around the costs involved in building manufacture and the ability to produce high-end homes and commercial buildings. In the past, manufactured buildings have often been perceived to be only used for site huts or temporary transportable rooms or offices which are common in Australian construction sites, mines, and schools, however the latest marked offerings allow for high quality precision designed buildings to be produced. Along with such perceptions that need to be addressed, the shift to aggregating construction of buildings to dedicated facilities to be transported to site for election presents a number of challenges to be addressed in order to progress the industry, namely:

Perceptions of Quality

- There is a need to shift perceptions of the industry and consumers around manufactured buildings being simply temporary reloadable structures to recognising them as high quality precision built buildings; this may be through independent quality verification, demonstration buildings, community education programs, and qualifying the specific benefits to consumers.

Design Processes and Controls

- There is a need to ensure that design, construction, and erection processes harness the full potential of the building manufacturing model and allow a streamlined delivery. This may include the updating of design codes and standards and associated changes to education and skills development programs. Key Ares for consideration include ensuring interoperability of standardised components and avoid re-invention of design practices by competing companies which may hinder the overall industry.
- There is a need to re-evaluate building project management processes related to materials and goods and services supply models to capture benefits from constructing multiple buildings in one location concurrently, such as being able to stockpile building materials and cluster buildings for sub-contractors to work on multiple buildings on one site.

- There is a need to standardise building transportation requirements and restrictions at a national level to allow for greater ease in interstate transportation of manufactured buildings or components.

Supply Chains

- There is a need to effectively engage with small businesses involved in building construction to shift from individual building contracts on various sites to a clustering of skills to deliver multiple building projects from a centralised factory-style facility. There is a need to also engage with advanced manufacturing business to assist in a transition from sectors such as the auto industry to supporting the building manufacture industry.
- There is a need to develop efficient and effective building transportation and erection processes and equipment to minimise associated costs and maximise accessibility to various site conditions. This will involve the building industry working with trucking and crane companies to a much greater extent.

Financial Models

- There is a need to address impacts on completion risks such that the building is in the possession of the manufacturer up until delivery and may not be able to be easily completed should the manufacture halt operations, or the client may not qualify for finance or withdraw part way through the construction process.
- There is a need to overcome in collaboration with banks and financial institutions the resistance to rearrange long standing financing structures that are based on progress payments at different stages of onsite construction to support factory style construction prior to transportation to site of completed product for erection.

Defects and Insurances

- There is a need for a clear and accountable process for the rectification of defects, especially when sourcing building modules from overseas. Further there are issues of the allocation of responsibility for defects given that the buildings can be constructed, transported, and erected using different contractors.
- There is a need for insurance and warrantee structures to support offsite construction and onsite erection.

Skills Development and Transitioning

- There is a need to provide capacity building to trades to adapt to building prefabrication, this may involve both the development of training courses and programs along with incentive schemes to encourage up-skilling.

3. Perceptions of Manufactured Buildings

3.1 What is the perception of manufactured buildings?

PrefabAUS Chief Executive Officer Warren McGregor believes the single biggest challenge for embracing manufactured buildings within Australia "*will be the change in mindset involved*", with this change needing to be "*widespread; including clients, contractors, architects and consultants, project managers and suppliers*". The lack of appreciation of the quality now possibly from manufactured buildings stems from the poor reputation of post-World War II social housing projects both in Australia and internationally. The pressing requirement for rapid rebuilding after the war years created an environment in which factory built structures came to the fore as they provided a low cost means to provide a high number of residential properties in a short time frame. While generations may have passed since then, a lack of knowledge has caused poor market perception of manufactured buildings to remain within Australia.

This negative bias has been increased through the association of prefabricated buildings with mobile and trailer homes, low socio-economic housing projects, temporary institutional buildings such as demountable classrooms and worksite offices. In a study by Steinhardt, Manley and Miller (2013) an Australian industry representative reflected that prefabricated buildings within Australia have on the whole been "*pretty cheap, nasty, flimsy, lightweight constructions*". Such associations have resulted in misconceptions about the quality and durability of manufactured buildings and has led to prefabricated buildings being seen as inferior products to traditional on-site constructed buildings, which is not in-fact the case. It is common for consumers to think of prefabricated buildings as standard sized shipping container like volumetric boxes. But prefabricated buildings have come a long way since those transported from London to Sydney in the early 1800s. Building manufacture now encompasses a wide range of off-site fabrication of components (for example frames and wall panels), subassemblies and volumetric modules that can be used across a broad spectrum of projects including residential homes, commercial buildings, hotels, apartments, offices, educational facilities, hospitals and worksite accommodation.

Figure 1: Adara Apartments, Western Australia (compliments of Housing WA)

3.2 How can the perception be changed

It is important for prefabricated buildings to use innovative design and new technology to be able to disassociate with traditional box-like features and change the current market perception. One such example, The Adara Apartments in Western Australia has achieved this (as shown in Figure 1).Designed by Campion Design Group and built by Hickory over a 12 month period, this building is a success story for the prefabricated building industry. Once the initial foundations and amenities were laid, 96 prefabricated modular components were brought and installed over a 10 day period. This structure boasts a reduction of 10- 12% less in construction costs, 35- 40% less aggregate funding costs and improved return on equity for investors.Despite new prefabricated buildings rising in cities around the world, the slow growth of prefabricated residential buildings is due in large to the reluctance of consumers to move away from traditional on-site building methods. In a US study into consumer perceptions of residential building methodologies in 2007, on-site built homes were more favourable than prefabricated homes, rating highest with '*respect to quality of construction, resale value, availability of financing, quality of surrounding neighbourhood and the look and feel of the home*' (HUD, 2007). Of these considerations, the perceived quality of construction was the most influential concern that consumers had when selecting building methodology. Additionally, consumers largely select traditional building methods as they provide for a sense of reliability and security. However manufactured products like 'The Auburn' in Australia shown in Figure 2 are changing the perception of the level of quality available.

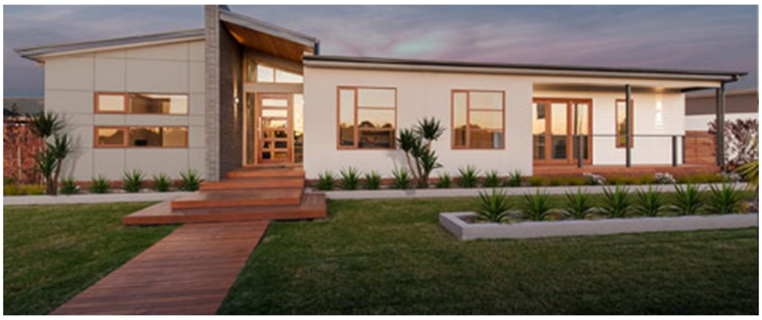

Figure 2: The Auburn (compliments of Allsteel Homes, Australia)

Shifting negative perceptions of manufactured buildings from temporary, low quality structures to high quality precision designed buildings is critical to increasing market share. However the marketing of prefabricated building needs to be carefully considered as despite being clearly more affordable and able to be delivered in much shorter timeframes using terms like 'low-cost' and 'fast' may resonate with perceptions of low quality. Terminology surrounding manufactured buildings can also impact perceptions of quality. Terms such as 'Modular' or 'Prefabricated' tend to again have associations with low quality buildings from the past, with companies now not making a point of the construction method but rather the quality, timeframes, and price.

The Japanese building sector has taken a targeted approach with companies such as Sekisui House, Sekisui Heim, Misawa Homes, and Daiwa House targeting upper socio-economic and environmentally conscious clients. These prefabricated models available are continuously analysed and improved with qualities such as thermal efficiency and energy consumption as well as seismic and acoustic performance. This strategy generally means a higher upfront capital cost do to the improvements but builds the reputation that efforts are being constantly made to reduce operating costs over the lifespan of the building, such as from energy and water consumption.

4. Overcoming Barriers to Financing Building Manufacture

4.1 Construction phase financing

The most often mentioned barrier to financing building manufacture is that as the construction phase takes place in a private facility, rather than onsite, it is difficult to use financing mechanisms that have been established to support onsite construction. Further as the value of the manufactured product is substantial compared with other manufactured goods a series of progress payments is preferred by builders. Hence the conflict between capturing the benefits of offsite construction and accessing progress payments using current financing arrangements presents a significant barrier to the upscaling of building manufacturing. This is due to the fact that unlike onsite construction, where the partially completed building is in the custody of the owner or developer and therefore forms collateral on the loan, using an offsite model calls for progress payments to be made while the building remains in the custody of the builder in a private facility.

Lending institutions are however accustomed to releasing funds for buildings constructed offsite after the building has been placed on site. The stage at which funds are released varies between lenders from when the building is installed on approved footings to when a certificate of occupancy has been issued. Hence the issue of progress payments is currently being overcome by developers, or even the building manufacturers, providing the funding required for the construction phase to then allow customers to seek purchasing finance based on the completed building. Although this model allows for the client or owner to secure traditional loan products based on a completed building there are two draw backs that are hindering the growth of the industry. Firstly it lends itself to large companies who can afford to provide construction phase financing, with smaller operators having to mortgage their own assets (or requiring customers that have appropriate assets to leverage), and secondly it means that the risk is carried by the builder or manufacturer until payment is made. Since the purchase finance cannot be secured prior to the construction stage this leaves the builder open to risks like the customer not being able to secure funding after the building is complete, or having the client change their mind before the building is completed.

4.2 Providing assurance of quality

A key element in ensuring the quality of buildings constructed offsite using prefabrication and/or manufacturing based processes is the provision of associated design codes and standards that can be assessed for compliance. In the USA, the U.S. Department of Housing and Urban Development can created a construction and safely standard for offsite construction and building manufacture, the '*Manufactured Home Construction and Safety Standards*'. This standard classifies a manufacture home as one that is '*constructed on a permanent chassis*' and provides standards for design, construction, and installation of manufactured homes to assure the quality, durability, safety, and affordability. The standards include a dispute resolution component along with the provision for inspections and record keeping.

A second key way to provide assurance of quality is through the provision of a warranty or assurance scheme. For example in Japan, where prefabricated housing represents some 13 percent of the building stock, building owners are provided with a standard 20 year warranty which entails strong after sales service. In the UK efforts to increase the viability of securing construction financing have focused on providing independent certification of the processes used in offsite construction and building manufacture in collaboration with the Council of Mortgage Lenders. The '*Build Offsite Property Assurance Scheme' (BOPAS)* seeks to provide assurance to lending institutions that buildings constructed offsite are sufficiently energy efficient and durable and will be readably saleable for a minimum of 60 years. The BOPAS certification process consists of two components:

(1) A *durability and maintenance assessment* that provides an independent technical assessment of the building's suitability and encompasses issues relating to reparability, maintainability, and suitability for housing (or other building types).

(2) Accreditation *of the design and/or construction processes* that is solely risk based, in which designers, manufactures and constructors are evaluated on key performance areas at each stage of project development from concept design to project completion. The major performance areas are: risk management, competency management, configuration management, procurement management, and process control.

The process accreditation occurs in two stages. An organisation initially undergoes a gap audit in which any significant weaknesses are highlighted and adoption of best practice is facilitated. A full implementation audit is then undertaken in which key performance areas are examined against a best practice standard, with accredited organisations undergoing regular visits to ensure proficiency is maintained. A key feature of the BOPAS system is the use of an online database that provides valuers, lenders and surveyors a single point of reference to find all accredited designers, manufacturers, constructors and building systems.

4.3 Provision of loan insurance

In the USA, the provision of government-insured mortgage loans offered by the Federal Housing Administration encourage mortgage lenders to finance manufactured homes by protecting the lender against the risk of default from the buyer. Traditionally, manufactured homes have been financed as personal property through comparatively high-interest, short-term consumer instalment loans. Mortgage lenders have now established appropriate products that allows buyers to finance their home purchase at a longer term and lower interest rate than with conventional loans. The buyer pays an upfront insurance premium, along with an annual premium based on the declining balance of the loan. The maximum loan term is 20 years for a manufactured housing loan. Despite such progress a study has found that from 2001 to 2010 in the United States an estimated 65% of manufactured housing customers who owned their land and took out a loan financed their purchase with a chattel loan, which is a secured loan where the financier takes charge over the asset. Although chattel loans have lower initial costs and may close sooner than mortgages, interest rates on chattel loans, however, are usually higher and chattel loans generally have lesser consumer protections than mortgages. Overall, customers buying prefabricated homes tend to pay higher interest rates for their loans than ordinary home buyers. In 2012, according to the Consumer Financial Protection Bureau (CFPB, 2014) approximately 68% of all manufactured-housing purchase loans in the USA were classified as high-priced mortgage loans.

4.4 Issues related to defects and contractual arrangements

Further to issues related progress payments there are issues related to the responsibility for defects given that the construction of the building is now undertaken in two stages that may involve different contractors. The first stage is the offsite construction stage to produce building components or modules, and the second stage is related to onsite construction, such as site preparation, construction of footings and building core, and transportation, lifting, and assembly of building modules. At each of these stages defects can be present and the responsibility for defect identification and rectification is not always clear cut which can lead to conflict between parties. Litigation can arise between the manufacture and the installer in cases where the contractual responsibility has been divided between the two, where both parties are likely to point the finger at one another over delays and defects.

The potential for such issues can also be of concern for lending instructions, causing a barrier to finance, however this can be overcome through a 'Design and Construct' contractual arrangement. In such an arrangement the builder or developer will undertake the design and enter into a subcontract with a manufacturer who will produce the modules. The builder will undertake associated on-site construction and installation of the modules. Within such a contractual arrangement, there is a single point of responsibility whereby the builder is accountable for all design, construction and manufactural faults and defects. The manufacturer of the modules or building components is responsible for rectification of defaults as if it were any other subcontractor.

5. Conclusions

The manufacture of buildings has the potential to provide high quality and cost-effective houses, apartments, office blocks and a range of other building types, utilising the technologies, materials, design knowhow, and construction experience currently in the both the building and manufacturing sectors. This together with the benefits pointed out previously suggest that it is likely that a large part of building construction will shift from individual buildings constructed onsite to the aggregation of construction in dedicated facilities to be transported for erection on site. Manufactured buildings are unlikely completely replace conventional building approaches, but they stand to significantly increase share in the market, particularly for multi-storey buildings. As with a number of other advanced industries, such as renewable energy technology, the slow recognition of the value that can be created through the manufacture of buildings in many countries such as Australia may lead to a missed opportunity with off-shore providers dominating the nation's future building market.

In order to capture the potential of building manufacture the building sector needs to quickly develop the infrastructure for the construction of buildings in centralised facilities and their transport and erection on site. This may involve a transition strategy that includes an initial push for the use of panelised onsite construction to build momentum in the manufacture and erection of prefabricated components and modules. It is particularly important to develop the sector in a manner that takes advantage of the cost effectiveness of sourcing building modules off-shore, otherwise such offerings will compete with domestic construction. There are already cases of off-shore building manufacturing plants that are importing Australian electrical and plumbing components to ensure that standards and codes are met when shipping to Australian customers. Hence, if countries like Australia do not seize the opportunity of building manufacturing, foreign companies will certainly continue to bring them to market, which if not harnessed as part of the sectors overall development could lead to job losses across the building sector and its supply chain.

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Economic Value and GHG emissions of the residential Internet of Buildings in Finland

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Abstract

Digitalization is a megatrend that is expected significantly to raise productivity across sectors. Among others, buildings and real estates sector possesses untapped economic and resource efficiency potential that may be reached with digitalized solutions. One of the most significant obstacles preventing the potential to realize is the restricted or non-existent sharing of information between buildings and real estate stakeholders. The Internet of Buildings (IoB) provides a solution for enabling the existing potential in buildings and real estates by networking buildings and real estate service stakeholders with information, energy and resource flows. The study introduces a definition for IoB as "an ecosystem of buildings, users and service providers using smart buildings as an enabling technology". This research estimates the economic value of IoB in Finnish markets. The economic value is estimated using statistical expenditure data of public and private consumption related to IoB related activities. Since the sector is also a big contributor to the climate change, the GHG emissions caused by the sector are analysed and the sub-sectors contributing most to climate change are identified. According to the study, the economic value of IoB-relevant consumption is around €70 billion per year, which accounts for major share of public and private consumption. The housing and public welfare services were the sub-sectors contributing the most to the economic value. Energy consumption, including heat, electricity and fuels, although representing a relatively low share of the economic value, accounts for the largest share (37%) of GHG emissions. Thus, IoB solutions and services aiming at energy optimization and increased efficiency have an excellent potential for successful climate change mitigation. The results indicate that the both economic and environmental value of IoB markets offer without doubt lucrative economic opportunities and motivation for digitalization as well as climate change mitigation.

Keywords: Internet of Buildings, real estate business, smart technology, climate change mitigation

1. Introduction

Digitalization offers substantial potential for private and public services across all sectors and is also widely considered as a cornerstone for international competitive edge in the future. Manyika et al. (2013) estimated that as few as twelve disruptive new technologies can have a potential economic impact of 14 to 33 trillion dollar per year in 2025 including only the technologies that we can anticipate today. Digitalization is also the cross-cutting theme of the current Finnish government's strategy in order to decrease the costs of public sector and increase the Finnish companies' potential in international markets (Finnish Ministry of Finance 2015). According to Kuusisto (2014), digitalization and smart services may be considered as a way to cut costs of current services and make them more efficient. Although consumer markets have been in the leading edge of development, digitalization and smart services are very likely to significantly transform business-to-business context and public sector as well.

The digitalization has already been opening up new opportunities within various sectors. Neirotti & Paolucci (2007) studied the strategic value of IT in Italian insurance sector and found out that the most firms on the sector increased their productivity through utilization of IT. Gastaldi & Corso (2012) analyzed the possibilities of digitalization in health care, specifically within hospitals and suggested criteria for successful digitalization process. Balta-Ozkan et al. (2013) stated that smart technology such as smart grids and smart meters have existed as concepts already in the past, but recent policies and objectives mandating energy efficiency and climate change mitigation significantly increased attention towards them over the last decade. Additionally, advancements in communication technologies and wireless devices have driven recent developments. In construction and real estate sector, the digitalization has been mainly focused towards building information models (BIM) and smart buildings with Internet of Things (IoT) –solutions. BIM is a computer-generated 3D model, which includes the relevant data to support the construction process (Eastman et al. 2011). According to Manyika et al. (2013) IoT refers to using sensors, actuators and data communication technology built into physical objects enabling the tracking, coordinating and controlling those devices across data network or Internet. These devices have recently spread from industrial use to consumer market, where people can monitor and control multiple numbers of private assets using apps on nowadays conventional smart devices (Rosemann 2013). However, currently most research concentrates on technological and within building activities. Hardly any studies have investigated the benefits of connecting users, service providers and buildings together and thus enabling more efficient solutions managing resource and service flows with a network of buildings.

In this paper, Internet of Buildings (IoB) framework is presented for the first time. We define IoB as an "ecosystem of buildings, users and service providers using smart buildings as an enabling technology". A smart home as defined by Balta-Ozkan et al. (2013) is "a residence equipped with a high-tech network, linking sensors and domestic devices, appliances, and features that can be remotely monitored, accessed or controlled, and provide services that respond to the needs of its inhabitants". The smart building technology serves as a technical platform for the IoB ecosystem where service providers can utilize digital solutions in transforming their business more resource efficient as well as generating new business opportunities. Even more importantly, users of buildings currently in a role of consumers can activate as service providers as well and start producing value for the ecosystem using smart buildings as a platform. IoB-framework is connected to several earlier themes in academia including smart buildings, resource efficiency via digitalization, growing demand for consumer-oriented and on-demand services and GHG assessments and climate change mitigation in the built environment.

This study provides an insight into the potential market size of suggested IoB ecosystem by presenting the economic value of current public and private consumption of IoB in Finnish economy. A consumption based LCA was selected in order to evaluate the monetary value and GHG emissions of the potential IoB-industry on residential sector. The consumption approach enable us to evaluate building as service, i.e. the value of buildings is delivered to users during the extensive time of using the physical building instead of a single transaction. Thus, users have very a critical role in ecosystems of real estate sector, and setting the scope of the research into the consumer-oriented value generation is a relevant approach to study the value and GHG emissions in digitalized real estate business.

The paper is structured in four chapters. Chapter two describes the research materials and methods and processes of data analysis. Chapter three presents the results of the study. Finally the conclusions and implications of the study are discussed in the fourth chapter.

2. Materials and methods

2.1 Research materials

The main research material is the Statistics Finland’s Household Budget Survey 2012 (Statistics Finland 2012a) and additional data on public welfare services including education, healthcare and social services (Statistics Finland 2012b). The Household Budget Survey includes detailed data on the expenditure of around 3500 Finnish households. The expenditure is divided into consumption categories according to the international COICOP-division (Classification of Individual Consumption According to Purpose, UN 2016). The data includes weight coefficients that correct the sample to represent the overall population of Finland. The weights are used in this study.

2.2 Research frame

The purpose of the study is first to define the concept of IoB, and second to provide a view to the current monetary value and GHG emissions of the consumption-based economic sectors related to IoB. The purpose of quantifying the current expenditure on IoB related sectors, and the following GHG implications, is to give insights for the parties interested in developing IoB solutions and services. A consumption-based approach was chosen, since it is meaningful within the context of IoB to take the perspective of the end-user, who in the residential sector is the resident of the building. The end-users are expected to take part to the value creation in IoB.

The selection of the consumption categories that are potentially part of IoB is based on literature references discussing smart houses and smart grid. Based on the literature framework was made with selection categories presented below and in Table 1.

Housing sector is considered the core of residential IoB. Especially the housing energy and maintenance have a high potential for new IoB solutions and services (Fang et al. 2012, Dimeas et al. 2014, Vermesan & Friess 2014).

Energy sector is an essential part of IoB. For example, smart grid, distributed renewable power generation and electric vehicles as flexible electric power storages, users and suppliers, are expected to play an important role in energy use optimization (Lund & Kempton 2008, Fang et al. 2012, Richardson 2013, Erdinc 2014).

Smart home applications are enabling IoB solutions and services. They can be divided into applications that aim to the energy optimization, for example by controlling the energy use of home equipment and other electronic devices (Dimeas et al. 2014), and other applications, such as *security* and *entertainment services* and *eHealth* (Robles et al. 2010, Balta-Ozkan et al. 2013, Vermesan & Friess 2014, Zhang et al. 2015). For example, eHealth can shift health services from health centres to homes (Rialle et al. 2002, Baker et al. 2007).

In addition to being potential sectors for new *eServices* and smart home applications, some services are included in the framework since *service spaces* as such are part of IoB, similarly as residential buildings. For example, the energy optimization solutions can be used similarly in service spaces as in residential buildings.

As one can see, some consumption categories are considered more essential parts of IoB, whereas the connection of others is looser. However, the framework is purposefully made as comprehensive as possible. It can be restricted for later purposes, if useful.

Table 1. Selection criteria and the selected consumption categories

	Selected consumption categories	Selection criteria			
		Housing sector	Energy (smart grid)	Smart home	eServices and/or service spaces
Consumers:	Housing energy	x	x	x	
	Housing maintenance	x		x	
	Rentals and imputed rentals without energy and maintenance	x		x	
	Motor fuels		x		
	Personal vehicles and services		x	x	
	Public transport		x		
	Home equipment (white goods)			x	
	Housing related and social services	x		x	x
	Telecommunications		x	x	
	Entertainment electronics			x (lifestyle)	
	Health services			x (eHealth)	
	Cultural and leisure services				x (lifestyle)
	Insurances			x (Security)	
Public sector:	Education				x
	Health services			x (eHealth)	x
	Social services				x

2.3 EE IO analysis and hybrid life cycle assessment

The assessment of the monetary value and GHG emissions of IoB related sectors is based on an environmentally extended input output (EE IO) model (Leontief 1970). The EE IO models are based on input-output economics. Input-output tables of an economy consist of matrixes presenting the monetary transactions between economic sectors. Each sector uses inputs to produce outputs that are inputs to some other sectors (intermediate products), or end products or services for consumers. In the environmentally extended version environmental indicators, for example GHG emissions, are added to the matrixes to assess the cumulative environmental impacts (Leontief 1970).

A consumption-based EE IO model provides the total expenditure on each consumption category within an economy, and the respective cumulative environmental impacts. The consumption categories cover all consumption. The cumulative environmental impacts are assessed so that they include all the impacts caused during the life cycle of goods and services (cradle-to-gate) (Wiedmann 2009). The main strength of the method is the comprehensiveness. Truncation errors from system boundary selection are avoided, since the method is systemic and top-down type (Suh et al. 2004). However, the EE IO models are rather aggregate, depending on the aggregation of the consumption categories. The EE IO models can be improved by integrating more accurate process-LCA data to the model. Models combining EE IO analysis and process LCA are called the hybrid LCA models (Suh et al. 2004).

In this study, the GHG emissions from the selected consumption categories are assessed with the EE IO model of Finnish economy, called ENVIMAT (Seppälä et al. 2009). The ENVIMAT model provides GHG intensities (CO_2-eq kg/€) for 52 consumption categories in Finland. In addition, a hybrid LCA model is used to assess the emissions from housing energy, motor fuels and personal vehicles more accurately. In the hybrid-LCA model, the coefficients of the combustion phase CO_2-emissions from the energy production are 209 CO_2-eq/MWh for district heating and 223 CO_2-eq/MWh for electricity (Motiva 2012). The upper-tier emissions from fuel production and distribution etc. are provided by the ENVIMAT model. The heat and electricity price differences between different housing types are taken into account in the assessment. Also, the emissions from housing construction are assessed separately by using a living space -based estimate derived from Ristimäki et al. (2013). The used estimate has been calculated with the production version of the ENVIMAT model, using the production-side prices of goods and services. The estimate is 1.1 CO_2-eq t/m^2. The GHG assessment method of the study is described in more detail in Ottelin et al. (2015). The model is rather detailed, since it is used for broad research purposes.

It should be noted that the expenditure on rentals and imputed rentals are not used in the assessment of the GHG emissions to avoid double counting. The emissions from housing energy and maintenance are assessed separately with the hybrid-LCA model using household expenditure data and data on average expenses of housing companies in Finland (Statistics Finland 2016). Thus, the only emissions allocated to the sector of rentals and imputed rentals are the emissions from housing construction. The other emissions caused by expenditure on this category are considered low, and excluded from the assessment.

3. Results

The total monetary value of the IoB related market in 2012 in Finland was €70 000 million. The share of heating, electricity and motor fuels was €8 400 million. Housing (without energy) accounted for €21 300 million and personal vehicles €9 800 million. The share of other IoB related consumer goods and services was €14 400 million euros. Finally, public sector with education, health services and social services accounted for €16 500 million. The consumption volumes and following GHG emissions of IoB related consumption categories are presented in detail in Table 2 (The GHG emissions include only the emissions from housing construction. The emissions from housing energy and maintenance are in the respective categories. The additional emissions caused by rentals and imputed rentals are not included, but are considered low). The table shows also the GHG assessment method for each consumption category. Figure 1 illustrates the share of IoB related consumption and GHG emissions of the total consumption and GHG emissions in Finland at an aggregated category level.

Table 2. The total monetary value and attached GHG emissions of IoB related consumption in Finland

	Consumption category	€1000 million	CO2-eq Mt	GHG assessment method
Housing energy and motor fuels	Housing energy	4,7	12,3	hybrid-LCA
	Motor fuels	3,6	6,7	hybrid-LCA
Housing other	Housing maintenance	4,7	2,5	EE IO
	Rentals and imputed rentals without energy and maintenance	16,6	3,8	production-side EE IO
Personal vehicles and services	Personal vehicles and services	9,8	3,2	hybrid-LCA
Other IoB related consumer goods and services	Public transport	1,1	0,6	EE IO
	Home equipments (white goods)	1,4	0,6	EE IO
	Housing related and social services	1,1	0,2	EE IO
	Telecommunications	2,3	0,6	EE IO
	Entertainment electronics	1,4	1,1	EE IO
	Health services	1,1	0,2	EE IO
	Cultural and leisure services	3,7	0,6	EE IO
	Insurances	2,1	0,3	EE IO
Public welfare services	Education	7,9	2,4	EE IO
	Health services	6,7	1,3	EE IO
	Social services	1,9	0,4	EE IO

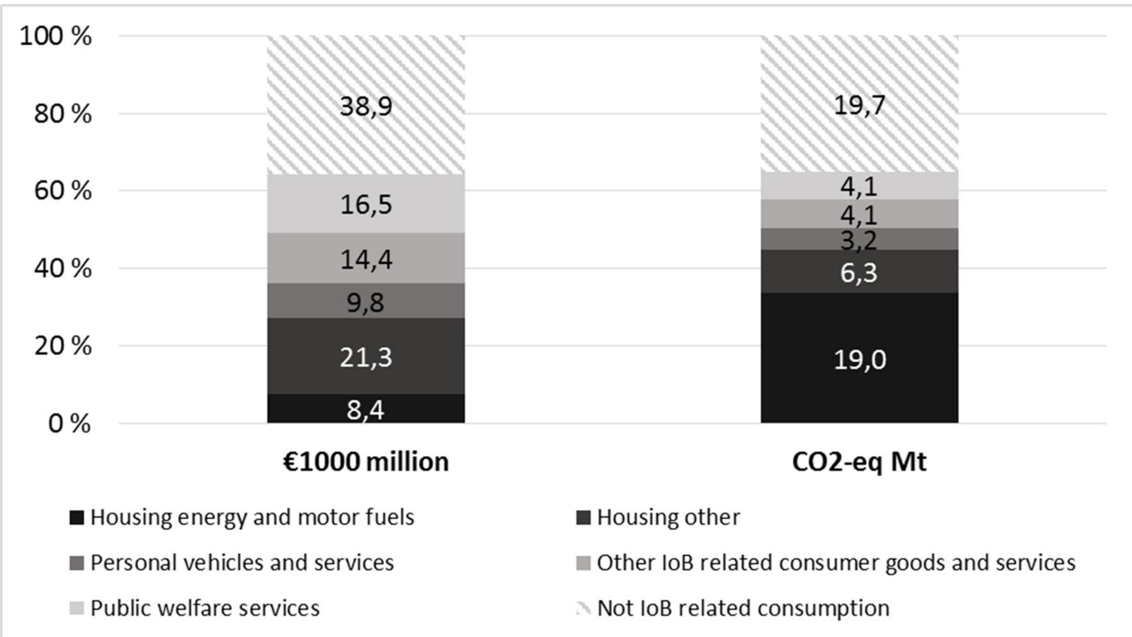

Figure 1. The share of IoB related sectors of the total consumption and GHG emissions in Finland

The results of the GHG emissions assessment indicate that housing energy's and motor fuels' relatively small shares of total monetary consumption result in very significant share of the total GHG emissions. The total GHG emissions from housing energy and motor fuels together are 19 Mt CO_2-eq. Since the total consumption-based GHG emissions in Finland are 52 Mt CO_2-eq, housing energy and fuels account for 37% of these.

4. Discussion and conclusions

The purpose of the study was to provide insight into a new concept called Internet of Buildings, in which digitalization enabled networking of buildings and real estate stakeholders will provide improved resource efficiency along with new business opportunities for real estate and construction sector.

The main contribution of the study is the presentation of the IoB concept and the assessment of the market value and GHG emissions of the current IoB related consumption in Finnish residential real estate sector. The total market value of IoB related activities is estimated to be €70 000 million, which means that currently consumers and public sector use more than half of their budgets on products and services that could potentially be a part of IoB. For comparison, the IoB related consumption is almost as significant as the combined turnovers of ICT (€45 000 million) and construction industries (€29 000 million) (FiCom ry, Statistics Finland 2016b).

It should be noted that some of the included consumption categories quite obviously belong to IoB, whereas the inclusion of some other categories is based on more far-reaching reasoning. Also, there may be consumption categories that are not included, but will become part of IoB, and more likely, consumption that does not exist yet, but will emerge, when the practical solutions of IoB develop. By improved knowledge of needs and behaviour of user and customer and by creating new innovative service packages based on the knowledge it would be possible to create an entirely new way to manage real estate.

In addition to the business potential, IoB carries also significant climate change mitigation potential. According to the assessment, the life cycle GHG emissions from housing energy and motor fuels consumption were 19 Mt CO2-eq in 2012, which accounts for 37 % of total consumption based emissions in Finland. Finnish energy production relies still heavily on fossil fuels, whereas wind and solar power and decentralized energy production are marginal. According to the Finnish Ministry of Employment and the Economy (2015) taking advantage of renewable energy is still in initial and planning phase, although several investment decisions of over €1 000 million have been made on wind and solar power as well as biofuel industries for the years 2016-2017. IoB, including smart grid and electric vehicles (EVs), would provide a possibility for much higher integration of renewables into the Finnish energy system.

Richardson (2013) concluded in his review on EVs and renewable energy that studies on this topic overall indicate that EVs have the potential to increase the amount of renewable energy, especially wind energy capacity installed in electricity systems. EVs can absorb and storage excess wind and solar energy that would otherwise be wasted. For example, Juul and Meibom

(2011) studied integration of electric power and transportation sectors in Denmark, and calculated 85 percent reduction in transportation related CO_2 emissions. Most of the studies concluded that especially high reductions can be achieved by using smart charging and vehicle to grid (V2G) capability. V2G means that EVs have the ability to store electricity and return it to the electric grid.

As one can imagine, EVs with smart charging and V2G capability fit well together with smart buildings and distributed energy generation such as solar panels and small wind turbines integrated to buildings (Fang et al. 2012). With two-way flows of electricity and information, buildings would be able to for example feed their excess electricity to the smart grid and avoid electricity consumption on peak times. Furthermore, smart building solutions already enable maintaining the optimal indoor conditions. Further energy savings have also been shown to be associated with remote energy management of buildings (Määttänen et al. 2014) and simply adjusting the settings of HVAC equipment in buildings and thus restoring and maintaining the original energy efficiency of buildings' technical equipment (Christersson et al. 2014). Thus, even the most conservative scenarios of IoB in the future reach significant reductions in energy consumption. In IoB, energy use is not optimized only within a building, but within a network of buildings. However, to support IoB, the electricity generation industry must transform into an information intensive service with capability to two-way flows of energy and information. Electricity as a product must become more consumer oriented with variability for different consumer needs.

There are some uncertainties in the study related to the initial data. First, all public consumption is not included in the assessment due to limitations in data availability. However, the public welfare services, included in the study, are perhaps the most relevant public sector considering IoB. They also constitute a significant share of the overall consumption in Finland, which gives a reason to include them in the assessment. There is a high potential for IoB solutions and services in this sector. However, the results involve higher uncertainty than the results on consumer goods and services. The data from the public sector is much more aggregate than the household expenditure data, and provided simply as an average expenditure on public education, healthcare and social services per capita in Finland.

Since information flows and big data will be the key factors for IoB business, the security issues related to the smart grid and IoT are equally important in IoB. All smart technologies must be combined with smart protection systems. Protection of IoB should be seen as a business opportunity and a competitive edge. IoB can only live up to expectations, if customers can trust its reliability, privacy and security. Bearing this in mind, we welcome the new digitalized era of the built environment.

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Evaluation of Attributes for Healing spaces of Medical Ward

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Abstract

The objective of this research is to examine the opinion of patients and visitors toward the environment of the medical ward of Maharaj Chiang Mai Hospital. The overall environment was assessed to identify the issues that have affected to the patients environmental adjustment. The adjustment is based on the idea of Healing Environment for improving health of both patients and visitors during their visit to the ward. Ten dimensions of surrounding and environmental factors that are evaluated using questionnaires consists of Lighting, Fresh air, Scent, Gardens and the outdoors, Interior environment, Quietness, Spatial layout, Comfortable atmosphere, Art and positive distractions and Colour. The study results which examined the evaluation from of the patients and the visitors of the medical ward was rated as poor. The comparison on the opinions of patients and visitors that are negatively affected by the environment suggests that the cause of the problem varies at significance level of 0.05, in which visitors evaluates environmental issues more highly than patients. These results will be analyzed and used for designing the healing environmental guidelines for the medical ward of Maharaj Chiang Mai Hospital.

Keywords: Attributes for Healing spaces, Patient and Visitors, Differences, Opinion

1. Introduction

The procedures that take environmental issues into account or healing environment plays a significant role in designing hospital at international level. However, this principle is relatively new and is very interesting for hospital architecture in Thailand.

The main purposes of the study are as follow:

1. Presenting an evaluation of environmental issues in patient wards by evaluating the opinion of both patients and visitors whose opinions are valuable for improving hospital design.
2. Comparing the differences among the opinions of patients and visitors
3. Proposing tentative guidelines based on the principle of healing environment

2. Background and Signification

Maharaj ChiangMai Hospital, the largest hospital in the North of Thailand with 1,400 patient beds and is fully operated by Ministry of Public Health (Thailand) and providing all treatment to all patients. However, current wards in the hospital buildings are in state of disrepair. Therefore, the policy of improving the environment for health promotion, by taking the principle of healing environment into account, has been announced; the important condition that needs improvement will be in accordance with the opinions of the patients, visitors, and staff.

The medical ward is used as Pilot Project Area, according to the evaluation; the condition of this ward is the poorest in the hospital. Hence, it is necessary to improve the ward. This ward is located on 11th floor of Sujinno Building, the reinforced-concrete of 15 stories. Natural ventilation is used along with the installed fans. The plan of the building is in a y-shaped. The total area of the ward is 1350 square meters, in which the area of patients' rooms is 554 square meters and consists of 15 rooms and 85 beds.

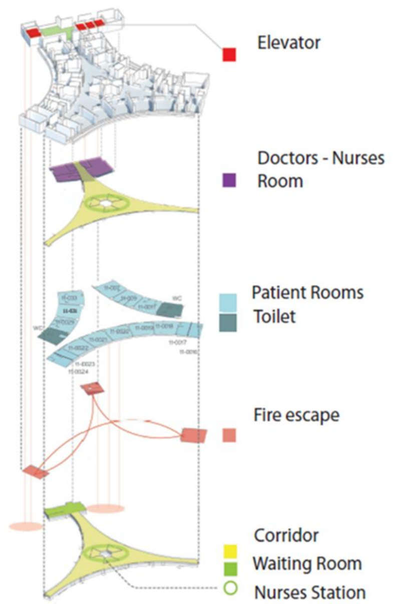

Figure 1: Medical Ward of Sujinno Building Functional Plan

*Figure 2: Patient Rooms in Medical Ward of Sujinno Buildin*g

The study begins by gathering research which is related to healing environment. The data is applied for creating evaluation form that will be distributed to both group of patients and visitors then who are the main users in Sujinno Building.

3. Literature review

Attributes for Healing spaces one research done by F. C. Bloemberg's researches in 2009 in Healing Environments in Radiotherapy Recommendations regarding Healing Environments for Cancer Patients has showed research outcome which demonstrated 10 physical factors that are used for healing patients' health in accordance with the combination of the research in the same field. The mentioned factors are as follow:

1. Lighting: Artificial lighting havecertain benefits, but certain characteristics have been argued to negatively affect mood and performance. The lighting should neither be too dim, nor too bright. Warm, indirect lighting is recommended. Lighting should not create sharp shadows; neither should it eliminate shadows completely. Providing lamps can also increase a homely feeling. (F.C. Bloemberg, 2009) Natural light in hospitals benefits effectively because it can improve psychological states for both patients and staff. (L.Edwards and P.Torcellini, 2002)

2. Fresh air: Fresh outdoor air is recommended, as this can influence temperature and humidity, whereas poorly ventilated buildings can affect uncomfortable symptoms of sickness. (F.C. Bloemberg, 2009) Poor ventilation in hospital is seen as the main cause of nosocomial disease. Providing pleasant and comfortable temperature that can be individually adjusted by patients in case of individual differences will support a sense of privacy. Install ventilation systems that widely generate fresh air and, again, can be adjusted for individual differences. Natural and mechanical ventilation systems are often preferred over air conditioning systems. Air-conditioning systems are to be preferred over natural ventilation only in certain circumstances, for instance, very hot climate, or rooms that require the highest standard of air quality for prevention of infections such as an OR or ICU. (Netherlands Board for Healthcare Institutions,2008 pp.30-32) Comfortable zones of Thai people are in the ranges of relative humidity 50% - 70% and effective temperatures of 24°C - 27°C for air velocity 0.2 m/s.(Juntakan Taweekun,2013)

3. Scent: Scent is perceived as positive as it can reduce anxiety, whereas negative scents stimulate stress and fear. Although food scents can be perceived as positive, they can make cancer patients feel nauseated. Aromatherapy can increase a sense of relaxation, does not decrease anxiety for cancer patients receiving radiotherapy.(F. C. Bloemberg 2009)

4. Gardens and the outdoors: People experience less stress when they have access to gardens. Elements such as trees, grass, water, visible sky, rocks, flowers and birds particularly provide this positive effect. Gardens in healthcare settings should not only idealy offer several different opportunities, but also offer both private as well as communal space. (F. C. Bloemberg 2009)

5. Interior environment: Patients who see the trees and water scenery are significantly less anxious during the postoperative period than patients who is assigned to see the other scenes and control conditions. Moreover, patients who are exposed to the trees and water scenery suffer less severe pain, because they shift faster than other groups from strong narcotic pain drugs to moderate strength analgesics.(Li.wang, 2011) To keep other factors constant for proper outcomes, the methods ensured that patients who see the trees and the wall are equivalent, in terms of age, weight, tobacco use, and general medical history. The result showed that those who see nature scenery, compared to those who look out at the wall, have shorter hospital stays and suffer fewer minor post-surgical complications.(Roger S, 2002)

6. Quietness: Loud noises can affect patients' health negatively. Therefore, reducing noise by using equipment and doors that create less noises is important. Sound-absorbing materials in the ceiling and on the walls contributes to this, although it might be harder for staff to hear when patients are calling for help. Certain sounds, like music, can have a positive effect on patients' anxiety levels and mood. Slow; smooth music without accented beats is preferred. As music can be disturbing as well, it is recommended to give patients freedoms to choose. (F. C. Bloemberg 2009) Eliminating and reducing noise sources, for instance, using soundless paging systems, wireless communication systems, switching off equipment that is not being used, and taking into account the noise level and the adjustability when purchasing the equipment. Also the realization of separate rooms for outpatients consultation, separation rooms from noisy zones, and the use of good logistics creates peace and quietness for patients and gives the staff the opportunity to focus on their duties. It is also important to train the staff to speak in a lower voice and aware of patients. The sound level of noise in hospital should not be more than 45 decibels (dB) during the day and 35 dB at night.(Netherlands Board for Healthcare Institutions, 2008)

7. Spatial layout: In the spatial layout of the hospital, it is crucial that people can find their way easily. Way-finding is important This can be achieved by making the building asymmetrical and using clear signs. A recognizable kind of way-finding is recommended, such as paths’ names. Different waiting areas should be provided for in and outpatients. Thus, walking distances should be kept as short as possible.(F. C. Bloemberg 2009) Solutions to improve orientation are found in integrated systems by providing simple, clear and consistent sign-posting combined with written and verbal information. (Netherlands Board for Healthcare Institutions, 2008) Room privacy perception is also likely to play an important role in the patient’s well-being, because privacy can lead to a positive perception of the room. Both the extent of visual access (quantity of view of the room) and the extent of visual exposure (the extent to which a person is visible to others) turn out to affect the privacy perception. (Ulrich, 1984)

8. Comfortable atmosphere: Seemingly sterile environments and making it feel more like home is advisable. However, this shouldn't be overdone as people expect a certain professional atmosphere in a hospital. Concealing technical equipment and clutter in cabinets and behind screens also contributes to a comfortable environment, as well as providing possibilities for children to play.(F. C. Bloemberg 2009)

9. Art and positive distractions: Works of art can improve the aesthetic appeal of a hospital and provide distraction. Other distractions, such as radio, television, internet and telephone, can also contribute to positive distraction.(F. C. Bloemberg 2009)

10. Colour: Most agree that it can decrease the institutional atmosphere of hospitals. In general it is recommended to use warm, soft, natural colours. Grey and dull shades should be avoided, as they can produce anxiety.(F. C. Bloemberg 2009) Natural colour creates healing atmosphere; the healthcare environment such as green is thought to be restful and healing, as it is the color that associated with balance, harmony and renewal. Blue has always been connected to calm. Room painted in natural shades could lower blood pressure and the heartbeat, and allows for deep breathing as it relaxes muscles and the mind. (Laura Guido-Clark Design, LLC, 2011)

The result of the study will be adopted for creating the questionnaire to evaluate the overall ward environmental issues.

4. METHODOLOGY

The research tools of this research are questionnaire, as it is survey research. The sample groups of this research are the patients and visitors of the medical ward in Maharaj Chiang Mai Hospital.

At present the Medical Ward has 130 visitor and patients per day. Which can be classified by 55 visitor and 75 patients Therefore the researcher has divided the simple groups into 2 as followed.

1) 63 sample patients are selected by the nurse as physically and mentally strong to complete the questionnaire and the patients have been treated in hospital for more than 5 day

2) 48 visitors who come in to visit the patient ward in the morning form 12:00 PM – 1:30 AM and 3:00 AM – 7:00 AM in the afternoon.

The simple population (size) is adapted from Krejcie & Morgan, 1970 which 95% validity.

The questionnaire, which is designed from the literature review, contains 36 closed-ended questions using Likert Scale for measurements. Every question is focused on negative-sense items that can be described as follows: (Table 1-2)

Table 1: Rating Scale for Questionnaire

Patients and Visitor Perspective	Scores	Rating	Description

Agree	3	3.00-2.33	Poor
Neither agree nor Disagree	2	2.32-1.67	Fair
Disagree	1	1.66-1.00	Good

This rating scores are used to measures the manner the environmental issues within the medical ward Maharaj hospital. Table 2 describes important aspects of environmental issues in the hospital building.

Table 2: Important environmental aspects for evaluation

Environmental Issues	
No.	A. Lighting
1	Disturbance from the bulbs(Day lighting)
2	Disturbing colour because of light(Day lighting)
3	Insufficient natural light(Day lighting)
4	Insufficient light in the patient's room(Day lighting)
5	Excessive light in the patient's room(Day lighting)
6	Disturbance from the bulbs(lighting night)
7	Disturbing colour of light(lighting night)
8	Insufficient light in the patient's room(lighting night)
9	Excessive light in the patient's room(lighting night)
	B. Fresh air
10	Insufficient air ventilation
11	Hot diurnal temperature
12	Hot nocturnal temperature
	C. Scent
13	Disturbance from food scent
14	Disturbance from chemicals/medical substances
15	Disturbance from outside
	D. Gardens and the outdoors
16	The lack of green area
17	The lack of outdoor area for leisure
	E. Interior environment
18	Small window that is not suitable for sightseeing
19	The unpleasant scenery from the window
20	The lack of combining nature with the interior design of patient's room

Table 2: Important environmental aspects for evaluation

No.	F. Quietness
21	The noises from the staff
22	The noises from the conversation of the visitors

23	Noises from outside
	Environmental Issues
	G. Spatial layout
24	Crowded resting area
25	Distant medical counter from the patient's room
26	Unorganized items
27	The lack of privacy of patient's room
28	Crowded patient's room
29	No clear signs for telling paths
	H. Comfortable atmosphere
30	Unmitigated atmosphere in the medical ward
31	Improper bed that causes stiffness
32	Improper chair that causes stiffness
33	Declined floor, wall and ceiling
34	The lack of convenient items like TV, book, and magazine
	I. Art and positive distractions
35	The lack of using artworks for interior design
	J. Colour
36	The colours inside the building that cause depression
37	overall environment

The questionnaire is evaluated by using the Cronbach's Alpha Coefficient from 50 samples of the customers before being used for researching. The ratings of the questionnaire is 0.85, which means this questionnaire is reliable (more than 0.8)

5. Results and Discussions

The result of comparison on the evaluation of environmental issues from patients and visitors using t-test for Independent is as followed. (Table 3)

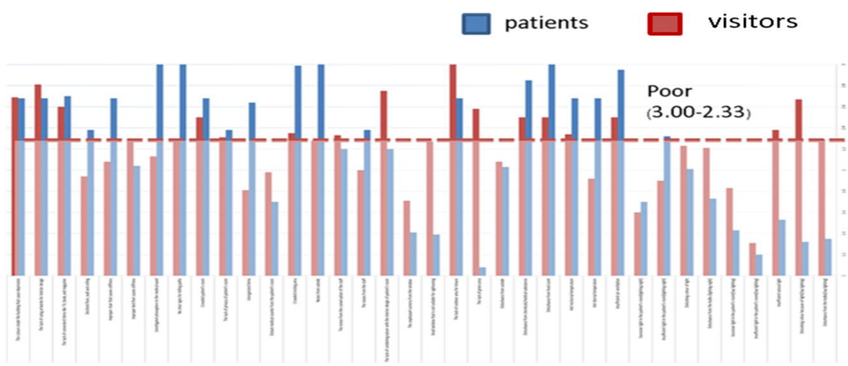

Figure3: Poor level environmental issues

Table 3: Results of t-test Independent for opinion differences among the patients and visitors

No.	Environmental Issues	Patients			t-test		Visitors		
		S.D.	mean	Criteria	t	p	Criteria	mean	S.D.
A.	A. Lighting								
1	Disturbance from the bulbs	0.48	1.35	Good	-10.7	.00*	Fair	2.29	0.46

	(Day lighting)								
2	Disturbing colour because of light (Day lighting)	0.47	1.32	Good	-15.3	.00*	Poor	2.67	0.48
3	Insufficient natural light (Day lighting)	0.56	1.53	Good	-6.48	.00*	Poor	2.38	0.79
4	Insufficient light in the patient's room(Day lighting)	0.44	1.2	Good	-1.3	0.19	Good	1.31	0.47
5	Excessive light in the patient's room(Day lighting)	0.60	1.43	Good	-2.51	.01*	Fair	1.83	1.00
6	Disturbance from the bulbs (lighting night)	0.96	1.73	Fair	-3.7	.00*	Fair	2.21	0.46
7	Disturbing colour of light(lighting night)	0.12	2.01	Fair	-3.45	.00*	Fair	2.23	0.43
8	Insufficient light in the patient's room(lighting night)	0.50	2.32	Fair	3.3	.00*	Fair	1.9	0.81
9	Excessive light in the patient's room(lighting night)	0.96	1.7	Fair	0.59	0.55	Good	1.6	0.87
B.	B. Fresh air								
10	Insufficient air ventilation	0.33	2.95	Poor	4.59	.00*	Poor	2.5	0.62
11	Hot diurnal temperature	0.47	2.68	Poor	5.53	.00*	Fair	1.92	0.87
12	Hot nocturnal temperature	0.47	2.68	Poor	3.79	.00*	Poor	2.34	0.48
C.	C. Scent								
13	Disturbance from food scent	0.00	3	Poor	5.59	.00*	Poor	2.5	0.62
14	Disturbance from chemicals/medical substances	0.36	2.85	Poor	3.56	.00*	Poor	2.5	0.62
15	Disturbance from outside	1.00	2.03	Fair	-0.3	0.76	Fair	2.08	1.00
D.	D. Gardens and the outdoors								
16	The lack of green area	0.40	1.08	Good	-11.8	.00*	Poor	2.58	0.82
17	The lack of outdoor area for leisure	0.47	2.68	Poor	-5.92	.00*	Poor	3	0.00
E	E. Interior environment								
18	Small window that is not suitable for sightseeing	0.54	1.39	Good	-8.3	.00*	Fair	2.27	0.61
19	The unpleasant scenery from the window	0.81	1.41	Good	-1.8	.07	Fair	1.71	0.97
20	The lack of combining nature with the interior design of patient's room	0.91	2.2	Fair	-4.45	.00*	Poor	2.75	0.44
F.	F. Quietness								
21	The noises from the staff	0.91	2.38	Poor	2.74	.00*	Fair	2	0.75
22	The noises from the conversation of the visitors	0.00	2.2	Fair	-1.04	0.3	Poor	2.33	0.48
23	Noises from outside	0.12	3	Poor	10.6	.00*	Fair	2.28	0.46
G.	G. Spatial layout								
24	Crowded resting area	0.12	2.99	Poor	8.2	.00*	Poor	2.35	0.53
25	Distant medical counter from the patient's room	0.96	1.7	Fair	-1.62	0.1	Fair	1.98	0.89
26	Unorganized items	0.49	2.64	Poor	5.85	.00*	Fair	1.81	0.89
27	The lack of privacy of patient's room	0.49	2.38	Poor	0.67	0.5	Fair	2.31	0.59
28	Crowded patient's room	0.47	2.68	Poor	1.67	.09	Poor	2.5	0.62
29	No clear signs for telling paths	0.00	3	Poor	8.8	.00*	Fair	2.27	0.57
H.	H. Comfortable atmosphere								
30	Unmitigated atmosphere in the medical ward	0.00	3	Poor	6.05	.00*	Fair	2.13	1.00
31	Improper bed that causes stiffness	0.20	2.04	Fair	-2.88	.00*	Fair	2.29	0.58
32	Improper chair that causes stiffness	0.47	2.68	Poor	6.94	.00*	Fair	2.08	0.45
33	Declined floor, wall and ceiling	0.49	2.38	Poor	3.31	.00*	Fair	1.94	0.84
34	The lack of convenient items like TV, book, and magazine	0.59	2.7	Poor	0.87	0.38	Poor	2.6	0.64
I.	I. Art and positive distractions								
35	The lack of using artworks for interior design	0.47	2.68	Poor	-1.73	0.08	Poor	2.81	0.39

Table 3: Results of t-test Independent for opinion differences among the patients and visitors

J.	J. Colour								
36	The colours inside the building that cause depression	0.47	2.68	Poor	-0.12	0.9	Poor	2.69	0.59
37	Overall environment	0.74	2.34	Poor	-0.26	0.79	Poor	2.38	0.76
* significant at 0.05 level.									

The result suggests that the condition of the environment, as evaluated by patients and visitors, is poor (score 2.36).The patient group evaluation results show that there are nineteen aspects that fall into poor evaluation level which include: insufficient air ventilation, hot diurnal temperature, hot nocturnal temperature, disturbance from food scent, disturbance from chemicals/medical substances, the lack of outdoor area for leisure, the noises from the visitors, noises from outside, crowded resting area, distant medical counter from the patient's room, unorganized items, the lack of privacy of patient's room, the lack of clear signs for telling paths, unmitigated atmosphere in the medical ward, improper chair that causes stiffness declined floor, wall and ceiling, the lack of convenient items like TV, book, and magazine, the lack of using artworks in interior decoration, the colours inside the building can cause depression.

While there are fifteen issues that are evaluated as poor by the visitors which included: disturbing colour of light(day lighting), insufficient natural light(day lighting), insufficient air ventilation, disturbance from food scent, disturbance from chemicals/medical substances, disturbance from outside, the lack of green area, the lack of outdoor area for leisure, the lack of combining nature with the interior design of patient's room, the noises from the conversation of the staff, crowded resting area, crowded patient's room, the lack of convenient items like TV, book, and magazine, the lack of using artworks for interior decoration, and the colours inside the building can cause depression.

The comparison on the evaluation of environmental issues from patients and visitors varies at significance level of 0.05 with 11 exceptional issues which are insufficient light in the patient's room, excessive light in the patient's room, disturbance from outside, The unpleasant scenery from the window, the noises from the conversation of the staff, distant medical counter from the patient's room, the lack of privacy of patient's room, the lack of convenient items like TV, book, and magazine, the lack of using artworks for interior decoration, crowded patient's room, and the interiors colours can cause depression. There is no significant differences of opinions on these 11 issues.

6. Conclusion

The improvement of environment in the medical ward has improved to a certain level that satisfies the customers. There should be the consideration of the different comments from both sides, as the result of the study shows that the majority of users, both patients and visitors, have different views in many aspects. The environmental adjustment in the building can be completed by dividing the analysis and the adjustment according to main users' preferences. For example, in order to improve the environment of patients' rooms, the opinions of the patients should be the main concern, as the majority of the area users is patients. On the other hand, visitors only spend one to five hours a day for the visit. If the evaluation from the main users has been analyzed for finding the average value, the result of evaluation might be incorrect and the improvements cannot satisfy both patients and visitors.

6.1 Proposing tentative guidelines based on the principle of healing environment

From the study the researcher found out difference opinion between both user of patients and visitors the first difference is the lighting colour that do not case the relax anion feeling (Day lighting no.2) Which the patients evaluated as good but the visitors evaluated it as poor. This study showed that the word uses day light from fluorescent lamp.

As from the in depth interview of 10 patients, they all preferred the day light that is presently used in the ward due to the clarity of vision and most patients said they also use it at their residence . This was opposed by the visitor's opinion, they evaluated it as poor which was supported by 7 in depth interview of the visitors. They claimed the day light gives old and dull feeling and it has made the ward, the office and the operation room unrelated and seemed old. One of the visitors has suggested using warm tone lighting in the hospital to promote the feeling as if they are in a hotel or resort that promotes relaxation.

Figure 4: Fluorescent lighting and Natural lighting in the building

The second difference of Insufficient natural light (Day lighting no.3), the patients have evaluated it as good on the other have the visitors gave it a poor, from the study, the lighting of the patients word have high intensity from the window from 6am-6pm at 512.13 lux. Also in depth interview of 10 simple patients showed the positive feeling towards the natural lighting. Some performed the natural lighting from the beds in control, the visitors' comments were unfavourable, they said that natural light am disturbed the patient and it gives a humid feeling

The above information obviously showed that patients opinion as the resident who are cared for in the ward for average of 5-7 day is opposed to the visitors as a guest who come to the visitors who come to the building for 1-3 hours per day.

It is cleared that the patients as the resident experienced the ward living more than the visitors. So there are different in evaluated and scale rating the real exposure to hospital ward of patients can be varied from the visitor. In the near future of hospital environmental design show include the user expectance into the design due to the real experience by patients might be difference from the visitors They sped only 1-3hr/day on this information is adopted to be use in hospital design the hospital will be able to serve the real needs of all parties 62 further suggestions

6.2 Future of suggestion

This research is the pilot study and the initiative for development of design theory for Thai hospital, We need to consider south east Asia demographic, geography, animate and social regions. These elements were distanced from the western design who claimed that colour of lighting can create the wearing feeling. however, the patients in this study has recommended and preferred the day light to warm lighting the warm lighting theory claimed that it can create the relation better than day light this proved that the users behaviour in each regions and geographies area have distinctive preference so, The researcher would like to suggest for further investigation of demographic area, geography, climate, social, religion and tradition into implementation with evidence – based design for South East Asia hospital.

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The Workplace for Researchers – Enhancing Concentration and Face-to-face Interaction

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Abstract

It has traditionally been assumed that academic research is lonely work by its nature, including concentration, privacy and an "ivory tower" kind of work environment. However co-operation, communication and interaction are important parts of the research processes too. Academic workplaces need to support new ways of working, which requires effective support for both interactive and individual work. In this paper we discuss about academic research work and its requirements. More precisely the goal is to investigate the workplace requirements of academic workplaces for researchers: What is required from workplaces that support both concentration and face-to-face interaction and are there any differences between generations in regard to this?

The empirical data for analysis was gathered by a national survey conducted in Finland. The number of responses from researchers was 1 020. The response rate in the survey was 10%. The sample was linearized to match the demography of researcher population. It was assumed that the low response rate would not cause bias to the difference between different age group for respondents compared to non-respondents. Open-ended questions about the research environment accumulated answers, which were analysed and clustered. Three categories identified were demand for workplaces supporting: concentration, face-to-face interaction or both. Deeper analysis was conducted by analysing answers to the third category (workplaces that support both concentration and face-to-face interaction) in the age groups ≤ 30 years old and > 50 years old. The analysis indicates that the older generation requires spaces that support both formal and informal interaction with internal and external partners, interdisciplinary and international interaction. The younger generation mainly prefers spaces in which to concentrate on one's work and to interact with one's research group.

The weakness of this study is the generalizability of the result to other cultures, since this survey was conducted in Finland. Some concern also arises since the response rate was low. The practical implications from this study reveal several topics worthy of future study. The multigenerational academic workplace can be investigated more thoroughly from both the perspectives of the design and use of the workspaces.

Keywords: academic, workplace, face-to-face interaction, concentration, generations

1. Introduction

Fostering collaborative partnerships in scientific research has emerged as a critical imperative for academic researchers. However the traditional research setting is connected to isolation and concentration – to the "ivory tower" of researchers. The increasing volume and accelerating pace of knowledge creation has transformed the research process to the point where one needs to redefine the requirements of physical workplace solutions in academic workplaces.

This paper aims to identify the social and spatial requirements for academic workplaces for researchers in universities – how academic research work is supported by diverse spatial and social solutions in office spaces. More precisely the goal is to describe what is required from workplaces for them to support both concentration and face-to-face interaction and to discover whether any differences in requirements exist between generations.

The literature review presents previous research about places for knowledge creation and requirements for academic workplaces. The method and data analysis section describes how the research data was gathered and analysed. The final section – the results and discussion – presents the findings.

2. Literature review: Academic workplaces

Academic research creates new knowledge. Knowledge is created through interactions amongst individuals or between individuals and their environments, rather than by an individual operating alone (Nonaka et al., 2001). Seeing the knowledge creation process as a spiral model – where tacit and explicit knowledge are in continuous interaction – was first described by Nonaka and Takeuchi (1995). The single most important factor shaping the quality of knowledge is the quality of place (Nonaka et al., 2001). Agnew (1987) defined the fundamental aspects of place as a "meaningful location, which has a location, locale and a sense of place."

The workplace has a role in each step of the process of knowledge creation and the requirements towards workplace's nature and characteristics differ accordingly. The demands for the nature of the workplace are presented in a classification system developed by Nenonen (2005). The physical, social and virtual work environments are the matters of interest.

The connective place is an environment that supports the exchange of tacit knowledge in the socialisation phase of knowledge creation. It is an interactive, open and cosy place with limitless information, which belongs to users. **The structural place** is an environment that supports the conversion of the tacit knowledge into the explicit knowledge; the externalisation phase of the knowledge creation process. The dynamic atmosphere of the place might be conservative and dedicated to task performance, like that of a formal meeting room. The virtual workplace serves as a facilitator; it is a technical source of information. **The formal place** is an environment that supports the analysis of explicit knowledge in the combination phase of knowledge creation. This place is more for individual and private work performances. The place supports the role of one individual, offering privacy and supporting concentration. The virtual workplace is dedicated to information. **The reflective place** is an environment that supports the sharing of explicit knowledge and transforming it into tacit knowledge in the internalisation phase of knowledge creation. The place supports the sharing of knowledge and creation of innovations. Internal privacy is respected. The place empowers reflection and relaxation. The virtual workplace facilitates the sharing of information and the transformation of it into new knowledge (Nenonen, 2005).

Harrison and Cairns (2008) presented office types developed to support academic work:

- Studies: Small private offices to support individual work and private meetings with lounge areas for more informal discussion.
- Quarters: Small private familial workspace for around four to seven people. These environments can support the building of relationships and provide both companionship and privacy.
- Clusters: Group-centred workspaces for clusters of staff with common interests or identities. This environment can support collaborative work on various scales. Workspaces are semi-open, flexible spaces for teams of six to twelve people.
- Hubs: Hub workspaces are larger open plan work environments to support teamwork, mentoring and awareness of others. Visibility and connectivity are key.
- Clubs: Clubs provide a non-territorial workspace in which to connect with colleagues and peers while working autonomously, enabled by mobile technology and working practices.

Studies and quarters are work environments that are protected from the external world and can be considered to support the requirements of a formal place. Clusters can be considered reflective places. Hubs and clubs are more open to the external world and can be considered connective places. The physical form of an office does not dictate the nature of it, since the form only shapes part of the atmosphere. Many of the office types can contain several of the elements required for each stage of knowledge creation.

In many regards, the traditional cellular office, with its formal nature, may be considered the ideal academic work environment. It allows its occupant to switch between activities that require quiet concentration and reflection, such as preparing lecture notes and writing papers, and noise generating activities, such as telephone conference calls, meetings and collaborative work (Pinder et al., 2009). For an academic, work on a task that requires concentration, such as writing a paper, is likely to take place over a number of days or even weeks and likely to be interspersed with work on other tasks. Any structuring that the academic has imposed on their work environment in relation to the task (i.e. piles of paper and so on) may, if left in place, facilitate its later resumption – in effect allowing them to "dip in and out" of the task more easily (Kirsh, 2001; Malone, 1983).

Harrison and Cairns (2008) conducted a survey on employees across seven academic institutions. Their results indicate that the staff generally considered that the most important quality of the work environment is that it is "a place in which you can concentrate on your work". The second most important feature of a workplace was it being “a place that supports quiet reflection and analysis”.

Individual face-to-face interaction is the only way to capture the full range of physical senses and psycho-emotional reactions (such as ease or discomfort) that are important elements in sharing tacit knowledge (Nonaka et al., 2001). Face-to-face interaction makes it possible for two people to send and receive messages simultaneously and to exchange both the verbal and nonverbal messages that result in shared meanings. Lansdale et al. (2011) studied interaction in research environments and defined face-to-face interaction to be two or more people engaging in reciprocal exchanges. Haynes (2008) studied office productivity, interaction and distraction. Interaction was found to be beneficial and distraction was reported to be negative. Heerwagen et al. (2004) state that face-to-face interaction is the most common form of interaction and communication in a variety of work settings. According to study by Melin (2000), increased knowledge, higher scientific quality and the generation of new ideas were the main benefits generated from collaboration. Although collaboration is defined as “working together”, effective collaboration entails both individual focused tasks and interactive group work (Heerwagen et al., 2004). According to a study by Lee and Bozeman (2005), more than half (51.1%) of research time is spent with colleagues in the immediate work group, with the next largest amount of time (15.9%) being devoted to working alone.

Finding the right balance and types of support for individual and group work requires an understanding of both social and cognitive processes (Heerwagen et al., 2004). Danielsson and Bodin (2008), and Been and Beijer (2014) have compared different office types and their capacity to support concentration and interaction. It would seem that one particularly effective solution to the quiet/interaction dilemma is the combi-office where each academic has their own small study, located off a shared open space that includes an array of breakout areas and additional storage, as well as a kitchen, a printer hub and a number of bookable meeting rooms (Pinder et al., 2009).

The Activity Based Working approach is regarded as one of the most advanced concepts (Ross 2010). It is supported by work environments that combine hot-desking with a variety of workplaces designed to support different types of activities (Hoendervanger, 2015). Appel-Meulenbroek et al. (2015) describes that the employees who work in activity based working environment are more satisfied with seclusion rooms, climate, décor, cleanliness and leisure compared to ones in traditional work environments.

Rothe et al. (2012) studied the differences between age groups in their workplace preferences. Younger groups preferred work environments that support teamwork, social interaction and innovation within the organization. Older groups preferred more networking possibilities with other interest groups within the building. The virtual environment and mobility are, in general, valued more among the younger respondents while personal services and being able to adjust the indoor climate are more important to the older groups. The smallest differences were found concerning privacy (Rothe et al., 2012).

Lee and Bozeman (2005) studied the differences between age groups in academic settings. It seems reasonable to expect that collaboration would be a different experience for tenured older faculty and research group leaders than for untenured young faculty, postdoctoral researchers or graduate students. A collaboration that is quite productive for an experienced young researcher may prove “inefficient” for the mentor (Lee and Bozeman, 2005). Pinder et al. (2009) point out that the starting point of an academic career – doctoral research – is largely a solitary activity and an individual achievement.

Pinder et al. (2009) argue that if efforts to reduce occupancy costs by ten percent result in even a one percent reduction in the income-generating potential of an academic (through lost productivity and motivation), then the benefits of the space efficiencies will be lost (Pinder et al., 2009). This underlines the importance of understanding the consequences each design solution has on productivity. To conclude the existing literature and research overview one can state that the discussion about both academic and office environments is connected to the diversity of workplace solutions as well as to the different ways of using the workplace. There is an increasing emphasis on supporting both individual and collaborative work processes. In the next chapters the emphasis is on increasing understanding of the demand for supporting both the concentration and face-to-face interaction that researchers are presumed to require from office premises. A research gap for research on the academic knowledge workplaces of different generations can be found. Is a formal or informal environment better for face-to-face interaction? Do researchers prefer internal interaction with their team or do they yearn for interaction with external partners, interdisciplinary interaction or international interaction. Is face-to-face interaction preferred compared to interacting by virtual services? Are the requirements the same for a young researcher compared to an older researcher? Are any differences aligned with the preferences of non-academic knowledge workers?

3. Method and data

3.1 Survey

The empirical data for analysis was gathered by an online survey conducted by University Properties of Finland in ten Finnish universities in 2013. Both the students and employees of ten universities were invited to answer an online survey through an invitation sent by email. In the survey there was a set of open-ended questions about the research environment. One thousand and twenty researchers answered the questions. Their background information is presented in Table 1.

Table 1: Background information on the 1 020 respondents to the open ended questions sent to researchers

Gender \ Age	≤ 30	31–40	41–50	> 50
Woman	165	241	99	80
Man	144	153	74	64

The response rate of the researchers was 10%. The sample was linearized according to both gender and age to match the demography of the researcher population. After linearization the sample size was 390 and distribution for each age group and both genders was the same as the total population of researchers in ten universities. The sample size exceeds the target sample size of 385, which was determined necessary for a margin of error of five percent and a confidence level of 95% with a total population of 10 000 (Holopainen and Pulkkinen 2014).

Questions about the research environment accumulated answers about the requirement for an office's ability to support concentration and face-to-face interaction. The first question was connected to description of the actual workplace and the second question was more about the ideal workplace for research work.

3.2 Data analysis

The data analysis included five phases. In the first phase answers were analysed regarding the aspirations for the workplace supporting concentration and face-to-face interaction. Data was analysed by clustering responses according to their thematic similarities and differences. Categories were identified concerning demand for the workplace to support (1) concentration, (2) face-to-face interaction, (3) both 1 and 2 (4) neither 1 nor 2. In this phase a more specific coding protocol (Saldaña 2013) was also developed:

- Category 1 – Concentration. Codes: "private", "a private room", "concentration", "quiet", "peaceful", "one's own work", "my work", "my own", "focus", "disturbance", "interruption", "voice", "noisy".
- Category 2 – Face-to-face interaction. Codes: "shared space", "face-to-face interaction", "teamwork", "team members", "discussion", "reflection", "collaboration", "share thoughts", "group", "bounce ideas", "opinion exchange", "cooperation", "new ideas".
- Category 3 – Both concentration and face-to-face interaction. Codes implying both concentration and face-to-face interaction.
- Category 4 – Neither concentration nor face-to-face interaction. No codes.

In the second phase clustering was implemented by a three-member research group following the protocol developed. The clustering required some intuitive evaluation keeping in mind the goal of finding out what respondents prefer instead of what they will settle for.

In the third phase the sample was linearized to match the researcher population in ten universities. Elimination of the respondents who were over-represented was executed using random numbers. In the fourth phase each category was divided into sub-groups by age.

In the last phase, phase five, the aim was to get a better understanding of the requirements of younger and older researchers. Thematic analysis was conducted by analysing the answers in Category 3, requiring the support of both concentration and face-to-face interaction, in two age groups. The age groups analysed were ≤ 30 years and > 50 years. It was assumed that the low response rate would not cause bias to difference between the age groups of the respondents compared to non-respondents. Analysis was conducted by allocating the responses according to a framework about the nature of places required for the different stages of knowledge creation. The four categories used were connective, structural, formal and reflective places and their nature (Nenonen, 2005), and they are presented in the literature review. The responses were analysed from the point of view of the framework and synthesis of the requirements was developed for each place in both age groups. The figures presented for phase five in Table 2 exceed the amount of respondents because the requirements for physical, social and virtual environments are counted in sum. All the phases of data analysis are presented in Table 2.

Table 2: The phases of analysis

Category / *Phase*	*Category 1 – Concentration*	*Category 2 – Interaction*	*Category 3 – Both*	*Category 4 – Neither one*	*Total*
Phase 1: Thematic clustering	*n = 135* *20%*	*n = 121* *18%*	*n = 419* *62%*	*n = 345*	*n = 1020* *n= 675 100%*
Phase 2: Coding	*n=115* *17%*	*n=120* *18%*	*n=440* *65%*	-	*n = 675* *100%*
Phase 3: Linearization	*n = 55* *14%*	*n = 62* *16%*	*n = 273* *70%*	-	*n = 390* *100%*
Phase 4: Age-groups					
Age ≤ 30	*n = 15* *17%*	*n = 20* *23%*	*n = 52* *60%*		*n = 87* *100%*
Age 31–40	*n = 17* *13%*	*n = 19* *15%*	*n = 94* *72%*		*n = 130* *100%*
Age 41–50	*n = 9* *12%*	*n = 11* *14%*	*n = 58* *74%*		*n = 87* *100%*
Age > 50	*n = 11* *12%*	*n = 12* *13%*	*n = 72* *76%*		*n = 95* *100%*
Phase 5					
Thematic clustering	*Connective*	*Structural*	*Formal*	*Reflective*	
Age ≤ 30	*n = 22*	*n = 19*	*n = 62*	*n = 76*	*n = 52*
Age > 50	*n = 51*	*n = 47*	*n = 77*	*n = 93*	*n = 72*

In terms of reliability, one aimed to increase it during analysis (Stake 2010, Creswell 2014). Phase one was conducted by only one researcher and the codes were described before phase two. Phase two was peer reviewed and some sections were compared and cross-checked by other members of the research group of three researchers. Linearization was conducted after coding and categorization, to find out the effect it had on the distribution of each category. Internal consistency was analysed in phase four. Distribution in each category was not affected by dividing responses by the gender of respondents. However, age had an effect on distribution. Since data is quantified from quality data by clustering answers, any statistical analysis is merely indicative. Chi-square test did not show any influence by gender on the distribution of clusters: ($\chi^2 2$) = 0.77, df = 2 and p = 0.681. Age had an influence on the distribution of clusters: ($\chi^2$2) = 731.38, df = 6 and p < 0.001. (Holopainen and Pulkkinen 2014).

The main guidelines for the distribution were consistent throughout each phase. The main emphasis was on Category 3, the requirement for the workplace to both support concentration and face-to-face interaction. The fifth phase was first conducted alone and then with a group of three researchers. Thematic clustering turned out to be less straightforward in phase five compared to phase one. It required continuous discussion of the results within the group of researchers conducting the analysis. Several iterations were conducted to confirm the interpretation when reporting the results.

4. Results

Three thematic categories were identified, concerning the demand for the support of (1) concentration, (2) face-to-face interaction and (3) both of the previous points. The majority of academic researchers emphasise the requirement for supporting both concentration and face-to-face interaction.

There are differences between age groups in terms of requirements. The responses from older researchers (> 50) have stronger representation (76%) in Category 3 compared to the responses from younger researchers (≤ 30) (60%). Analysis indicates that the emphasis of the requirements of an academic workplace lie on it being a place that supports concentration and face-to-face interaction. This is visible in Figure 1.

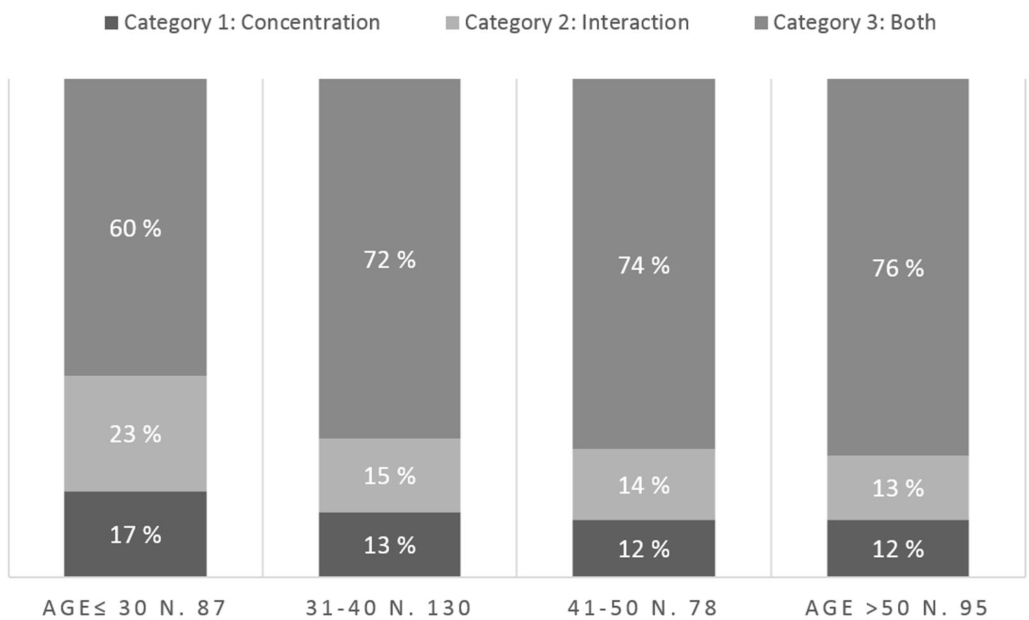

Figure 1: Distribution to Categories requiring support for concentration, face-to-face interaction or both. Each age group had the most requirements for Category 3: on requiring support both for concentration and face-to-face interaction. The older generation were more represented in the Category 3 compared to the younger generation.

The results concerning what is required from workplaces and the differences and similarities between generations are presented in the next chapters. The results are presented from the point of view of the framework used. The framework was about the nature of places required for the different stages of knowledge creation and it was presented in the literature review (Nenonen, 2005).

The majority of both older and younger researchers emphasise the requirement for supporting both concentration and face-to-face interaction. When analysing that from the point of view of the framework, one can state that demands for concentration can be mapped as demands for a "formal place": an internally open formal place supporting individual work. The analysis of requirements concerning face-to-face interaction indicate that most of them can be considered as demands for a "reflective place": an internally open informal place, supporting reflection within one's research group. Analysis of the requirements concerning face-to-face interaction also indicate that some of them can be considered as demands for a "connective place" supporting reflection with external partners in an externally open, informal place, and some of them can be considered as demands for a "structural place" that is externally open and has a formal atmosphere, like a meeting room.

As a similarity, both age groups emphasise requirements typical of internally open places more than they emphasis requirements for externally open places. As another similarity, both age groups emphasise formal and informal places equally. As a difference, analysis indicates that when comparing aspirations for internally open places, young researchers demand them more often. Analysis also indicates that when comparing aspirations for externally open places, older researchers demand them more often than younger researchers. Older researchers seem to require support for a larger interaction network: international connections and interaction outside their research team and university.

As another difference, several older researchers want a private office with private meeting facilities in it, as well as a sofa for rest and as a comfortable reading place. Several younger researchers also describe the same aspiration for the workplace supporting concentration, having meeting facilities and being a place to rest and read, but they indicate that access to shared places with diverse functions would satisfy their needs.

An internal lounge and café spaces dedicated to one's team were the main source of face-to-face interaction, which both age groups suggest to be the primary source of new ideas. The older researchers express their requirements connected to an internally open informal place as a pleasant place for easy access interaction in order to share ideas. Some respondents of the older group mention serendipitous encounters with international visitors to be the source of new ideas. Younger researchers set requirements like having inviting places for interaction and inspiration for new ideas. In such places many younger researchers felt that there is licence to ask for advice.

The majority of older researchers want to have a private room as a space for concentration. Some of older researchers indicate that they just want to have access to a place dedicated to concentration. The majority of older researchers want to have virtual connections to information, such as electronic databases/journals, and services to help using virtual technology. About half of the younger researchers want to have a room of their own; the rest of them want to have access to a peaceful place where they can concentrate. Respondents wish for access to virtual connections to information, such as electronic databases/journals.

More than half of the older researchers require the characteristics of connective place, like landing places (e.g. desks) for national and international partners and services to support virtual communication. Less than half of the younger researchers describe similar requirements to the older researchers. They also ask for possibilities to enjoy the existing social connections of older researchers.

Older researchers require serviced meeting places. Younger researchers want to have high-quality meeting places. Both requirements can be considered as requirements for structural places.

The summary of the results of the last phase are in the following figure, Figure 2.

Tacit to tacit	Socialization	Externalization	**Tacit to explicit**
Externally open, informal	**Connective place** **> 50:** Landing places for national and international partners and services to support virtual communication. **≤ 30**: Senior researcher's international contacts to be shared. Services to support virtual communication.	**Structural place** **> 50:** Serviced meeting places **≤ 30**: High-quality meeting places	Externally open, formal
Internally open, informal	**Reflective place** **> 50:** Pleasant places for easy access interaction in order to share ideas. **≤ 30:** Inviting places for interaction. Inspiration for new ideas. A licence to ask for help.	**Formal place** **> 50** A private office that can fulfil all functions and serviced virtual connections to electronic databases/journals. **≤ 30**: Access to diverse places that can fulfil diverse functions and connectivity to digital environment.	Internally open, formal
Tacit to explicit	Internalization	Combination	**Explicit to explicit**

Figure 2: The requirements of an academic workplace in age groups ≤ 30 and > 50.

5. Discussion and Conclusion

The aim of this paper was to investigate the workplace requirements of academic workplaces for researchers: What is required from workplaces that support both concentration and face-to-face interaction and are there any differences between generations in regard to this? The results are described in the previous chapter and the figure 2 above by using the framework of classification developed to understand the nature of workplaces suited for knowledge creation as supporters for the different phases of knowledge creation. The results in this paper are mainly aligned to the workplace preferences of different generations presented by Rothe et al. (2012) and did not conflict with the literature review about the nature of academic work. The findings in this paper also support previous research about informal face-to-face interaction as a source of new ideas.

The results give new insights into what researchers of different ages prefer in their work environments. The information of user preferences is valuable both for user organizations and facilities management. Based on the results it is evident that the workplace for researchers is no longer only a private office in an ivory tower: one has to pay more attention to the diverse nature of workplaces. Researchers mainly require internally open places but they do also require externally open places. Analysis also indicates that when comparing aspirations for externally open places, demand is stated more often in responses from older researchers, who seem to require support for larger interaction network. Both younger and older researchers require formal places as much as informal places.

As a limitation, this research does not segregate diverse disciplines and the different requirements they might have. In order to gain more knowledge on this matter, a study that segregates diverse disciplines should be conducted. Additionally the cultural context has to be taken into account when generalising the results as this research is limited to ten universities in Finland.

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Observing repair and maintenance costs using the example of the German ecclesiastical building stock

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Abstract

Knowledge of repair and maintenance costs is the major key to optimize the future budget. Cost-optimized real estate management can only be provided if the causal relationship between repair and maintenance costs and their influential factors is known. In times of declining tax revenues and decreasing numbers of church members, church facility managers today are forced to reduce their maintenance budget.

Regarding budget planning, repair and maintenance costs are the most relevant part of buildings' running costs. They can be differentiated in continuous and inordinate costs. For budget planning the inordinate costs are difficult to value, because they are very cost-intensive and appear unsteady.

Since they represent the most important part of the ecclesiastical building stock, the emphasis of this study lies on sacral buildings. Analyzing the inhomogeneity of these buildings regarding building age and size, historical value and specific conditions (e.g., bell-towers) and considering the lack of specific maintenance cost know-how, most important influential cost factors on repair and maintenance costs are determined in the current study. In the first step, a literature review identifies the most common influential factors on maintenance cost of different types of buildings, e.g., office buildings. In the second step, the relevance of these factors is verified and new factors are determined with the help of expert interviews, considering the special conditions of sacral buildings.

The result of the study is a detailed table with the relevant influential factors on repair and maintenance costs (respecting the maintenance strategies, the building characteristics, location, condition, and usage) for sacral buildings. The described study serves as a base for an empirical research with several hundred buildings.

Keywords: Repair costs, maintenance costs, ecclesiastical building stock, sacral buildings, Germany

1. Introduction

Today, the existing building stock in Germany is of increased interest for the ecclesiastical management. In times of decreasing tax revenues the managers are forced to organize maintenance in a way that is optimized with respect to use and costs. Compared to others, managers of ecclesiastical real estate are in charge of a great variance of buildings. In the ecclesiastical building stock, sacral buildings are the most important ones and suffer most from the lack of specialized budgeting know-how for repair and maintenance.

Nonetheless sacral buildings are not only a special type of building: They often have relevance for towns setting and cities' history, too. Some of them have a complex building history that evolved over different architectural styles and periods. Often they are a listed monument. Additional to that, church buildings have special relevant characteristics, which differentiate them from other buildings: Firstly, the towers, mostly with bells, have to be mentioned. Secondly, valuable facilities like historical altars and seats, historical wall paintings and objects of art and also organs have to be considered regarding the interior space.

Systematic real estate management, which could be located in the bishop's administration, is hindered by the owner's structure and tax system. Each parish is the owner of its buildings. It is responsible for the buildings' use and also their maintenance. In case of a larger renovation, they can ask the financial administration of the diocese for a subvention, which in the past was often granted without problems.

Reliable maintenance cost estimation is also needed on the level of a parish. Nowadays, formerly independent parishes are united into bigger ones (Freiburg 2015). Often, such a new parish has to reduce its building stock because of less churchgoers and reduction of the number of priests. It is not possible to offer religious services in every church anymore. Therefore, the number of church buildings has to be reduced.

In times of decreasing taxes, the current subvention system has to be reconsidered. To calculate the future maintenance budget, the facility managers of a diocese have to know which amount of maintenance costs they should expect in the following years (even in a mid-time and long-time perspective). The question underlying is how many buildings they can afford in the next 10 to 20 years and, in consequence, how much financial reserve has to be built up, starting from now.

In this context, cost-optimized real estate management can only be provided if the causal relationship between maintenance costs and their influential factors is known. The first steps (literature review and evaluation of relevant influential factors) of the intended research study are described in the following.

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2. Objectives

The present research study wants to examine relevant causal interrelations that exist between repair and maintenance costs of sacral buildings and their influential factors. Thereby the study takes a wide range of both theoretically and practically relevant factors into account.

In a first step, a literature review gives an overview of different approaches used in former studies. In a second step, relevant factors are carved out by a literature review and are evaluated with expert interviews (Chapter 3). The results are presented in Chapter 4 and summarized in Chapter 5. They serve as the foundation for an empirical study, which is planned. An outlook of the following steps is given in Chapter 6.

3. Literature research and limitations

In the literature, two different main approaches can be found. One group of researchers built on the idea to use maintenance as described in German standard DIN 31051. Other researchers have analyzed occupancy cost as defined in German standard DIN 18960. The latter group investigates operating and repair costs of buildings. Table 1 gives an overview of the two corresponding norms. DIN 31051 describes measures of maintenance like service, inspection, repair and improvement. DIN 18960 is the “classic” norm for cost. It can also be used for life-cycle analysis according to ISO standard 15686-5 “Buildings and constructed assets – Service-life planning, Part 5: Life-cycle costing”, 2008. It points out four different cost groups for the phase of use of a building: The capital costs (cost group 100), facility management costs (200), operating costs (300) and repair costs (400).

Table 1: Structure and content of DIN 18960 and DIN 31051 (German Institute for standardization)

DIN 18960 CG		**Occupancy costs** Cost group	**DIN 31051** No.	**Maintenance fundamentals** Measures
100		Capital costs		
200		Object management costs		
300		Operating costs		
		…		
	340	Inspection and maintenance of building construction	4.1.2	Maintenance Service
	350	Inspection and maintenance of technical installation	4.1.3	Inspection
		…		
400		Repair costs		
	410	Repair costs of building construction	4.1.4	Repair
	420	Repair costs of technical installation		
		…		
	440	Repair costs of fittings, furnishings and equipment	4.1.5	Improvement

Cf: Bartsch et al. (2008), p. 76

As a representative for that group, Bahr et al. (2008) can be mentioned. Their study's aim was to find out a better budgeting method for the public building stock. Four different approaches are considered for determination of maintenance budgets: key data-oriented or history-based budgeting, value-based budgeting, analytical calculation of maintenance budgets, and budgeting by condition-description. All these budgeting methods are analyzed in the BEWIS research project, which investigated maintenance data of 17 existing public buildings. The research team compared real budget with budget calculation using the four different methods. They discovered that all methods fail to satisfy the needs of a public Facility Management (discrepancy up to 200% between the calculated value and real costs). Based on this analysis, a new method called PAPI-Factor was developed. Using replacement value as the base, a literature review was performed and indentified four other cost drivers: Year of construction, type of use, geometrical dimensions (building size dimensions) and quality of construction. Thereby, different factors are developed for continuous and inordinate maintenance measures (Bahr 2008).

Bossmann (2011) adopted this approach for sacral buildings using the example of 30 protestant churches. Analyzing the empirical data with statistical methods, the following significant influencing variables were identified: building age, building geometry, architectural complexity and the status as listed building (Table 2). He changed the calculation base from replacement value to the average maintenance costs per year for all buildings in the portfolio in relation to the building volume.

Table 2: Comparison data base, kind of costs and influential factors I

Study	**Type of utilization and data base**	**Consumption and Costs**	**Influential factors**
Bahr (2008)	17 office and school buildings	Maintenance costs	Building characteristics, Utilization
Bossmann (2011)	30 sacral buildings	Maintenance costs	Building characteristics, Preservation order

Budgeting and benchmarking together is the approach of Stoy and a team of researchers at the Institute for Construction Economics of the University of Stuttgart. They analyzed occupancy cost in empirical studies of more than 100 buildings of the same type. Stoy (2005) analyzed cost data of office buildings, Beusker (2012) used this approach for school buildings, and Hawlik (2015) adapted it to day-care facilities for children. In each case in a first step the researcher developed an expert interview to find out the possible cost drivers for each building type. The interview was structured in four main parts: Building use, building parameters, place related information and strategies. Based on expert answers, a questionnaire was developed and used for collecting building information, also using construction plans. The questionnaire asked for basic data like the age and place-related information, standard and age of technical installation, type and condition of construction and technical installation, and also the size, type, and condition of the related surrounding. Cost data was contributed by the finance department of the respective partners.

Table 3: Comparison data base, kind of costs and influential factors II

Study	Type of utilization and data base	Consumption and Costs	Influential factors
Stoy (2005)	116 office buildings	Capital costs Object management costs Operating costs Total maintenance costs	Strategy Building characteristics Utilization, Location
Beusker (2012)	130 school buildings	Operating costs Repair costs	Strategy Building characteristics Utilization, location
Hawlik (2015)	125 Day-care facilities for children	Personal costs (educational personal) Operating costs Repair costs	Strategy Building characteristics Utilization, Location

By analyzing cost data und building information (use, building parameters, place related information and strategies) with statistical methods, this group of researcher identified the cost drivers for each cost group of DIN 18960. The identified cost drivers for different cost groups are shown in Table 3.

A third group of researchers – especially with focus on benchmarking – analyzed more than hundred buildings, but with less building information. The OSCAR (Office Service Charge Analysis Report, Jones Lang LaSalle) and the FM- Benchmarking report are mentioned as typical representatives. Different factors are used as building characteristics: Building age and floor size (FM Benchmarking), but also numbers of levels and quality standard (particularly air conditioning). The OSCAR also takes the location and the technical standard into account, the FM Benchmarking report refers to the intensity of use and cleaning. An overview is given in Table 4.

Table 4: Comparison data base, kind of costs and influential factors III

Study	Type of utilization and data base	Consumption and Costs	Influential factors
JLL OSCAR 2015	219 office buildings	Capital costs Object management costs Operating cost	Building characteristics Location
FM Benchmarking report 2015	4,578 buildings (different types of Utilization)	Operating costs Repair costs	Building characteristics, Intensity of use and cleaning

4. First results

The current research, the methods introduced by other researchers of the Institute for Construction Economics are continued. In all these studies, the relevant influential factors were identified by an expert interview. Therefore, fifteen experts were interviewed.

The interview was realized with an almost equal number of participants from the ecclesiastical administration (finance and administration experts), architects (specialized on sacral architecture) and others (user, specialist engineers, consultants). Further information concerning the expert positions and experience is shown in table 5.

Table 5: Interviewed experts

Expert	Position/Field	Number of interviews
Administrator	Head of diocesan building management department	2
	Department head of diocesan finance management	1
	Assistant, diocesan administration	2
Architect	Head of diocesan building construction department	2
	Project leader, diocesan building construction department	2
	Owner of an architectural firm	1
Engineer	Owner of an engineer company	1
	Senior researcher, department of architecture	1
User	Priest (experience with building activity)	1
Consultant	Director (consulting agency)	1
	Project leader (consulting agency)	1

The interview was structured in these four parts: Utilization, buildings characteristics, location and strategy. Construction and technical characteristics refer to the German DIN 276. All relevant factors of the above mentioned studies were listed. Additionally, some special sacral buildings related factors were added.

The experts were asked to do the following:

- Identification of cost drivers (from the 40 suggested drivers of literature research, see Table 6)
- Denomination of further cost drivers
- Weighting of each cost driver (on an ordinal scale from 1 to 10)

Table 6: Proposed influential factors and their characteristics

Factor group		Influential factor (Variable)	Characteristic
Use	1	Type of (additional) use	Kind and extensiveness of additional use
	2	Intensity of use	Average services time
	3	Pastoral relevance of the sacral building	National, regional, local relevance
Building characteristics			
Basic information	4	Building age	Year of construction
	5	Architectural design	(Declaration)
	6	Significant extension and transformation	(Declaration)
	7	Preservation order	Yes/no
	8	Building size	Gross floor area in m², Volume in m³
	9	Orientation	East-west, other, no orientation
	10	Typology of cubature	One-wing, multi-wing church, central-plan building, free form
	11	Towers	Number, Height, with/without bells
	12	Building height	Height in m
	13	Compactness	Surface in m²/volume in m³
	14	Cellar/Crypt	Yes/no
Construction characteristics	15	Foundation	Type, material and condition of foundation
	16	External walls	Type, material and condition of
	17	Internal walls	Type, material and condition of internal walls
	18	Ceilings	Type, material and condition of ceilings
	19	Roofs	Construction, material and condition of roofs
	20	Fittings	Type, material and condition of fittings
Technical characteristics	21	Sanitation, water supply system	Standard
	22	Heating system	Energy source, age, standard, condition
	23	Air treatment system	Standard
	24	Power installation	Age, standard
	25	Communication systems	Standard
	26	Transport system (lift)	Exist yes/no
	27	Function-related equipment and fitments	Yes/no, system
	28	Building automation	Yes/no
Fittings/Setting	29	Artistic value	Description, value
Location	30	Outdoor facility	Type, size, condition
	31	Topography	Flat, sloped
	32	Soil conditions	Condition
	33	Building situation	Detached /cramped
	34	Climatic conditions	Temperature, humidity (average)
	35	Cyclical influence	Urban, suburban, rural
	36	Church tax	Tax in €/member in a parish
Strategy	37	Diocesan subvention	Limitation (in €)
	38	Procurement strategy	Declaration of strategy (choice)
	39	Pastoral development concept	Exist yes/no
	40	Coordination effort (church and municipal administration)	High/low effort
New (Expert declaration)		Demanding member (related to the building)	Yes/no
		Engagement of honorary and pastoral members	High/low engagement
		Organ	Exist yes/no, age, value, size
		Requirements of nature protection	Yes/no (declaration)

Not only the factors, but also their measurable characteristics were suggested and also evaluated by the experts. The results are shown in Table 7. Factors that got less than 3 points on average have no or only minimal influence and won't be regarded anymore. Factors with 7 or more points on average are regarded to have high influence, and factors with 3 to 7 points are assumed to have medium influence.

Table 7: Results of expert interviews

Ranking	Influence	Determination of influential factors
1	High	External walls
2		Towers
3		Ceilings
4	Medium	Heating system
5		Artistic value
6		Preservation order
7		Fittings
8		Power installation
9		Foundation
10		Architectural design
11		Roofs
12		Building size
13		Function-related equipment and fitments
14		Soil conditions
15		Intensity of use
16		Building age
17		Church tax
18		Internal walls
19		Typology of cubature
20		Diocesan subvention
21		Procurement strategy
22		Building height
23		Topography
24		Type of (additional) use
25		Climatic conditions
26		Cyclical influence
27		Coordination effort (church and municipal administration)
28		Demanding member (related to the building)
29		Pastoral relevance of the sacral building
30		Engagement of honorary and pastoral members
31		Organ
32		Requirements of nature protection

5. Summary

The experts confirm the relevance of building characteristics. Especially the outer shell - the external walls and the towers - seems to have high relevance regarding the maintenance costs. According to the experts' knowledge, the costs for scaffolds rise exorbitant, with the highness of the towers. Even bells cause additional maintenance costs.

Furthermore, the influence of the ceilings is appraised as high. The interviewees pointed out that the interior situation (design, material, condition, artistic value) of the sacred space has high relevance. Also, the building age, building size (volume), and the status as listed monument are important and have to be considered in a further research. Another important point is the artistic value of the sacral building and fittings/settings.

For years, sacral buildings have been buildings with a low level of technical installation. However, according to expert opinions, it seems that in the future, sacral buildings (that are still intended to be used) will have higher level of technical installations. To provide more comfort for the churchgoers during sacral ceremonies and concerts etc., technical installations become much more relevant. First the heating system has to be mentioned, followed by public address systems (combined with hearing impaired systems) and illumination systems.

Also, the users' behaviour and activity of each parish seem to be very relevant for maintenance strategy and consequently for the costs. According to the experts, there is a great variance of users' demands, which are often the starting point for maintenance and modernization projects.

Regarding the location, the experts affirm the known factors (climatic situation, cyclical influence and soil condition of the building plot). Additionally, the experts specify also the tax income in relation towards the number of members in each parish.

The experts declare that most of the parishes do not have any maintenance strategy: Only in the case of a break down, the need of repair or renewal appears. The diocesan subvention often is the only way to finance big maintenance measures. It is connected with conditions (like financing plan and time interval for defined maintenance measures). A positive cooperation with municipal administration helps the church administration to realize the target project.

The question concerning surroundings was cancelled. It was not possible to define a related zone to the church building. Organs and bells will be considered in the upcoming research.

6. Outlook and conclusion

The presented study is the base of an empirical research. It is intended to collect data of about 400 sacral buildings: Building information, as given by expert interviews, shall be connected with the cost data as provided by church facility management. With the help of statistical methods, the most important influential factors on costs shall be found and evaluated.

The following steps are suggested for the study:

- Transfer of the expert interview results into a questionnaire
- Pilot study with approx. five buildings of every participating diocese to proof the procedure and the questionnaire, parallel collection of cost data
- Adaption of the questionnaire if necessary
- Phase of collecting building and cost data
- Statistical analysis like regression models to develop cost indicators
- Transfer of the theoretical results into practice

The questionnaire will be edit by the architects (building and technical characteristics) and administration stuff (usage, location and strategies) of the diocese. Information about climatic condition, like the average temperature and humidity can be found in climatic publication of meteorological services. The Federal Statistical Office (Destatis) provides indexes for development of prices, which will be used to respect the cyclical influence.

The finance administration of the dioceses will provide cost data. The cost data will include periodic costs (e.g., yearly maintenance service of the heating system) and costs which appear in irregular, often long intervals (e.g., repair and maintenance). The project intends to use cost data of the last five years.

Employing statistical methods like regressions models, the correlation between the costs and the influential factors should be revealed and cost indicators will be generated. The determination of cost indicators requires a consistent definition of the underlying cost data (repair and maintenance costs), a consistent definition of an appropriate reference value e.g. gross external floor area GEFA, and the provision of further descriptions. In a further step, the results will be transferred into practice e.g. by the provision of cost indicators for maintenance measures.

Today, church facility managers do not know their future maintenance budget requirements. This is due to the fact that general information about repair and maintenance costs and their significant influential factors are not available in a structured way. In times of expected decreasing tax incomes and high responsibility for valuable buildings, accurate maintenance planning is needed. The goal of this project is to fill this gap. Finally, this project provides support for church facility managers to calculate the maintenance costs for sacral buildings in a medium and long term perspective.

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Evaluation to Condensation Prevention Performance of Double Glazing Window with Real Scale Test

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Abstract

Condensation prevention performance plays significant role in the improvement in occupants' living satisfaction and reduction of defect. Civil complaint about residential environment such as the condensation problems are rapidly increasing by the growing interest in residential environment from improvement of the quality of life. In the case of double glazing window installed for a expanded balcony apartment, the inside window condensation as well as the complaints about the outdoor window condensation is also tendency to surge. This study shows analysis of TDR(Temperature Difference Ratio) for inside window surface and intermediate space air temperature on according to full scale mock-up test. It is found that Case 4(Low-E is located in outside) only it satisfied the requirements TDR conditions(-15℃) and air temperature in intermediate space was significantly increased. The results of this study can significantly contribute to the improvement in condensation prevention performance.

Keywords: Condensation prevention performance, TDR(Temperature difference ration), Full scale mock-up test, Double glazing window

1. Introduction

Windows have relatively low thermal insulation performance. Thus, a decrease in the condensation prevention performance of windows is highly likely not only to increase the risk of surface condensation but also to cause secondary damages such as the occurrence of fungi and the detriment to finishing materials.

The existing windows mainly serve for heat loss prevention and ventilation. However, residents are increasingly expressing concerns over residential environment with the improvement of the quality of life, and filing complaints with the increases in defects caused by condensation. Besides, complaints are rapidly increasing about the condensation on not only the inside but also, recently, the outside of windows in domestic common housing where double-glazing windows are mostly applied with an extension of balcony.

As window condensation is very easily visible in daily life, it has been the major causes of residents' complaints and the subsequent defect repair cost. Yet, it is difficult to quantitatively assess the cost incurred from window condensation.

So, ‘Condensation Prevention Design Criteria for Common Housing’ was established based on Public Notice No. 2013-854 by the Ministry of Land, Infrastructure and Transport for more than 500-unit common housing effective from May 7, 2014.

However, cost-effective window products are not yet sufficiently developed to realize condensation prevention performance under ‘Condensation Prevention Design Criteria for Common Housing’. Thus, a development of window products to enable cost saving and to meet condensation prevention performance at the same time is emerging as an important issue.

The method for evaluating condensation prevention performance through the existing mock-up test is not consistent with the site conditions and the sizes of windows that apply to real common housing. Consequently, real sites are experiencing condensation prevention performance different from the result of mock-up test.

So, this study intends to test actual condensation prevention performance of double-glazing windows applied to common housing through full-scale performance test, and also to derive an optimal combination to enable cost saving and to meet condensation prevention performance at the same time by inducing an increase in the temperature of air space through the combination of major structural members of the existing windows.

2. Methodology

Full-scale performance test was conducted for a total of 5 cases applied to domestic common housing according to the location of low-e glass and the type of spacer. A performance test was conducted in ‘Condensation Mock-up Laboratory’ in Residential Performance Research Center of S construction company located in Yongin, Gyeonggi-do, using a testing method under KS F 2295 and 'Condensation Prevention Design Criteria for Common Housing'.

2.1 Design Criteria and Evaluation Methods

The location of measurement and the conditions for a test (Area Ⅱ: -15℃) was determined and a test was conducted according to a test method under KS F 2295. 'Condensation Prevention Design Criteria for Common Housing' uses Temperature Difference Ratio (hereinafter referred to as TDR) as the index to evaluate condensation prevention performance. TDR is the relative ratio of a difference between indoor air temperature and the indoor surface temperature of an target part to a difference between indoor air temperature and outdoor air temperature. TDR is calculated according to the following formula and ranges from 0 to 1.

$$\text{TDR} = \frac{\text{Indoor air temperature} - \text{Indoor surface temperature of an applicable object}}{\text{Indoor air temperature} - \text{Outdoor air temperature}}$$

25℃ was set for indoor temperature and 50% for indoor relative humidity as indoor conditions. This test applied –15℃, which is the criterion of area Ⅱ, as outdoor air temperature (Table 1)

Table 1: Criteria for condensation prevention performance by major parts considering areas

Target part		*TDR Value*		
		Area Ⅰ	*Area Ⅱ*	*Area Ⅲ*
Window exposed directly to outdoor air	*Central part of glass*	*0.16 (0.16)*	*0.18 (0.18)*	*0.20 (0.24)*
	Corner of glass	*0.22 (0.26)*	*0.24 (0.29)*	*0.27 (0.32)*
	Window frame and sliding frame	*0.25 (0.30)*	*0.28 (0.33)*	*0.32 (0.38)*

To calculate TDR value on the inside of a window of a specimen, the surface temperature of the total 39 points were measured with addition of 2 points of parts in low thermal insulation to 37 points under 'Condensation Prevention Design Criteria for Common Housing', and, to identify the change in condensation prevention performance according to the change in air temperature of air space, air space was divided into upper part, middle part, and lower part and the air temperatures of each part were measured (Figure 1 and Table 2).

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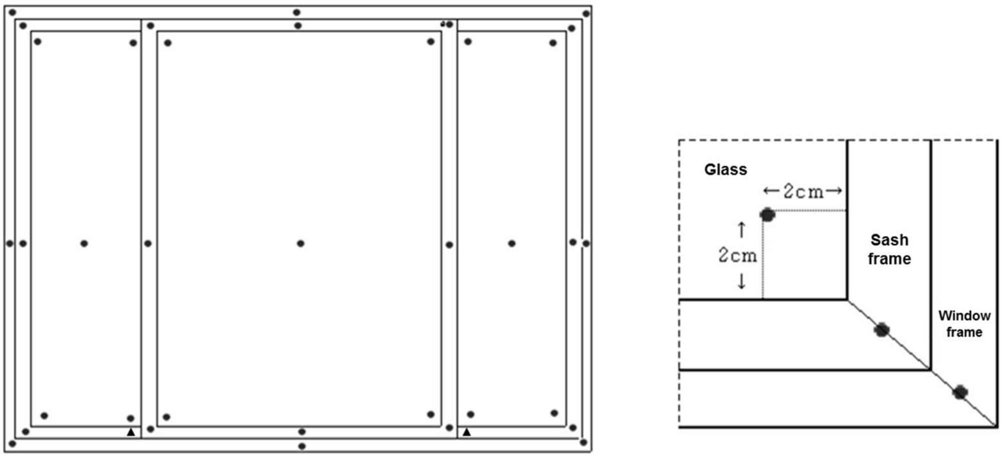
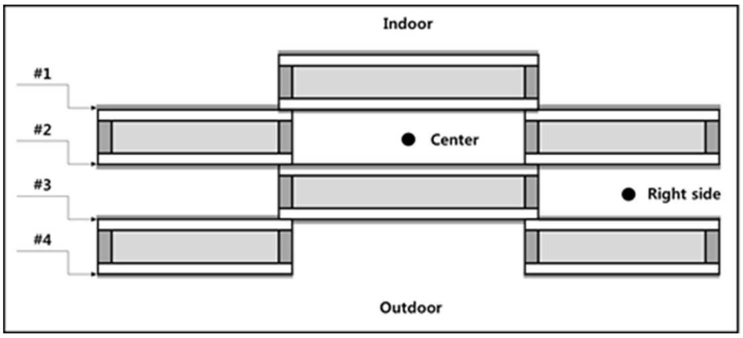
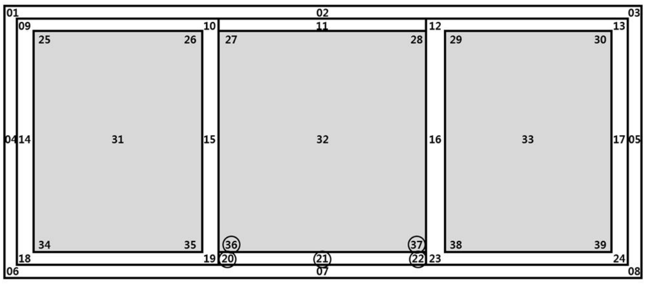


● : **Example of locations for calculation**

▲ : **Addition of locations for calculation (on parts in low thermal insulation)**

Figure 1: Locations for TDR calculation (addition of parts in low thermal insulation)

Table 2: Criteria for condensation prevention performance by major parts considering areas

Classification	*Locations for calculation*
Air space	
Window indoor surface temperature	

2.2 Realization of Full-scale Double-glazing Windows

The method for evaluating condensation prevention performance through the existing mock-up testing is not consistent with the site conditions and the sizes of windows that apply to real common housing. Consequently, real sites are experiencing condensation prevention performance different from the result of mock-up testing.

This experiment tested actual condensation prevention performance of a double glazing window applied to common housing, adapting the conditions of real construction sites and the size of double-glazing windows applied to real common housing (Figure 2 and 3).

[Indoor] [Outdoor]

Figure 2: Full-scale mock-up laboratory: indoor(left), outdoor(right)

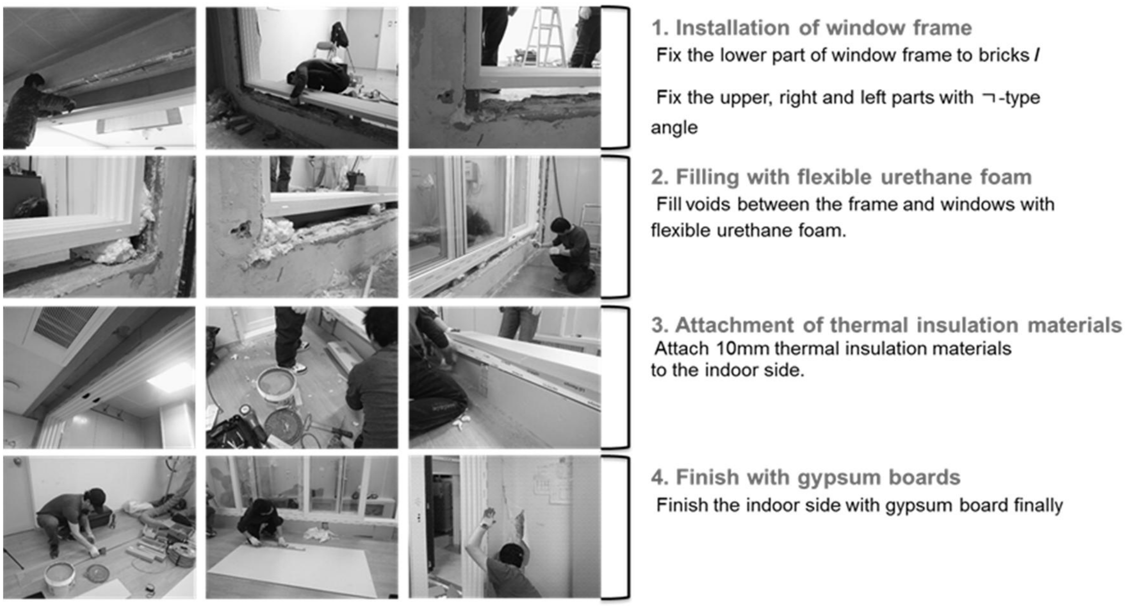


Figure 3: Double-glazing window installation method

2.3 Case

A total of 5 cases were selected according to the locations of low-e glass and types of spacer in the inside and outside window of a double-glazing window. Low-e glass was classified into indoor and outdoor glass depending on the location, and glass spacer was classified into TPS thermal insulating spacer and normal aluminum spacer. The thickness of insulating glass was all 22mm, and 246 mm PVC was uniformly applied to the frames (Table 3).

Table 3: Experiment case summary

Case	*Outside*					*Inside*				
	Thickness	*Specification of glass*	*Location of low-e glass*	*Spacer*	*Type of gas*	*Thickness*	*Specification of glass*	*Location of low-e glass*	*Spacer*	*Type of gas*
Case1	*22*	*5CL+12Air+5CL*	-	*AL*	*Air*	*22*	*5CL+12Air+5LE*	●	*AL*	*Air*
Case2	*22*	*5CL+12Air+5CL*	-	*AL*	*Air*	*22*	*5CL+12Air+5LE*	●	*TPS*	*Air*
Case3	*22*	*5CL+12Air+5CL*	-	*TPS*	*Air*	*22*	*5CL+12Air+5LE*	●	*TPS*	*Air*
Case4	*22*	*5CL+12Air+5LE*	●	*TPS*	*Air*	*22*	*5CL+12Air+5CL*	-	*TPS*	*Air*
Case5	*22*	*5CL+12Air+5LE*	●	*AL*	*Air*	*22*	*5CL+12Air+5LE*	●	*TPS*	*Air*

3. Result

5 cases were selected according to the locations of low-e glass and types of spacer in the inside and outside window of a double-glazing window, window indoor surface temperature was measured through full-scale performance test for condensation prevention, and TDR was calculated.

3.1 Comparison of Air Temperature of Air Space

The mean temperature of air space of Case4 was highest, followed by Case5, Case2, Case3, and Case1 in order. In particular, the mean temperature of air space of Case 4 was around 2℃ higher than that of Case 5 where low-e glass was applied to both the indoor and the outdoor, and rose by around 4℃ compared with Case 3 where only the location of low-e glass was differently applied to the outdoor and the indoor. In other words, as the location of low-e glass is set to the outside window like Case 4, indoor warm air is relatively free to flow in air space, and accordingly convection in air space increases the air temperature of air space (Figure 4).

3.2 Comparison of Indoor Surface Temperature of Parts in Low Thermal Insulation

Using the measurement values of window indoor surface temperature of parts in low thermal insulation, TDR was calculated, and the compatibility was evaluated for the criteria for condensation prevention performance in the criterion of area Ⅱ under ‘Condensation Prevention Design Criteria for Common Housing’ (Figure 5).

According to the result of a review over the compatibility with the criteria for condensation prevention performance, only Case4 and Case5 satisfied the criteria of area Ⅱ under ‘Condensation Prevention Design Criteria for Common Housing’, and in the mean window indoor surface temperature of parts in low thermal insulation, Case4 was highest, followed by Case5, Case3, Case2 and Case1 in order. In other words, condensation prevention performance of Case 4 turned out most excellent. In short, the location of low-e glass set to the outside window brings about an increase in the air temperature in air space, and accordingly the window indoor surface temperature of double-glazing windows increases, which improves condensation prevention performance.

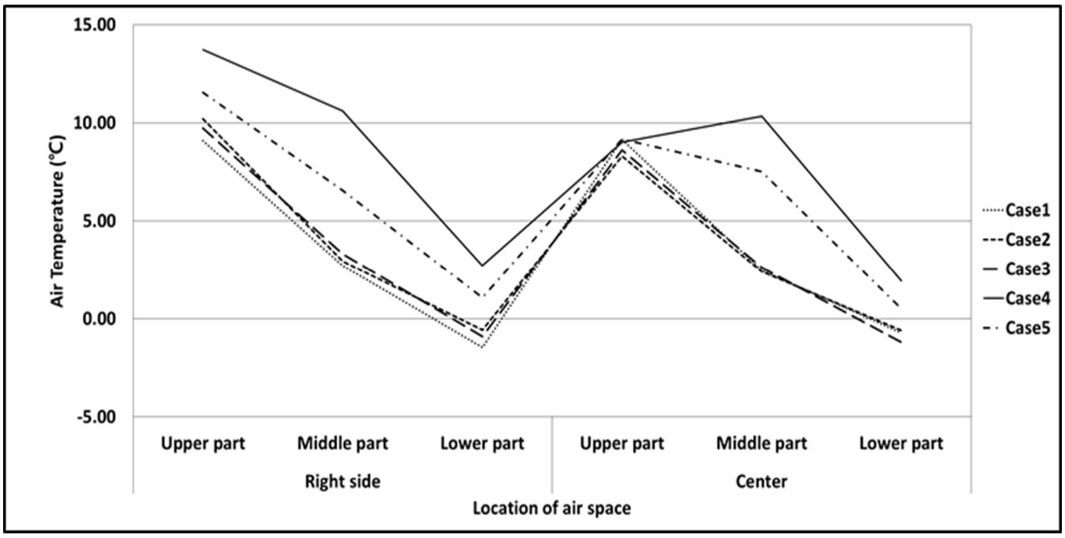


Figure 4: Air temperature in air space

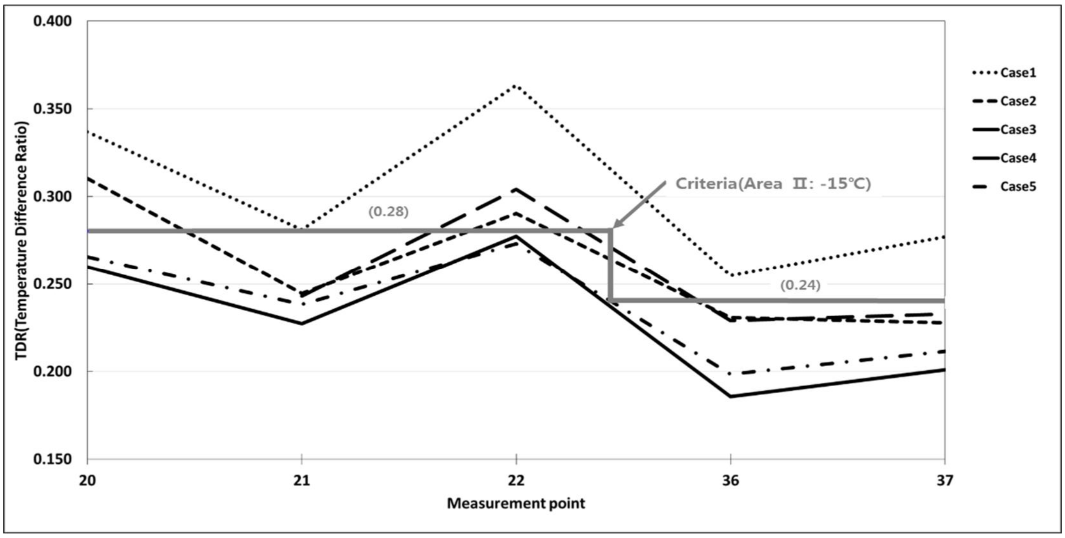


Figure 5: TDR of the inside window (parts in low thermal insulation, #4)

4. Result

Based on the experiment results of this study, it is found that the application of low-e glass to the outside window can increase the air temperature in air space and improve the condensation prevention performance of windows. The specific contents are as follows:

(1) According to the results of a full-scale performance test for the improvement of condensation prevention performance of double-glazing windows in common housing, only Case 4 (the location of low-e glass: the outside window) and Case 5 (the location of low-e glass: the outside and the inside windows) satisfied the requirements of TDR under the criteria of area Ⅱ.

(2) As the location of low-e glass changed from the inside window to the outside window, the air temperature of air space rose remarkably, and not only the inside window but also the outside window was found to have the likelihood of an improvement of condensation prevention performance with an increase in the air temperature of air space.

(3) The condensation prevention performance of Case 4 turned out more excellent than that of Case 5, and both the inside window and the outside window was found to have the likelihood of both an improvement of condensation prevention performance and cost-saving.

Acknowledgements

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The Energy Loads According to Thermal Performance of Window Glazing

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Abstract

Recently, efficient use of energy is more important in buildings. Window is the biggest part of heating and cooling energy loss on building facade. To predict thermal performance of the window systems generally is calculated based on the U-value of window glazing. However, there is a limit to predict the thermal performance of the window systems. Because the solar radiation is coming indoor through the window glass. An SHGC (Solar Heat Gain Coefficient) of window is a determinant of total energy of solar radiation coming indoor in heating and cooling loads. In this study, thermal performance was evaluated according to the U-value and SHGC of window glazing. As a result, this experiment analysed cooling energy consumption reduction effect by window glazing. And it is useful to select a good SHGC (Solar Heat Gain Coefficient) performance of window glazing in the office buildings.

Keywords: Energy Load, Thermal Performance, Window Glazing, SHGC (Solar heat gain coefficient), U-value (Thermal transmittance), VLT (Visible light transmittance)

1. Introduction

Windows are the parts with the largest heat loss among building envelopes and these parts influence up to approximately 40 % of heating and cooling energy. Since the ratio of area occupied by the windows in the building envelope as the preference of occupants such as the assessment of openness and design elements is increasing these days, it is expected that heat loss from the windows will increase gradually.

The thermal performance of windows is decided according to the performance of glass and frame, and especially glass significantly affects the inflow of radiant energy, so it is important to understand and apply the performance of glass properly according to the purpose of building and objective. If glass showing improper performance is applied, it may increase loss of heating and cooling energy in the building.

In this study, the energy simulation was performed in order to identify the influence of glass's thermal transmittance (U-value), solar heat gain coefficient (SHGC) and visible light transmittance (VLT) on the heating and cooling energy loads in the building.

2. Methodology

The performance evaluation was carried out through the execution of the experiment. In the experiment, the energy and environmental performance evaluation was carried out using a chamber where the performance evaluation was available in its own outdoor air environments. The elements for performance measurement through the experiment in this study are as shown in the following Table 1.

Table 1: Performance verification elements of envelope system

Classification	*Contents*	*Note*
Characteristics of seasonal environments	*Evaluation of environmental performance for summer and winter seasons*	-
Characteristics of solar radiation	*Evaluation of influence of solar radiation on the envelope system*	*Analysis of indoor and outdoor solar radiation*
Characteristics of energy saving performance	*Evaluation of energy saving performance according to the envelope system*	*Analysis of energy loads*
Characteristics of surface temperature	*The indoor and outdoor surface temperature of envelope system*	*Analysis of surface temperature*

The performance analysis procedures are as follows;

1) Performance evaluation of envelope system
- Analysis elements: Outdoor and indoor environmental conditions, energy loads
- Comparison and analysis of 3 CASE glazing
2) Performance evaluation of envelope system based on the measured experiment result

- Analysis of indoor temperature, transmission solar radiation, surface temperature, energy consumption
- Performance comparison and analysis of developed double glazing in comparison to the previous double glazing
3) Analysis of mock-up model information and actually measured meteorological data
- Analysis of experimental chamber information for implementing the simulation model
- Analysis and processing of outdoor environmental elements for producing meteorological data
4) Performance analysis of window glazing
- evaluate the effects of double glazing based on the result of experiment measurement

3. The experimental chamber

The experimental chamber used in this study is located in Korea, and the experiment and measurement of up to 3 envelope systems are available. The surface of the experimental chamber used in the experiment except for glass part comes into contact with the monitoring room that collects the experiment result. In order to create actual environmental condition of the building, the lighting fixture and HVAC system are installed inside the Test Room, and the power outlet enabling the use of electricity is also installed. Also, the 1 meter-high plenum has been constructed.

The size of experimental chamber is 9.8 m wide and 7.0 m long, and the wall of the experiment chamber is produced in the sandwich panel made of rigid polyurethane foam (steel sheet 1.0 ㎜ + rigid polyurethane foam 100 ㎜ + steel sheet 1.0 ㎜). The specifications of all heating and cooling systems are same, and two systems in the monitoring room and one system in each Test Room are installed.

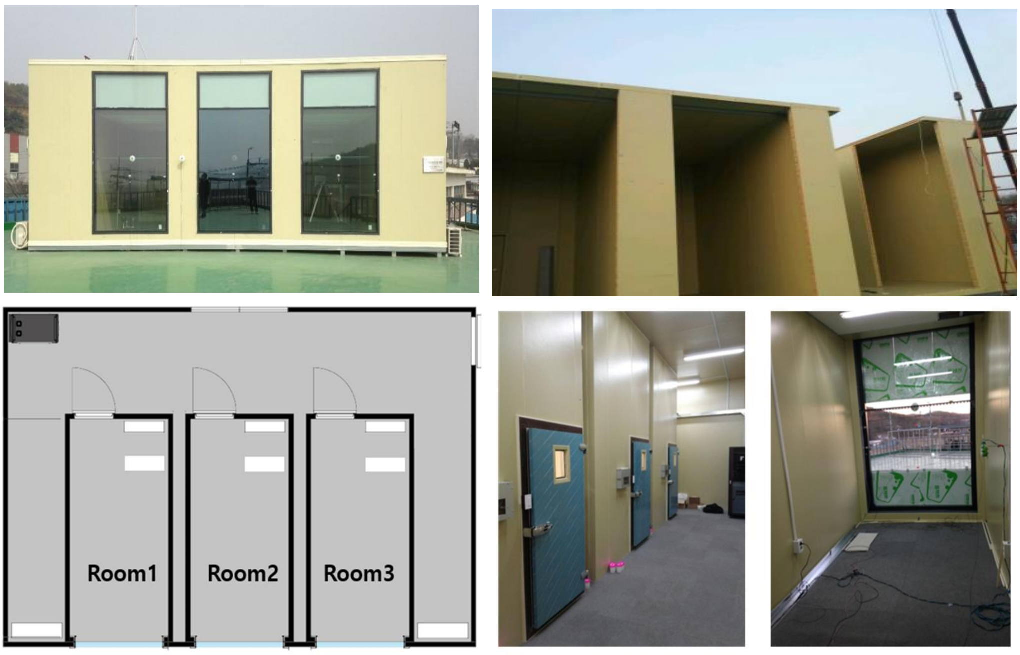

Figure 1: Outside/inside view of experiment chamber

Table 2: The specification of experimental chamber

Type		Details
Location		Paju-si, Gyeonggi-do, Korea
Airt		Full south aspect
Scale	Test Room	2.2 m *4.5 m
	Window glazing	1.8 m *3.8 m

3.1 Operation of experimental chamber

Air conditioning is available in three Test Rooms according to the outdoor environment and the set indoor temperature, and the measurement of indoor environments (temperature, humidity, illumination, air velocity) and energy consumption (power consumption of HVAC systems) according to the performance of envelope is possible. The inverter heating and cooling systems are installed for air conditioning so that temperature control is available, and the energy consumption of each Test Room can be collected accordingly.

3.2 Composition of measurement equipment

The heating and cooling systems that were operated separately were installed on three Test Rooms where the experiment was carried out, and the thermo-hygrometer and anemometer were installed on the air outlet. The surface temperature of each target envelope system for experiment was measured using a thermocouple inside, and the internal air temperature and humidity were measured through the thermo-hygrometer.

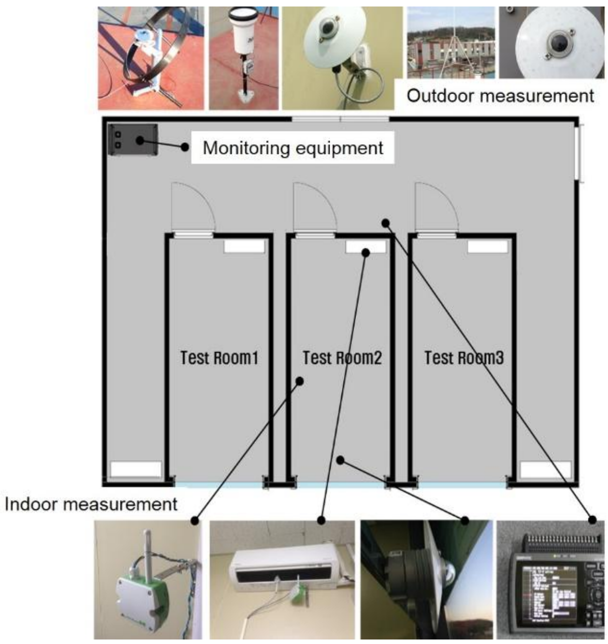

Figure 2: Measurement equipment

The surface temperature on the central part, edge and frame of the target envelope systems for measurement was measured, and the pyranometer was installed inside and outside the central part of glass. The pyranometer (global solar radiation and diffused solar radiation) and anemoscope/anemometer were installed on the roof of the chamber to measure meteorological data. Data measured from the experiment was recorded on the database of distribution box in the equipment room.

3.3 Experiment plan and method

In the experiment, two performance measurement experiments on the envelope system were carried out, and the performance of the selected experiment target was measured by combining various key technologies according to the period. The experiment target and the performance measurement period are as follows.

Table 3: Experiment schedule and details

Classification	*Period*	*Contents*
Envelope system (double glazing)	*Summer*	*Performance evaluation of Low-e coated double glazing according to the performance of U-value/SHGC*
	Winter	
	Summer	*Performance evaluation of glazing according to environment and operating condition change*

In the experiment, the level of influence from indoor environments and performance of the building were compared and analysed by carrying out the experiment and measurement of envelope system meeting the performance standards of envelope specified in domestic construction laws and the envelope system where the technology developed through the research was applied under the same conditions.

In this study, the envelope system was installed on the experimental chamber according to the plan shown above and the performance measurement experiment was carried out, and the performance evaluation was carried out based on the indoor environments and energy consumption according to changes such as summer and winter seasons, and operating conditions of building. The summary of experiment is as follows;

- Outdoor condition: Actual outdoor environments in the experiment area
- Measurement period: August 2014 ~ September 2015
  (Carry out the analysis of experiment result by selecting the period considered to represent the optimum weather conditions during each solar term)
- Set temperature: Varies according to the experiment condition
- Comparison and measurement elements for each experiment target
  - Set indoor temperature
  - Surface temperature of envelope system

- Comparison of internal vertical solar radiation
- Comparison of power consumption according to heating and cooling

4. Results

4.1 Performance of double glazing

The measurement details for the period satisfying the optimum conditions for each solar term during the experiment period during summer and winter seasons were utilized for the experiment result analysis, and the period used for the measurement result analysis is as shown in the following Table 4.

Table 4: Specification of glazing (1st)

Classification		Test Room 1			Test Room 2			Test Room 3		
Window glazing		Single Low-e double glazing			Triple Low-e double glazing			Single Low-e triple glazing		
Spec.	Glass 1 (Outside)	6 ㎜ Low-e (#2)			6 ㎜ Low-e (#2)			6 ㎜ Low-e (#2)		
	Gap 1	12 ㎜ Argon			16 ㎜ Argon			12 ㎜ Argon		
	Glass 2	6 ㎜ Clear			6 ㎜ Low-e (#4)			6 ㎜ Low-e (#4)		
	Gap 2	-			-			12 ㎜ Argon		
	Glass 3	-			-			6 ㎜ Clear		
	Performance	U-value [W/㎡K]	SHGC	VLT	U-value [W/㎡K]	SHGC	VLT	U-value [W/㎡K]	SHGC	VLT
		1.781	0.615	0.729	1.222	0.178	0.277	1.018	0.507	0.611

Table 5: Experiment conditions (1st)

Classification	Summer	Winter
Period	2014.08.31 ~ 2014.09.02	2015.01.10 ~ 2015.01.12
Heating and cooling time	08:00 ~ 18:00	
Set temperature	24 ℃	
Measurement elements	- Meteorological elements: Global solar radiation, diffused solar radiation, vertical solar radiation, outdoor temperature, relative humidity, air volume, air velocity - Indoor environmental elements: Vertical solar radiation, indoor temperature, surface temperature, energy consumption	

The following figure and table show the energy consumption during the measurement period. The measurement result showed that the Triple Low-e double glazing (Test Room 2) was effective for saving energy during both summer and winter seasons. It was confirmed that Triple Low-e double glazing (Test Room 2) showed an approximately 33.7 % energy saving effects during summer season and an approximately 17.4 % energy saving effects during winter season in comparison to Single Low-e double glazing (Test Room 1). On the other hand, it was confirmed that Single Low-e triple glazing (Test Room 3) showed an approximately 11.9 % energy saving effects during summer season and an approximately 9.0 % energy saving effects during winter season in comparison to Single Low-e double glazing (Test Room 1).

Table 6: Energy consumption (summer)

Classification	*08/31*	*09/01*	*09/02*	*Total*	*Reduction Ratio (Compared to Test Room 1)*
Test Room 1 [Wh]	*1,830*	*2,600*	*1,350*	*5,780*	-
Test Room 2 [Wh]	*1,140*	*1,660*	*1,030*	*3,830*	*33.7*
Test Room 3 [Wh]	*1,640*	*2,190*	*1,260*	*5,090*	*11.9*

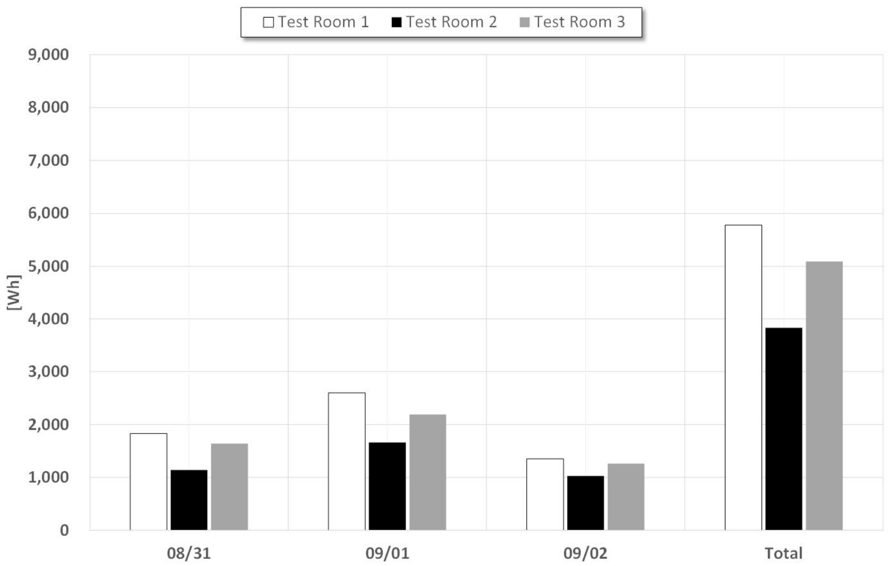

Figure 3: Energy consumption (summer)

Table 7: Energy consumption (winter)

Classification	*01/10*	*01/11*	*01/12*	*Total*	*Reduction Ratio (Compared to Test Room 1)*
Test Room 1 [Wh]	*2,770*	*2,560*	*2,870*	*8,200*	-
Test Room 2 [Wh]	*2,400*	*2,010*	*2,360*	*6,770*	*17.4*
Test Room 3 [Wh]	*2,530*	*2,290*	*2,640*	*7,460*	*9.0*

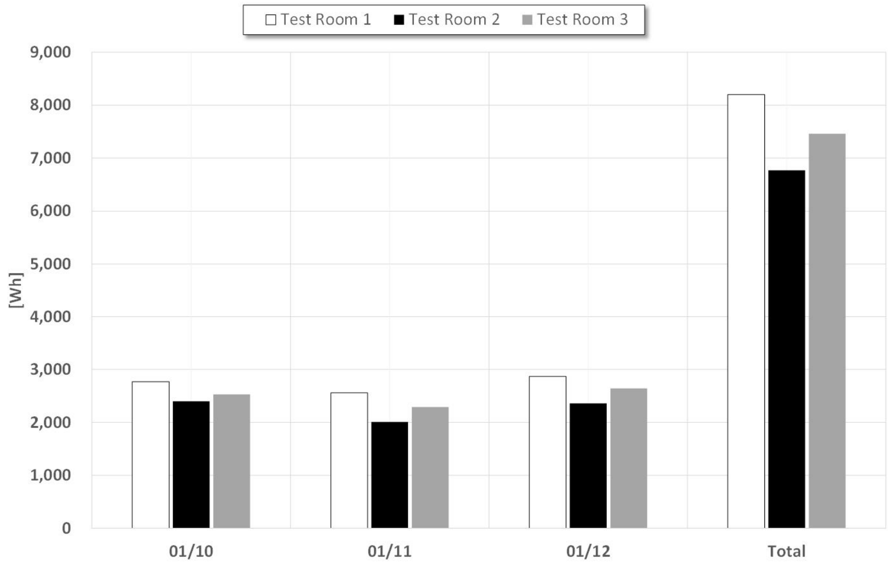

Figure 4: Energy consumption (winter)

4.2 Performance of double glazing according to the indoor operating condition

In order to analyse the performance characteristics of double glazing, the influence of experiment glass on the indoor environments and energy consumption according to operating condition change was evaluated. Especially, the performance to interrupt solar heat and save cooling energy was an important evaluation item so that the experiment measurement was carried out during the summer season. The specifications of applied double glazing and indoor operating condition are as follows.

Table 8: Specification of glazing (2nd)

Classification		Test Room 1			Test Room 2		
Window glazing		Single Low-e double glazing			Triple Low-e double glazing		
Spec.	Glass 1 (Outside)	6 ㎜ Low-e (#2)			6 ㎜ Low-e (#2)		
	Gap 1	12 ㎜ Air			16 ㎜ Argon		
	Glass 2	6 ㎜ Low-e (#3)			6 ㎜ Low-e (#4)		
	Gap 2	-			-		
	Glass 3	-			-		
	Performance	U-value [W/m²K]	SHGC	VLT	U-value [W/m²K]	SHGC	VLT
		1.876	0.589	0.686	1.222	0.178	0.277

Table 9: Experiment conditions (2nd)

Classification		*Period*	*Cooling time*	*Temperature*
CASE 1	*Daytime Cooling*	*2015.08.27 ~ 2015.08.29*	*08:00 ~ 18:00*	*26 ℃*
CASE 2	*24-hour Cooling*	*2015.09.04 ~ 2015.09.06*	*24-hour*	*26 ℃*

In CASE 1, the following figure and table show the energy consumption during the measurement period. The measurement result showed that the Triple Low-e double glazing (Test Room 2) was effective for saving energy. It was confirmed that Triple Low-e double glazing (Test Room 2) showed an approximately 40.3 % energy saving effects in comparison to Single Low-e double glazing (Test Room 1).

Table 10: Energy consumption (CASE 1)

Classification	*08/27*	*08/28*	*08/29*	*Total*	*Reduction Ratio (Compared to Test Room 1)*
Test Room 1 [Wh]	*2,000*	*2,060*	*2,200*	*6,260*	-
Test Room 2 [Wh]	*1,200*	*1,220*	*1,320*	*3,740*	*40.3*

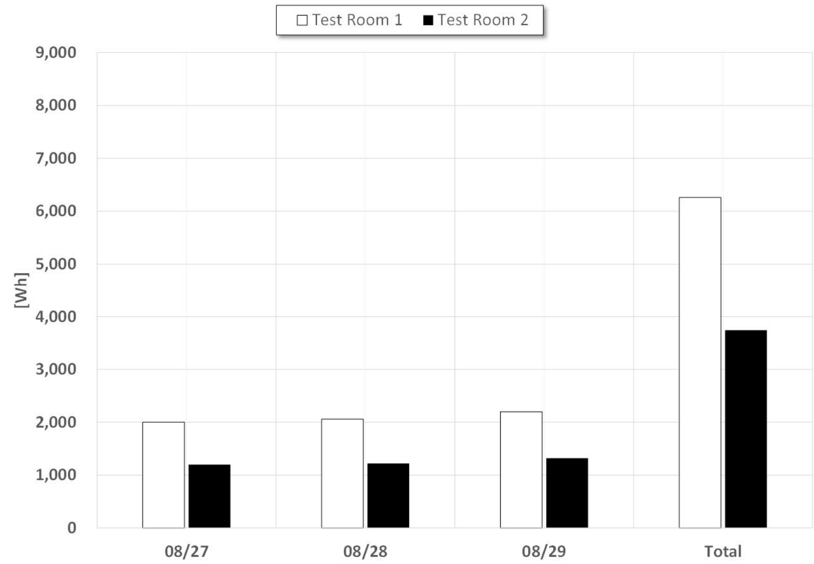

Figure 5: Energy consumption (CASE 1)

In CASE 2, the following figure and table show the energy consumption during the measurement period. The measurement result showed that the Triple Low-e double glazing (Test Room 2) was effective for saving energy just as CASE 1. It was confirmed that Triple Low-e double glazing (Test Room 2) showed an approximately 30.6 % energy saving effects in comparison to Single Low-e double glazing (Test Room 1).

Table 11: Energy consumption (CASE 2)

Classification	*09/04*	*09/05*	*09/06*	*Total*	*Reduction Ratio (Compared to Test Room 1)*
Test Room 1 [Wh]	*2,880*	*690*	*1,560*	*5,130*	-
Test Room 2 [Wh]	*1,890*	*610*	*1,060*	*3,560*	*30.6*

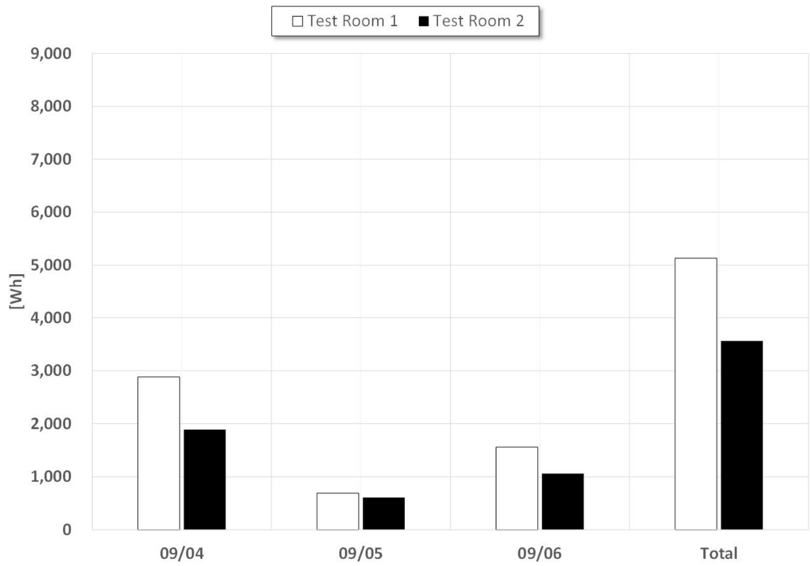

Figure 6: Energy consumption (CASE 2)

5. Conclusions

In this study, the experiment measurement comparing the performance of three types of double glazing in terms of indoor thermal environment and energy saving was carried out. And, energy consumption of window glazing was compared and analysed according to performances such as SHGC (Solar heat gain coefficient), U-value (Thermal transmittance), VLT (Visible light transmittance). The result of this study can summaries as below.

(1) The result of experiment measurement showed that Triple Low-e double glazing (Test Room 2) was effective for saving heating and cooling energy in both summer and winter seasons. It is speculated that the biggest cause is an effect of SHGC (Solar Heat Gain Coefficient) of window glazing (Test Room 2).

(2) Also, it showed an excellent performance to interrupt the effects from outside temperature and incoming solar radiation in summer season, especially.

(3) In particular, it is useful to select a good SHGC (Solar Heat Gain Coefficient) performance of window glazing in the office buildings due to effect of energy saving for daytime cooling.

Acknowledgements

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Energy regulations for housing and the performance gap

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Abstract

The goals of energy saving and CO2 reductions to create an energy neutral building stock seem only to be reached by strict and supportive governmental policies. In Europe the Energy Performance of Buildings Directive and the Energy Efficiency Directive are driving forces for Member States to develop and strengthen energy performance regulations both for new buildings (via building approval procedures) and the existing building stock (via energy performance certificates or labels). The effectiveness of these current governance instruments and their impact on actual CO2 reductions are found to be inadequate for ensuring actual energy performance is achieved. To realize the very ambitious energy saving goals a radical rethink of regulatory systems and instruments is necessary. Building performance and the behaviour of the occupants is not well understood by the policymakers. Alternative forms of governance are needed which have more impact on the actual outcomes. Supportive governance to stimulate near zero renovations in combination with performance guarantees is a promising approach. Furthermore engagement with occupant practices and behaviours is needed. To ensure accurate outcomes-based governance a better understanding of building performance and behaviours of occupants must be incorporated.

Keywords: Building control, building regulations, energy performance, governance, housing stock, occupants

1. Introduction

Climate change mitigation is the most important driver for the ambitions to reduce the use of fossil fuels. There are also other reasons for implementing energy efficiency policies in the EU and its Member States. These include the wish to diminish the dependency on fuel imports, the increasing costs and the fact that fuel resources are limited as well as the impacts on public health. The European building sector is responsible for about 40% of the total primary energy consumption. To reduce this share, the European Commission (EC) has introduced the Energy Performance of Buildings Directive (EPBD) (2010/31/EC) and more recently the Energy Efficiency Directive (EED – 2012/27/EU). These frameworks require Member States to develop energy performance regulations for new buildings, a system of energy performance certificates for all existing buildings and policy programmes that support actions to reach specific goals (e.g. building only 'Nearly Zero Energy Buildings (NZEB)' by 2020 and realizing an almost carbon neutral building stock by 2050). Formulating ambitions and sharpening regulations are relatively easy to do. Technical solutions are currently available to realise the NZEB standard in building projects and an increasing number of NZEB projects are being built. However, substantial evidence exists that mainstream of building projects do not realize the expected energy performance in practice - the building performance gap. What is perhaps even more important in this respect is that the focus predominantly should be on the existing building stock. About 75% of the buildings that will comprise the European housing stock in 2050 has already been built today. Therefore, it is important to get insight in whether the energy performance certificates (EPCs) give reliable information or not. Many researchers have found evidence of the performance gap. This paper elaborates on this subject in next section. This is followed by reference to results of research by Guerra Santin (2009, 2010) focusing on the situation in newly built houses. The fourth section presents the findings of Majcen (2013a, 2013b, 2015) who studied in detail the relation between the energy labels (Energy Performance Certificates) and the actual energy use in dwellings. The fifth section discusses these findings in order to answer the main question: What could be adequate policies and regulatory tools to control the actual energy use in houses? The conclusions are presented in the final section. This paper is adapted from Visscher et al 2016.

2. Performance gap

Building regulations can only partially influence the energy use in a building. The other significant influence is determined by the behaviour of the occupant. The design and materialisation of a building can give better conditions for comfortable temperatures and in multi-occupancy residential buildings the lighting in the communal areas and use of lifts, so these aspects are subject of the regulations. All other forms of energy use in dwellings, (e.g. plug loads - refrigerators, washing machines, computers and cooking appliances) are not controlled by building regulations but covered by other legislation. In general, for older buildings the energy demand for space heating and cooling is dominant. In newer buildings with a very high level of insulation, the energy demand for appliances becomes dominant. Regulations focus on the design and in the best cases there is even some control on the performance of a building at the end of the construction process. However, after the building is occupied there is little if any control over the energy use. The energy calculation methods that are used or referred to in regulations are based on models and parameters of the performance of construction types and materials used an on the expected or modelled heating behaviour of the occupants. It is clear that all these models and assumptions do not accurately portray the actual energy use. This can be called the performance gap. The performance gap occurs for several different reasons: the built artefact does not match the design (substitutions and poor built quality), the mechanical services are not commissioned correctly, the inhabitants do not understand how to operate the building, the inhabitants' behaviour and practices are not as expected. Over the past 20 years numerous studies have compared the actual energy use with the expected or modelled energy use (Branco, Lachal, Gallinelli and Weber 2004; Cayre, Allibe, Laurent and Osso 2009; Sorrell, Dimitropoulos and Sommerville, 2009; Gram-Hanssen, 2010). The general pattern that follows from these studies is that for dwellings with a good (theoretical) energy performance the actual energy use in general is higher than modelled. For the dwellings with a bad (theoretical) performance, the actual energy use is lower. There are various explanations for these findings. For the presumed good performance buildings it is a combination of under performance of the building due to design and construction faults and changed behaviour of the occupants. This is partly the rebound effect (Berkhout et al. 2000; Galvin, 2015): if the conditions improve and the inhabitants think that the building is more energy efficient, they become less careful in their energy use behaviour (e.g. they use higher temperature settings, wear thinner clothing and operate the heating for longer periods). For the 'bad' performing buildings there is also evidence that the quality of the building could be under estimated. The U-values of solid walls in England were under estimated. Solid walls had been assumed to have U-value of 2.1 W/m2K, however recent research has shown a value in the range of 1.6 W/m2K (Li et al., 2015). Rasooli et al. (2016) found similar results in a study in the Netherlands. In addition to this there is large impact by the behaviour of the occupants. The models assume an average heating of the whole building, however in poorly insulated buildings the occupants are frugal and use heat sparingly, they also tend to heat only the spaces that they actually use.

3. Energy performances of new dwellings in practice

In 1995 energy performance regulation for space heating and cooling of newly built constructions were introduced in the Netherlands. The regulation consists of a standard (norm) that prescribes the calculation method which is called the Energy Performance Norm. The standard results in a non-dimensional figure called the Energy Performance Coefficient. Every few years the level of this Energy Performance Coefficient was decreased, representing a lower energy use demand for building-related energy use. In 2021 this Energy Performance Coefficient will be on the level of nearly energy neutral according to the EPBD. Since the introduction of the energy performance regulation there has been little assessment of the regulation's effect on the actual energy use in the houses. Two studies found no statistical correlation between the Energy Performance Coefficient level and the actual energy use per dwelling or per m2. Guerra Santin (2009, 2010) compared the actual and expected energy consumptions for 313 Dutch dwellings, built after 1996. The method included an analysis of the original energy performance calculations that were submitted to the municipality as part of the building permit application, a detailed questionnaire and some day-to-day occupant diaries. These combined approaches generated very detailed and accurate data of the (intended) physical quality of the dwellings and installations, about the actual energy use (from the energy bills) and of the households and their behaviour. The dwellings were categorised according to their Energy Performance Coefficient. Due to the relatively small sample size, the differences between the actual heating energy of buildings with different Energy Performance Coefficient values were insignificant. Nonetheless the average consumption was consistently lower in buildings with lower Energy Performance Coefficient, but not nearly as low as expected. In this sample, it was found that the increased level of the energy performance had very little effect on the actual energy use. Guerra Santin found that building characteristics (including heating and ventilation installations) were responsible for 19% - 23% of the variation in energy used in the recently built building stock.

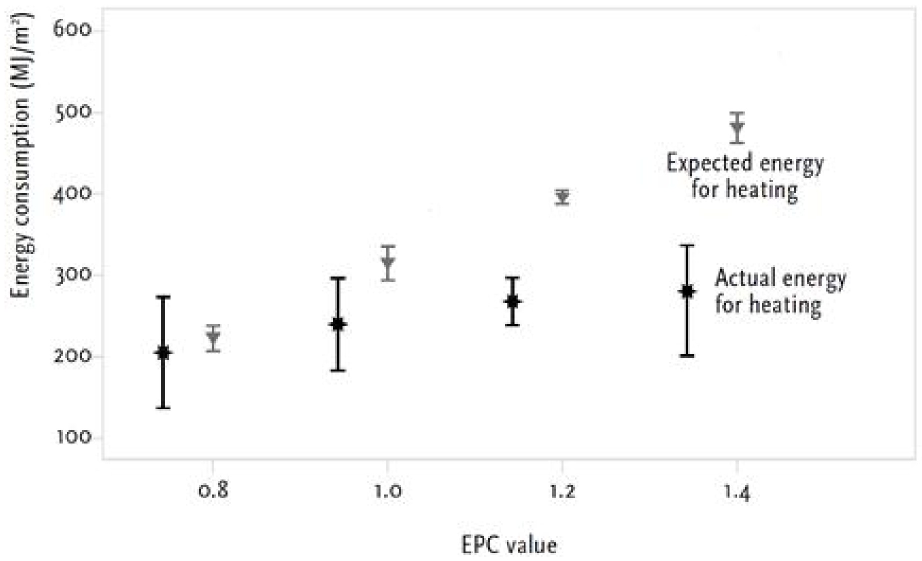

Figure 1 Mean and 95% confidence interval for the actual energy consumption (MJ/m2) and expected energy for heating (MJ/m2) per EPC value Source: Guerra Santin, 2009

Taking into account the above findings, it is doubtful whether further tightening of the energy performance regulations will lead to improvements in actual outcomes. Other and more efficient solutions exist to decrease the actual energy consumption of newly built dwellings. Important ingredients of the solution are: ensuring that appliances and installation are correctly installed, monitoring the calculated performances in practice; enlarging the know-how and skills of building professionals and creating an effective and efficient building control and enforcement process. Monitoring the actual performance in the completed building becomes more important.

4. Actual versus calculated energy use: existing dwellings

The largest energy saving potential is in the existing building stock. New dwellings add about one per cent per year to the housing stock in Europe. The most important policy tool required by the EPBD in the European Member States is the issuing of Energy Performance Certificates (or EPCs). These EPCs give a hypothecated indication of the required energy to provide a certain average temperature in the building and depend on physical characteristics of the building. The certificate has no mandatory implications in the sense that owners could be forced to improve their buildings to certain levels. Nonetheless it is a crucial instrument for benchmarking and formulating policy goals. Building owners in all EU Member States have to obtain an EPC for a building at the moment it is sold or rented out. This is not yet current practice everywhere, mostly due to lack of enforcement. This especially applies to the private housing stock. In a research project by Majcen (2013a, 2013b) the actual energy consumption was compared with the theoretical use according to the EPC's (see figure 2).

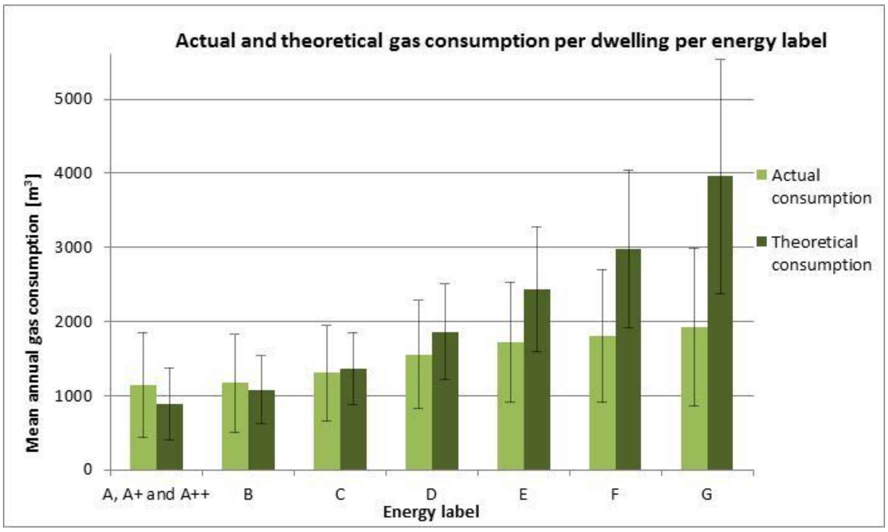

Figure 2 Actual and theoretical gas consumption in Dutch dwellings - per m2 dwelling area, Source: Majcen et al., 2013a

This research was based on the Dutch energy labels issued in 2010 - a total of over 340,000 cases with 43 variables (regarding building location and technical characteristics, the properties of the label itself etc.). This data set was derived from the publicly available database of the EPCs. This data was, on the basis of the addresses of the households, linked to actual energy use data. The energy data was provided by the CBS (Statistics Netherlands), which collected this data from the energy companies. The combined data file was then cleaned by deleting incomplete or obvious incorrect EPCs. This resulted in 193,856 usable cases. This still large sample proved to be representative for all housing types and energy label classes.

To understand how the energy label relates to the discrepancies, the gas and electricity consumption in various label categories were examined and analysed. The actual and theoretical gas use per dwelling was compared and then analysed per m2 of dwelling (figure 5). Little difference exists between the actual and theoretical energy use calculated per dwellings and per m2 , except the difference in actual gas use between label A and label B. At the level of individual dwellings, the actual consumption was identical, but at the level of m2 the dwellings in category A use less gas than dwellings in category B. This may relate directly to the fact that dwellings in label category A were found to be considerably larger than all other dwellings. From these figures it is clear that although better labels lead to higher actual gas consumption, there is a clear difference between the mean theoretical and mean actual gas consumption for each label. For the most energy-efficient categories (A, A+ and A++) and for category B, Figure 5 shows that the theoretical calculation underestimated the actual annual gas consumption. This is in contrast to the rest of the categories for which the theoretical calculation largely overestimated the actual annual gas consumption. This research indicates that the energy label has some predictive power for the actual gas consumption. However, according to the labels, dwellings in a better label category should use on average significantly less gas than dwellings with poorer labels, which is not the case.

5. Discussion: alternative policies and regulations to control energy use in dwellings

It is evident that current general regulatory instruments can only partly influence the actual energy use in houses. Regulations only address the energy use that is (partly) related to the physical condition of the building (as appliances and users are outside their scope). However, there needs to be a shift in focus to ascertain the 'as built' quality. For example, nearly zero energy buildings would require airtightness tests and infrared scans (to highlight any thermal bridging). The adequate functioning and the capacity of ventilation systems also needs testing. A differentiation is needed in regulations to account for in-use performance. This is because any mistake during the construction process will lead to a reduction of the minimum required performance and efficiency, thereby negatively influencing the energy demand. Analysing the actual energy use compared to the indications of the EPC's gives a clear insight in the under prediction of the use in houses with good labels and large over predictions in the house with bad labels. This also leads to wrong assumptions of payback times of the investments. Strict regulations for new houses and retrofits will improve the physical performance of the building, but have a limited influence on the actual energy use. Given the limitations of current building regulations, what other forms of governance could be used to reduce the domestic energy use and CO2 emissions?

An innovative approach for deep energy renovations to nearly zero in the Netherlands is called the Net Zero Energy Renovation concept. Houses from the 1960s and 70s with a poor energy performance are retrofitted with a new highly insulated skin, air source heat pump heating and PV panels. The renovation process is highly industrialised and the renovation time is limited to two weeks or less. Currently these deep retrofits are mostly done to social housing (houses from housing associations). A change in governance has been influential. A new law allows the housing associations to increase the rent by the cost of the average energy bill. After the retrofit, the tenants only pay a higher rent but no energy bill at all, provided their actual energy use within a prescribed limit. This only works if the theoretical estimations of the actual energy demand are correct. Concurrent with this is the development of a new contractual obligation: an energy performance guarantee by the construction company. This is a kind of Energy Performance Contract where the owner occupant pays for the retrofit and gets a guarantee for a zero energy bill. In principle, the increase in rent should be offset by not having to pay an energy bill. The first evaluations are appearing now (Energiesprong, 2016), but they are only based on just a few cases. Some of the occupants are satisfied, but others are dissatisfied because the energy demand concept is below their expectation. It is based on lower indoor temperatures (20°C), short times for showering and an energy sober life style. If these occupants exceed the allowed level of energy use, then they have to pay extra for it. There will be much variation among users but a reasonable baseline for normal energy demand may act as a positive influence on behaviours and practices. The near zero concept of houses will help to reduce the variation, but still there will remain some variation and really zero can't be guaranteed. This suggests that in addition to the physical aspects of creating a near zero building, there are also social aspects relating to energy demand that need to be addressed. However, the overall impact on energy and CO2 reductions from these buildings (and the underlying regime that created them) has been significant. Energy Performance Guarantees are basically a voluntary development by market parties. Until now, the underpinning governance has been supportive. The initiative was developed by an agency (Energiesprong which translates as 'Energy jump') and financially supported by the government. Recently the support programme has stopped and the expectation now is that the market should further develop it.

The policies for the existing stock are largely based on the EPC's. In the first place home owners and occupants are informed about the energy performance of a dwelling. This can influence buyers and should stimulate owners to renovate their homes. Often the incentive schemes use the concept of payback times. This is based on the argument why not invest (e.g. € 10,000) if this can be earned back in 10 years by a lower energy bill? The insights presented in this paper show that this hardly works for renovations on the skin of a building to reduce the heating demand. There is a slight reduction of energy use, but the comfort level increases (higher temperatures). To have a real impact on savings the retrofit should go to the level of near zero.

Another investment strategy is in on-site renewable energy generation. This is independent from the occupant behaviour. However, it is dependent on the energy price. The drastic reduction of the oil price in 2015 illustrates this. The feed-in tariffs for electricity are set by governments and are also unpredictable. In the Netherlands, homeowners can yearly feed in 3000 kW for the same price as the price they have to pay for electricity, which includes 75% taxes. This arrangement makes it very profitable to buy PV-panels. However the government is now considering a change to this regulation in 2020. This shows that taxes and incentives can be a very strong governance tool.

Murphy (2012, 2014) investigated how owner-occupiers respond to various kinds of incentives by the National and Local Dutch governments. Most of these incentives were connected to EPC's and advise on making houses more energy efficient. These forms of governance had only modest success. The willingness to invest in energy renovations is still limited, especially due to many uncertainties about the reliability of the contractors and the actual energy savings as found by Galvin (2014) in Germany.

Other forms of information about actual energy use seem more promising. Quarterly energy use reports of the energy companies give better insights and are related to previous year's corresponding quarter and to neighbours' energy patterns. Smart meters are nowadays installed on a large scale. In a few years most homes will have one. At the same time energy management displays are more and more used. Smart meters and these displays can be seen and used on smart phones. The insight will increase, but is this enough to stimulate energy saving behaviour including renovation investments? Studies (e.g. Darby, 2008) about the potential of giving accurate feedback to users about their behavior indicate that 5 to 10 % savings might be achieved.

6. Conclusion

To improve this situation for new buildings it has to be assured that constructions and installations are installed properly and in such way that they are not vulnerable for unpredictable or misuse by the occupants. This will set demands on both the construction industry and the control / enforcement process. The public building regulations and enforcement systems will continue to have an important role. The improvement of the existing building stock forms a big challenge. The potential energy savings are large, but the barriers to overcome are also high. Actual energy savings in renovated dwellings stay behind expectations due to rebound effects and lower than expected energy use in the old dwellings. Many owners believe that the benefits of the measures do not outweigh the costs. For all kind of governance policies and instruments, an accurate insight into the actual performances of buildings, actual energy use, behaviour and preferences of occupants will be essential. The unexplored territory for governance is how occupants' expectations, behaviours and social practices in using energy can be changed. Rational, economic incentives do not appear to be convincing or effective. Other levers, narratives and instruments are needed to monitor and encourage a frugal approach to energy demand and its management. To ensure the success of governance strategies and instruments, the support and engagement with occupants will have a vital role. This represents a new area for (national and municipal) governments and the construction supply side. For the latter, it will necessitate new forms of engagement with occupants to demonstrate optimised use and new social practices, as well as ensuring that energy performance guarantees deliver. The creation of positive feedback loops for inhabitants seems essential.

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Are building regulatory systems in European countries climate proof?

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Abstract

Demands on the energy performance of new and existing buildings hold a prominent place in the regulations of all European countries. The influence of EU policy goals and contents of EU Directives reverberate strongly in the energy regulations. Goals set by the European Union are that all newly built constructions must have a zero energy level by 2020 and that the total building stock must be energy neutral by 2050. The Energy Performance of Buildings Directive and the Energy Efficiency Directive are designed to give Member States the regulatory tools to develop and strengthen energy performance regulations. There are indications that the current (energy) regulations alone are inadequate to realize the energy saving goals set by the EU and its Member States. The goals can only be reached by more strict and supportive governmental regulations. That does not only mean formulating more stringent demands. It also poses new challenges to the way the construction process is organized and the regulations are enforced and the roles and responsibilities of constructors (building and installation companies). In the quality control procedures focus should be put on the quality of the building as it is built and preferably as it is going to be used. The question is if current quality control frameworks are organized adequately in European countries to meet these demands. To give a beginning of an answer to this question we look at the regulatory systems of seven European countries (England & Wales, Ireland, Germany, France, the Netherlands, Norway, and Sweden) where private building professionals already play a dominant role in the quality control process. The paper zooms in on the robustness and focus of the quality control process and the demands that are made on building and installation companies with respect to meeting the quality demands. It appears that current building regulatory systems are not yet geared completely with the future demands.

Keywords: building regulations, quality control, European Union, housing quality

1. Introduction

Traditionally quality control of construction work in Europe has been a governmental responsibility. In most European countries local authority building control has been issuing planning or building permits and were responsible for plan approval, site-inspections and checks on completion of constructions. During the last decades however these building control tasks have been outsourced more and more to private parties. The main driving force behind this development has been the wish of governments to deregulate. The shift of responsibilities to private parties should not only improve the quality of construction works but it could also streamline administrative procedures and processes. In the eyes of the policymakers this leads to a win-win situation: less regulation, leading to a qualitative better building stock through optimised (cheaper and faster) quality control procedures. It is exactly because of these reasons that the Dutch government is on the brink changing its quality control system of constructions towards a more private model (MBZK, 2015). In the Netherlands the discussion to change the quality control system has been going on for many years. The dominant line of policy of subsequent governments has been “privatise if possible and keep it public when necessary”.

Simultaneously with the strong wish to deregulate, new quality goals emerged that require regulatory governmental intervention. The reduction of energy use and environmental impact of construction have been the most important new policy goals the last decades. The European Union and its Member States have implemented regulations and enforcement schemes that should ensure very energy efficient new buildings and have introduced instruments to improve the energy performance of the existing building stock. On a European level the Energy Performance of Buildings Directive, the EPBD (2010/31/EC) and the Energy Efficiency Directive (EED – 2012/27/EU) have been the dominant frameworks for the Member States to fit in their national regulations. So although the general deregulation trend in Europe has led to less governmental intervention in the building sector, in the field of energy efficiency the number of regulations has increased and became more stringent.

Recent studies show that the (energy) regulations are probably inadequate to realize the energy saving goals set by the EU and its Member States (summarized in Visscher et al, 2016). To reach the goals, more strict and supportive governmental regulations are needed. That does not only mean formulating more stern demands. It also poses new challenges to the way the quality control process of constructions is organized and the regulations are enforced. The roles and responsibilities of (private) quality controllers and builders are an essential part of this. This paper explores if the regulations and the quality control processes in the ´average´ European building regulatory system are fit for the task that lies ahead. Section 2 focusses first on the research project(s) the paper is based upon. The subsequent section 3 characterises the essentials of the systems in England & Wales, Ireland, Germany, France, Norway, Sweden and the Netherlands. In the closing sections 3 and 4 the results are discussed and the main conclusions are drawn.

2. Research approach

For many years OTB – Research for the Built Environment, Delft University of Technology, has been involved in studying alternative visions on building regulatory systems in international comparative projects. Recently we have been involved in a study for the DG Internal Market to (Ecorys and Delft University of Technology, 2015). For the Dutch government we recently compared the proposed Dutch quality control system with those in some selected European countries: England and Wales, France, Germany, Ireland, Norway and Sweden. In these countries the roles, tasks and responsibilities were analysed of public and private parties in assuring and guaranteeing the technical quality of construction works. Starting point was our existing dataset on building regulatory systems in Europe. Additional and updated information about the quality control systems was inventoried via desktop research. Relevant regulatory documents and other sources were analysed. The project started in the fall of 2015 and was finished in the spring of 2016 (Meijer et al, 2016). Within the boundaries of this paper the highlights of the research are presented.

3. Outline of the control systems of other countries

This section summarises the research results for the seven European countries. Attention is paid to the nature of the quality control and the roles and responsibilities of the building professionals. Focus lies on the quality control of the technical demands. In all countries only municipalities can grant planning permission for the construction or modifications of new and existing buildings.

3.1 England & Wales

Minor construction work in England & Wales is exempt from technical building control. For the construction of relatively simple work the application of a building notice is sufficient. All other construction plans are subject to a quality control procedure. For the technical quality control of these plans, applicants can choose between local authority building control (LABC) or a private Approved Inspector. This dual quality control system has been in operation for more than 30 years. Approved Inspectors have to be certified and registered before they can act. There are no legal obligations concerning the way quality control should take place (e.g. concerning methods and giving an account of the control results). Nonetheless both public, as well as private controllers, have voluntarily committed themselves to the Building Control Performance Standards. These standards give guidelines how qualitative good building control should be performed (DCLG, website). The quality control process has a clear beginning and ending. LABC has to give building approval and issues a completion certificate at the end of the procedure. Approved Inspectors have to inform LABC that they are involved of the quality control of a construction at the begin and the end of the process (Meijer et al, 2016). Builders have to comply with the general rules concerning materials and workmanship. There are no general recognition or certification schemes for contractors or builders. However specialist installers can join a Competent Person Scheme. When recognised or certified (depending on education and practical experience) these installers can self-certify certain types of building work (e.g. glazing, heating systems), For these works building regulations approval is not needed. It is assumed that the work meets the requirements (Planning Portal, website). In practice many installations are being placed by these competent persons. Although there is no certainty that all these competent persons deliver adequate work, the certification framework in which they have to operate give certain basic assurances. At least their workmanship, capabilities and experiences have been tested before they are going to operate in practice. In general all parties responsible for a construction project (e.g.

owner/applicant, advisor, designer, builder or installer) must ensure that the work complies with all applicable requirements of the Building Regulations. Indemnity and warranty insurance schemes should protect the building owner for financial risk in case of defects and failures. There are no regulations that apply to a post occupancy testing of for instance if the regulations are being met. Between 2007 and 2010 owners had to provide a Home information Package before a property in England and Wales could be put on the open market for sale. This requirement has been suspended from May 2010 on and was formally repealed in the beginning of 2012. As in all other Member States EU legislation still requires building owners to provide an Energy Performance Certificate (or energy label) at the moment of a transaction.

3.2 France

For technical control a public-private construction supervision system has been in operation in France for almost forty years. Three categories of construction works are distinguished. Renovation activities and small risk-free works are exempt from any control procedure. Simple building activities (up to a certain floor area) have to be reported to the municipality. Once the work is finished the municipality has to be notified, after which a completion certificate will be issued (Meijer et al, 2016). All other construction need a building permit and are eligible for a regular procedure. The complexity of the plan defines the quality control procedure. For relative uncomplicated works (like a house) a registered architect has to declare that the plan meets the regulatory demands. When the building is completed a notification has to be sent to the municipality before it can be taken into use. In practice these works are hardly being controlled during construction either by municipalities or private controllers (Deman, 2013). For complex construction works with a higher risk quality control by private control organisations is obligatory. Control starts in the phase of plan approval and continues until completion. After plan approval the control organisation has to a deliver an initial technical report with his findings. Before construction starts a control or inspection plan has to be drawn up. Private controllers are legally liable to control the structural safety and the safety of persons. Site inspections are held at random. After completion the private controller has to deliver an end report on the technical control. Public and high-rise buildings must have a user permit before they can be used (MLHD, website). The private control organisation has to be certified and accredited and must be independent of the applicant/building owner. Organisations can be certified for various control scopes (e.g. all regulations, only fire safety regulations, regulations for installations etc.). A decisive factor behind this system is the French insurance and guarantee system for building works (Meijer et al, 2016). The relevant law (dating from 1978) dictates that every building professional involved with a construction project must have appropriate guarantee insurances (e.g. covering professional indemnity). Builders and contractors have to be registered otherwise there is no certainty that they can meet the guarantee provisions.

3.3 Germany

To map the German situation we focussed on the regulation of North Rhine Westphalia. The German model can be best described as being a mix between public and private quality control. Municipalities are formally responsible for issuing the (building and completion) permits and the quality control procedure. Recognised or registered building professionals however play an important role in the system. First of all a certified and registered architect and/or structural engineer must submit the permit application and usually takes care of plan approval. In addition -– depending of the construction type and control scope – a state recognised expert (*Prüfsachverständige*) must be involved in the quality control process. State recognised experts have to be independent and comply with strict demands on education and practical experience (Building Code of NRW, 2015). Procedure wise Germany distinguishes construction works that are exempt from building control, works that must follow a 'simplified' procedure and works that are eligible for the regular permit procedure. Many minor construction works are exempt from building control. If there is a zoning plan in place dwellings of a medium or lower height could also be built without a building permission. Beforehand though evidence must be delivered to the municipality (certified by the architect and the state recognised expert) that the building plan meets the essential demands. The simple permit procedure applies to the construction of low rise residential buildings and other low risk buildings. Local building control does not check plans if designers certify that they comply with the building regulations. The structural design must be calculated by a qualified structural engineer and his design must be proofed by a state recognised expert. No completion certificate is being issued. The regular building permit procedure applies to the remaining construction works. The building application (and the supporting documents) must be signed by a certified architect or engineer. Normally a state recognised expert verifies compliance with the technical requirements (especially structural stability and fire safety). For the construction phase a contractor and a – independent- site manager has to be appointed. Both the builders as the other building professionals have to meet statutory insurance requirements regarding liability. During construction, building control is exercised by local building control and the site manager. Building authorities usually delegate site inspections on structural stability to a state recognised expert. The completion of the shell and the completion of the building have to be reported to the local building control authorities so it can be checked. If satisfied the local authority issue a completion certificate. (Meijer et al, 2016).

3.4 Ireland

Ireland has recently (2014) changed its system to an almost entirely private system of quality control. In the new system competent private building professionals are responsible for the quality control of construction works. The system includes all kinds of new responsibilities and roles. Applicants for building approval must submit a Commencement Notice and ensure themselves that supervision during construction is carried out by a certified independent party: an Assigned Certifier. Some (simple) works are exempt from this obligation. This applies to construction works that do not need a planning permission or a fire safety certificate, like regular maintenance activities and or the construction of small extensions. In all other cases the applicant or building owner has to submit a Commencement Notice. Besides the inclusion of a certificate of design compliance, proof must be delivered that an Assigned Certifier is going to inspect and certify the works and a builder has been hired to carry out the works. Furthermore the certifier and the builder must declare that they will meet the regulations. Finally the Commencement Notice must be accompanied by an inspection notification framework and an inspection plan. After completion of the project, both the certifier as the builder must certify that the completed construction complies with the demands of the Building Regulations (DECLG, 2014). Shortly after the new regulations came in to force, it came apparent that for the construction of one-off dwellings and extensions on existing houses. the costs of quality control were highly disproportionate. This has led to an amendment to the system. The mandatory requirement for statutory certificates of compliance for these constructions was removed. Owners and self-builders have the choice to opt-out of the statutory certification and are allowed to demonstrate by other means that the work is going to meet the demands. At the same time the government announced the development of a new local authority quality control process for single dwellings and residential and commercial buildings (Meijer et al, 2016). The effects of this change (on the number of applications or the construction quality) is yet unknown. For building professionals inclusion on statutory registers is the primary means of establishing competency. For architects and engineers these registers already are in operation. The register for builders should be in place shortly. Furthermore building professionals must ensure that they are adequately covered for liabilities (DECGL, website).

3.5 Netherlands

In April 2016 the new law on Quality Assurance of buildings has been sent to the Dutch Parliament (MBZK, 2015). This law will change the quality control system of construction work in the Netherlands fundamentally. All control activities on compliance with the technical building regulations will be transferred from public authorities to private parties. In the new system the list of exemptions containing the risk-free construction works also will be extended. Besides that a new category ‘Technical control free construction works’ will be introduced. These are the same construction works as the exemptions, only difference is that these works have to get planning permission. All other construction works will be classified in three groups according to their complexity and possible consequences in case of failure. Class 1 contains for instance one family housing. Hospitals and high rise buildings are assigned to class 3. The technical quality control of these construction works will be carried out by private parties. An independent Admission Organisation is going to assess and recognise these private quality controllers and their quality control instruments. Municipalities stay responsible for checking planning and aesthetic issues. In the new system an applicant has to notify the municipality about his plans and the way quality control is going to be arranged. The appointed private controller carries out plan approval and makes an inspection plan and takes care of the control during the construction phase. At the end of the process the quality controller declares that the building meets the technical demands (IBK, 2014) and a completion file has to be delivered to the owner or applicant. To strengthen the position of the ‘building consumers’ the liability of builders (e.g. for hidden faults) will be sharpened in the Civil Code. A decade ago the initiative was taken by the government to introduce a Building File. This document should describe the condition of the building in relation to the building requirements, should help consumers to make their choice between buildings, and could function as a manual for use and maintenance. Although the Dutch government welcomed the idea, the concept did not get enough support at that time of the most important interest groups of the building sector. In the new system a completion file has to be delivered at the end of the quality control process. This could bring the Building File concept back to life.

3.6 Norway

In the 1990's Norway (1997) changed its public quality control system drastically. The new system was largely based on self-certification by approved building professionals (architects, engineers and builders). These enterprises could self-certify their own construction works and that of others. In practice it quickly appeared that this new model proved to be highly ineffective. The main problems were that self-certification by building professionals was inadequate and that local authorities failed to supervise the private parties (World Bank Group, 2013). From 2012 on a new regulatory framework has come into force. The essence of the system (self-certification) has not changed, but the checks and balances to assure the quality of the quality control process have been sharpened considerably. The demands and supervision on both quality as independence of control have become stricter. Building professionals have to meet demands on education and practical experience. Norway makes a distinction between construction works that need a permit and risk-free works that are exempt from a permit and a procedure. The other projects require an application and building permission. The other construction works are eligible for the quality control procedure (KoRD, 2015). All parties involved (applicants, designers, engineers and builders) have to be approved by the central government as a responsible enterprise. All roles have to be filed in properly before the authority issues a building permission (DiBK, website). The process starts with an obligatory preliminary consultation meeting where the parties involved decide about an inspection plan. This inspection plan is used during the construction and completion phase. For critical building elements (e.g. structural components, fire safety, energy efficiency and the building envelope) in more complex constructions independent private control is obligatory (Meijer et al, 2016). At the end of the construction process the controller/applicant has to make a completion report and file an application to the municipality for a completion certificate. At completion the applicant and builder has to supply the user or occupant of the building with an user and maintenance manual of the building. A last interesting feature in Norway is that local authorities have the statutory duty to make a strategic policy plan about building control. Certain elements have to be addressed in that plan, like prioritising the supervision and control on certain areas. Those priority areas could be certain construction types or certain technical requirements. The national ministry has the right to give the municipalities orders to set these priorities. In the period 2013-2014 the local authorities had, by ministerial order, to check if all construction projects carried out in their municipality met de minimum energy performance requirements.

3.7 Sweden

The general rule in Sweden is that for a work needing building approval there must be at least one private person/party involved that controls the quality during construction. The demands on the private controller are established in the Law of Building and Planning 2010. The quality controllers must be certified before they can operate in practice (Boverket, website). Sweden also recognises various categories of construction works. Besides construction works that are exempt, Sweden distinguishes a category works that in principle is exempt, but mainly because of planning reasons has to be reported to the municipality before construction can start. For the construction and renovation/adaption of single single-family and semi-detached houses, the requirements are also generally less stringent (Deman, 2013). When private quality control is necessary an inspection plan has to be made and a technical meeting has to be organised. All parties involved must attend this technical meeting. Only if the municipal building committee agrees with the inspection plan the building permit is issued. The municipality building committee controls the essential elements (structural and fire safety, sustainability, insulation and health issues) of the intended construction plan during plan approval. During construction a certified independent quality controller has to take care of the inspections. The applicant/ owner and the builder stay responsible for an adequate quality control process. No specific demands are made on the builder with respect to registration or practical experience. The building regulations expect that a builder complies with the regulations. Liability-issues of the various building professionals involved in a project are usually arranged in standard contracts. After completion an end meeting is held that establishes if all the agreements and commitments have been met that were stipulated in the approved inspection plan. If the municipal building committee is satisfied a written notice is issued to the applicant/owner. This written notice is comparable with a completion certificate.

4. Discussion

4.1 Focus on the as built situation

The main goal of a quality control system is to assure that buildings – after they have been constructed - meet the regulatory quality demands. Traditionally the countries studied, focussed their attention on the beginning of the process. Applicants had to submit a plan. During plan approval the drawings and calculations were controlled by local authorities and after the issuing of building approval, construction could start. During construction and at completion the progress and end result were inspected, but emphasis laid on the building approval phase. The countries that are included in this project all have developed systems where the checks and balances have been more evenly distributed throughout the building process. During the process qualified architects and engineers (e.g. Germany and France), qualified builders (e.g. Norway, France, Ireland) and qualified controllers (all countries) have to make sure that constructions meet the demands. After completion controllers, and sometimes builders too, have to report their experiences and the results of the inspections before the local authority issues a completion certificate. With these kinds of procedures in place the chances are fair that buildings meet the intended minimum quality. At the same time all countries have been trying (and still are trying) to streamline and simplify their quality control procedures for construction works. Without exception, the countries studies, decided that deregulation and privatisation was the way forward. This has led to a greater emphasis on the responsibility of building owners and the transfer of actual quality control from municipalities to private parties.

4.2 Emphasis on energy regulations

As we have sketched above the emphasis of quality control has moved from the design phase to the as built situation. Strict regulatory demands are made on the requirements that should be tested and sometimes the way it should be controlled. As we have seen in the country descriptions these demands always focus on the control and inspection of the structural and fire safety requirements.

What is more, these statutory demands on control and inspection always apply to complex constructions. In most countries dwellings are outside the centre of the quality control attention. An example of this is France, where due to the insurance and guarantee system, the structural and fire safety of complex constructions is inspected thoroughly and adequately. Dwellings are hardly controlled by professionals, because the insurance risks are lower. More in a broader sense one can argue if a regulatory system that is heavily funded on insurance regulations is helpful in the face of climate change. The height of the energy use and the sustainable quality of construction does not affect insurance heights and is no driving force to realise a better environmental quality.

The high potential and expected energy savings in buildings increases the need for accurate quality control. As we just have sketched this theme still does not get the attention it deserves in the regulatory developments. However the regulatory infrastructure is already available and more attention for energy and sustainable requirements can be easily incorporated in the current regulatory framework. The first step would be to give energy requirements the same status as currently is being done with structural or fire safety requirements. Private quality controllers should be made explicitly responsible to check these requirements. Only in Norway quality controllers are statutory obliged to control the energy efficiency of complex constructions. Also steps could be made on another policy level. Again in Norway (but for instance also in Ireland) statutory demands are made on municipalities to prioritize supervision on the control of certain requirements. In the period 2013-2014 the national Norwegian ministry ordered municipalities to check if all construction projects met the minimum energy performance demands.

4.3 Demands on building professionals

Other interesting developments are the growing demands on the quality and workmanship of builders and installers. All countries have incorporated various forms of guarantees in their systems to make sure that builders and contractors deliver what they are supposed to do. In England individual installers can certify their own work when they are recognised as competent persons. In France builders have to be registered before they can be qualified for insurance and thus can operate in practice. Ireland is working on a register of builders. In Norway persons and parties who want to perform construction work and building control tasks can be approved and in all cases have to declare that they are fit for the task. In Sweden the builder must appoint a certified site manager who is responsible for the quality control. On top of this, all countries have strict rules for building defects insurances. With these developments a step is made to a further professionalization of builders. However for a successful transition to energy neutral constructions more stern demands must be set on the knowledge and skills of the building professionals. They will have to use new techniques and improve the quality and accuracy of the work. Maybe the English and Welsh Competent Person Scheme could be an example how to deal with the growing need for accurate quality control. This Competent Persons Scheme specifically focuses on construction elements that matter regarding the energy performance of buildings (e.g. windows, glazing and installations). Further study will be needed to determine the accuracy and effectiveness of this scheme.

4.4 Statutory post occupancy monitoring is missing

Regulatory attention for post occupancy monitoring is completely absent in the countries studied. Some countries have had in the recent past some regulations and guidelines relating to the user phase of constructions. The Home information Pack in England and the Building File in the Netherlands have been mentioned in this paper. Due to political considerations and the fact that parties involved did not support the instrument, the initiatives were stopped. Generally the instruments were considered to be too much of a burden and too expensive. Currently in most countries the quality control procedure ends with the delivery of a completion file. Norway makes even regulatory demands with respect to a user and maintenance manual. Besides that building owners all over Europe have to provide an Energy Performance Certificate when they rent out or sell their buildings because of European regulations. While it may be not foreseeable that post occupancy monitoring will be incorporated in the building regulatory systems of countries, the current practice seems to provide at least a basis for post occupancy monitoring. Besides that the growing big datasets with the actual energy use in buildings provide a wealth of information about the effects of the energy regulations on the actual use of occupants.

5. Conclusions

This paper pictures the state of the art of quality control systems for constructions in seven European countries. What can be noticed in the countries is that the balance slowly shifts from public control and enforcement towards a more dominant role of private parties and building professionals. This development goes hand in hand with the materialisation of more robust and reliable certification and accreditation schemes to guarantee the quality and qualifications of building professionals. With respect to the scope of quality control we see a strong focus on control of the design to monitoring of the building process and testing of the quality of the final building. Post occupancy monitoring is nowhere an established part of the building regulatory system. With respect to the contents it can be noticed that statutory demands on control (when present) usually are focussed on structural and fire safety issues. Of course attention is paid to the check of the energy performance requirements, but the priority in general does not seem to be high. All along the line more simple constructions (e.g. dwellings) are controlled to a far lesser extent. The leading question in this paper was if current quality control frameworks are adequately organized in the light of the regulatory needs related with the expected climate change. In organizational terms the framework looks adequate enough to make the regulations more climate proof. What is needed is the political will and determination to give the energy and sustainable requirements the same status as for instance the demands on structural or fire safety. The last decades the themes energy saving and climate change have been dominating the political agenda. It seems merely a question of time before the regulatory framework will be adapted. In the end however it is also about the question how the systems function in practice. In our future research we intend to lay emphasis on these practical experiences. Only then a more definite and more balanced judgement can be made about the climate ‘proof-ness’ of quality control systems for construction in the various countries.

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Transaction Costs (TCs) in Building Regulations and Control for Green Buildings: Case Study of Hong Kong

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Abstract

About 40% of global energy consumption and nearly one-third of global CO2 emissions are on account of buildings. In Hong Kong, buildings consume up to 90% of electricity during construction and operation, where all the design and construction of private developments is subject to control under the Buildings Ordinance. The way building regulations are applied and the arrangement of supporting systems can affect the effectiveness of building energy consumptions and the corresponding costs induced. Among all the incentives and regulatory instruments, Gross Floor Area (GFA) concession becomes a popular scheme to promote green building (GB), which grant bonus GFA to the developers who comply with the Sustainable Building Design Guidelines (SBDGs) and achieving at least the minimum level of BEAM Plus certification. Transaction costs (TCs) have been debated over the past decades that affect the effectiveness of the policy implementation. This study applies the lens of transaction costs theory to explore the TCs inventories of implementing GFA concession practice in Hong Kong. This paper aims to analyze how the GFA Concession Scheme induces TCs among various stakeholders in practice, and how in turn it affects the effectiveness of building control for GB. Interviews are conducted to identify the TCs determinants regarding the GFA Concession Scheme. Examples are provided from the real practice to illustrate the nature of TCs. Policy implications to reduce TCs are proposed accordingly.

Keywords: Transaction costs (TCs), building regulations and control, Hong Kong, Gross Floor Area (GFA) concession scheme, green building (GB)

1. Introduction

Building energy consumption accounts for over 40% of global energy use, contributing to one-third of global greenhouse gas emissions (UNEP, 2009). In Hong Kong, buildings consume almost half of all energy and about 90% of electricity (Environmental Bureau, 2008). Apart from energy consumption, building sector influences environment in ways, such as solid waster generation, resource depletion, and environmental damage. Therefore, green building (GB) as a solution of environmental issues gains its popularity and governments' support. Various building standards and design guidelines have been released to regulate the design and construction of GB, such as Building Environmental Assessment Method (BEAM) Plus, and Leadership in Energy and Environmental Design (LEED).

The Gross Floor Area (GFA) Concession Scheme earns its popularity amongst all the incentive and regulatory instruments. The GFA Concession Scheme is developed from the notion of "make developers pay" (Tang and Tang, 1999). Government grants the developers extra GFA bonus in exchange for their contributions to the public amenities so that government can save the public investments (Tang and Tang, 1999). In Hong Kong, it is designed to facilitate the adoption of BEAM Plus and Sustainable Building Design Guidelines (SBDGs). As Hong Kong has restricted land provision each year, extra GFA is very much attractive to developers (Qian, 2010; Fan et al, 2015). After implementing the first GFA Concession Scheme in 2011, the registered GB increased around 30% within one year (Liu and Lau, 2013). In the following years, the registered GB kept increasing, but the percentage of GB is still very small. From 2011 to 2013, only around 30% of total real estate projects participated in the GFA Concession Scheme (Building Department, 2014). It is claimed that transaction costs (TCs) affect the effectiveness of the policy implementation (McCann et al, 2005, Qian, 2012), and hinder developers entering energy efficiency market (Qian, 2012; Qian et al, 2013; Qian et al, 2015a; Qian 2015b,). Therefore, analyzing the TCs amongst the stakeholders induced by the GFA Concession Scheme are essential to understand the low participation rate and ultimately reduce TCs.

This paper aims to analyze how the GFA Concession Scheme induces TCs and therefore affects various stakeholders in practice, and the effectiveness of building control for GB. The section 2 presents the applications of TC theory to the environmental programs that form a foundation for the analysis. The details of GFA Concession Scheme are described in the section 3. The section 4 explains how the three determinants influence the TCs of implementing GFA Concession Scheme. Discussion and conclusion were presented in the section 5.

2. Transaction costs (TCs) in the context of environmental issues

Transaction cost (TCs) has been defined by a lot of researchers (Coase, 1937; Arrow, 1969; Williamson, 1985;). In the area of environmental policy, TCs is defined as the cost to create and use a policy (Coggan et al, 2013; Garrick et al, 2013). When it comes to implementing an environmental regulation from the private sectors' perspective, TCs refers to the cost to comply with the regulation (Wong et al, 2011). When analyzing the technology change in building sector, TCs is understood as the cost of technology arrangement and implementation occurring ex-ante and the cost of monitoring and enforcement occurring ex-post (Qian 2012, Qian et al, 2013, Kiss, 2016). In this paper, TCs is defined as the extra costs to fulfil the requirement of building regulation and control.

The existing literature has studied TC typologies, which are slightly different, associated with implementing the environmental policy and energy efficiency project. For energy efficiency project, TCs include information searching cost, negotiation cost, monitoring and verification cost, trading cost, and decision making cost (Qian, 2012, Mundaca et al, 2013). In the respect of implementing environmental policy, TCs consist of searching cost, negotiation cost, approval cost, validation cost, monitoring costs, verification cost, certification cost, enforcement cost, transfer cost, and contracting cost (Dudek and Wiener, 1996; Ofei-Mensah and Bennett, 2004; McCann et al, 2005; Qian, 2012; Coggan et al, 2013; Qian et al, 2016). Some of these costs are overlapping and it is difficult to divide them clearly. Even if a lot of literature has studied TC types, only a few of them have identified stakeholders who bear the TCs accordingly (see e.g. McCann et al, 2005; Coggan et al, 2013;).

2.1 Determinates of Transaction Costs

2.1.1 Asset specificity

Williamson (1985) stated that there are three dimensions, namely asset specificity, frequency and uncertainty, influence TCs. To be more specific, there are four types of asset specificity, including site specificity, human asset specificity, physical asset specificity and dedicated assets. Table 1 illustrates the definition of four kinds of asset.

Table 1: Definition and measurement of three dimensions of TCs (Source: adapted from Williamson, 1985)

TC determinants		*Definition*
Asset specificity	*Site specificity*	*Site specificity will arise when specific investments have to be located in a particular site.*
	Human asset specificity	*The specialized skills, knowledge and learning-by-doing cannot be transferred to alternative transactions*
	Physical asset specificity	*The specialized instruments and equipment used in a particular transaction*
	Dedicated asset	*A discrete investment in generalized production capacity to selling number of products to particular buyers, such as expanding the existing plant for a specific customer*

Specifically, site specificity, physical asset specificity and human asset specificity exist for the environmental goods for the reasons that the transaction value of an environmental good largely depends on the site (site specificity) and inputs (physical asset specificity), and the transaction needs investment in specific knowledge (human asset specificity) (Coggan et al, 2010).

2.1.2 Uncertainty

Three types of uncertainties surrounding the transactions are extracted from Williamson (1985) and explained in the context of agri-environmental scheme by Mettepenningen and Van Huylenbroeck (2009). The uncertainty of future state of nature is primary, which means that the environmental outcome of certain transactions could have high uncertainty because of the uncertain physical and natural environment. The secondary uncertainty arises due to lack of communications between contracting partners. This type of uncertainty is understood as the uncertainties resulted from implementing poorly specified contract. The third type of uncertainty refers to behavioral uncertainty attributable to opportunism. In the context of environmental scheme, it concerns the trust between contracting partners.

2.1.3 Frequency

Frequency refers to the frequency of transactions, which influences TCs by recovering the costs of specialized governance structures (Williamson, 1985). TCs could be reduced by repeated transactions because of fewer efforts on information collection and learning (Mettepenningen and Van Huylenbroeck, 2009). However, it is important to notice that only if the past experience is transferable to new experience, TCs can be reduced (Coggan et al, 2015). Therefore, TCs are essentially reduced by the transferable past experience developed in the transactions, such as transferable knowledge, skills, information, etc. In this sense, an incentive scheme should contain more transferable knowledge or skills to reduce TCs.

3. GFA Concession Scheme to control building design and construction

Since 2011, Hong Kong has implemented Gross Floor Area (GFA) Concession Scheme to promote GB development and address climate change, which grants GB developers additional GFA (up to 10%) to reward their contributions on the built environment. This scheme is voluntary basis, but regulates the GB design and construction by the twelve green and innovative features, Sustainable Building Design Guidelines (SBDGs) and Building Environmental Assessment Method (BEAM) Plus that are tailored for the Hong Kong built environment. Developers who would like to acquire extra GFA have to comply with SBDGs and BEAM Plus and the certain green or innovative building. In this way, environmental protection could be guaranteed, especially building energy efficiency addressing climate change.

The SBDGs have three basic elements for GB design, namely building separation, building setback and site coverage of greenery, which contributes to better air ventilation, enhancing the environmental quality of living space, and providing more greenery and mitigating the heat island effect. Specifically, for different sizes of sites, building height, building length, and assessment zone, there are different design requirements for each of three elements. For example, in terms of building separation, in the site area less than 20,000 m^2 and with building length no less than 60m and building height no more than 60m, the permeability of buildings should not be less than 20%. The complicated requirements bring a lot of difficulties to the architects to make the design scheme, especially in the situation that no specific training is provided. According to the Environmental Report (Building Department, 2014), from 2011 to 2013, around 25% of total projects applying for GFA concession get disapproval due to failing to fulfil the SBDGs.

BEAM Plus has four ratings, namely Platinum, Gold, Silver, and Bronze. It is designed to control the process of building construction and operation in the aspects of building site, material, energy use, water use, and indoor environmental quality, which respectively have the total credits of 22, 22, 42, and 32 to achieve. Each credit has specific requirements illustrated in the BEAM Plus, but without implementation measures. However, Hong Kong Green Building Council (HKGBC) provides trainings particularly to help professionals integrate GB standards and practices, and advise project team on how to achieve the credits. Professionals who take the training of BEAM Plus and pass the exam can get the certification of BEAM Pro. Nevertheless, it is not mandatory to employ BEAM Pro to do GB project, but BEAM Pro's involvement can get the project one credit bonus.

There are five green features and seven amenity features that can be granted GFA concession, subject to 10% overall cap. The architects would integrate several of these features into the design scheme depending on the site context and building layout (Development Bureau, 2011). Apart from the twelve features, other features beneficial to community with practical need or environmental friendly (e.g. communal sky gardens, covered walkway with provision of greenery) and other items (e.g. car parks, sunshades and reflectors) could be granted GFA concession as well with no overall cap of GFA concession. Therefore, the architects should be familiar with the SBDGs, BEAM Plus and the above building features in order to implement the GFA concession well.

4. Determinates of TCs in the GFA Concession Scheme

4.1 Asset Specificity

Applying the TCs theory to the GFA Concession Scheme, asset specificity means the specific investments to do the GFA concession projects. To be more specific, four types of asset specificity exist in the GFA Concession Scheme. Site specificity refers to the GB design for the specific site. Each site has its particular size, shape and surroundings that restrict building design and construction by the GFA Concession Scheme. Therefore, the traditional design pattern may be changed to adapt to the new rules, which causes research cost borne by architects. Human (knowledge) asset specificity is understood as the specific knowledge and information required by the GFA Concession Scheme. For example, participants of the GFA Concession Scheme have to learn the SBDGs, BEAM Plus and collect relevant information that causes learning cost and information searching cost. Physical asset specificity refers to the investment in the specific contract between stakeholders. Stakeholders need to negotiate and clarify the responsibility of each participant, and do some research to develop the non-standard contract particularly suitable for the GFA concession project, which generates TCs in the process like negotiation cost and research cost.

4.2 Uncertainty

Adapting three types of uncertainty to the GFA Concession Scheme, they refer to the technology uncertainty arising from uncertain performance of green equipment, the institutional uncertainty due to ambiguous contracting or government documents and behavioural uncertainty because of opportunism and bounded rationality. Technological uncertainty exists in the process of implementing BEAM Plus. To achieve the credits of energy and water saving, the applicants have to provide evidence as to the energy efficiency rating, which generate verification costs. Institutional uncertainty arises due to the poorly specified official documents. For example, BEAM Plus does not specify how to achieve the credits in the handbook, which leads to extra communications between practitioners. Behavioural uncertainty also brings more communications due to lack of trust and common understanding in the new partnership, such as partnership of GB consultant and architects, GB consultants and contractors, and contractors and new suppliers.

4.3 Frequency

Frequency in the GFA Concession Scheme means how frequently the experience, such as knowledge, information, and partnership, gained in the previous GFA concession project could be used in the later projects. In other words, it is the transferability of experience that influences TCs. Therefore, transferability is employed to measure to which extent the TCs in the GFA Concession Scheme could be reduced. For example, the communication costs could be saved if architects and contractors keep working with the same group of GB consultants as they have developed common language and working pattern.

5. TCs analytical framework

Starting with the TCs determinants in the GFA Concession Scheme, through literature review a preliminary list of TCs are identified, and mapped on the stakeholders who bear them (Table 2). 10 interviewees (Appendix 1), including architects, developers, contractors and BEAM consultants have been interviewed to verify the list in the Table. According to Table 2, information searching cost, research/learning cost, coordination/negotiation cost, approval cost, monitoring cost, and verification cost exist in the process of the GFA Concession Scheme implementation due to the specific knowledge, specific information, specific contract, design for specific site, behavioural uncertainty, institutional uncertainty, and technological uncertainty embedded in the GFA Concession Scheme design. All the stakeholders have borne the extra TCs. Specifically, professionals bear the TCs most frequently in the transactions, followed by contractors. Developers ranked 3nd, followed by suppliers. However, this frequency does not mean that professionals bear the highest TCs because each type of TCs may cost different in time and efforts. In Table 2, we will derive a set of specific transactions under each of the sub-determinants to conduct interviews with experts later to extract the more detailed TCs incurred.

As discussed before, frequency influences TCs by reducing the time and efforts spent on the information collection and learning in the repeated transactions, but only the transferable experience gained in previous transactions, can reduce TCs. Therefore, transferability should be employed to measure the potential of the GFA Concession Scheme to reduce TCs. It indicates how efficient the GFA Concession Scheme able to be implemented when the market progresses mature.

Table 2: Analytical framework of transaction costs in the GFA Concession Scheme (Source: Interview)

TCs determinants	***Sub-determinants regarding the GFA Concession Scheme***	***TCs caused by GFA Concession Scheme***						***Stakeholders:***
		Information searching cost	*Research/learning cost*	*Coordination/Negotiation cost*	*Approval cost*	*Monitoring cost*	*Verification cost*	
Asset Specificity	*Specific knowledge*		ü					*P, C, S*
	Specific information	ü						*P, D, C*
	Specific contract		ü	ü		ü		*P, D, C, S*
	Design for specific site		ü	ü			ü	*P, D*
Uncertainty	*Behavioural uncertainty*	ü		ü				*P, C, S, D*
	Technology						ü	*C*
	Institutional uncertainty			ü		ü		*P, C*

Note: P: Professionals, C: Contractors, S: Suppliers, D: Developers

6. Discussions and Conclusions

6.1 Other private sectors bearing extra TCs with no evident benefits except for developers

All the key stakeholders in private sectors have borne TCs due to the implementation of the GFA Concession Scheme (Table 2), but only developers can benefit directly from this scheme with bonus GFA. It in turn influences the effectiveness of the GFA Concession Scheme negatively. It seems that the developers have to use GFA concession to offset the extra TCs. If they pay other participants more for their extra efforts, developers will benefit less from the GFA Concession Scheme. In this situation, developers may not have interests in GB development because of its high opportunity cost. If nobody can obtain extra fee from developers in a competitive market, all the other stakeholders have to absorb the TCs by themselves. This may explain the slow growth of the GFA concession projects. If 10% GFA concession is the only benefit, TCs must be reduced to make the GFA Concession Scheme implemented more efficiently. It is obvious that at the time of designing the GFA Concession Scheme, TCs were ignored. It has affected the implementation efficiency of the GFA Concession Scheme and should be taken into considerations when design the benefits allocation of the GFA Concession Scheme.

6.2 TCs changed with the design of the policy instrument and highly specific to the policy

It is recognized that three dimensions, asset specificity, frequency and uncertainty, of the GFA Concession Scheme would induce TCs. This paper identified the sub-determinants regarding the GFA Concession Scheme. It illustrates that at the time of designing the building regulations and control, the transaction determinants have been generated. For example, the BEAM Plus is designed ambiguously, which leads to a lot of transaction uncertainties and induces TCs. Therefore, if the BEAM Plus is changed to be more precise, and participants only need to follow the certain standards, the TCs resulted from transaction uncertainties could be reduced. Mover, every policy instrument has its own sub-determinants under the three main transaction dimensions, which induce different types and the amount of TCs. Therefore, TCs are highly specific to the policy, as supported by Mundaca et al (2013). However, there are some common relationships between the regulation design and TCs involved: 1) the more criteria the regulations have, the more TCs induced; For example, before 2011, developers could also apply for the GFA concession as long as they provide the twelve building features according to the Joint Practice Note (JPN) 1 and JPN 2. While after 2011, they have to comply with the SBDGs and BEAM Plus that are prerequisite to be granted GFA concession. This induced a lot of TCs in the process (see Table 2). 2) The more stakeholders involved, the more TCs induced. For instance, to fulfil the BEAM Plus, GB consultants have to be involved that induces more coordination and negotiation costs. 3) The more precise and standard the regulations are, the less TCs borne by private sectors. As mentioned, BEAM Plus is ambiguous that participants have to spend more time reducing uncertainties.

Acknowledgement

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Appendix 1

Profession	*Qualification and Position*
Architect	*Authorized person; more than 20 years working experience; Director of Architectural firm*
Architect	*Registered architects; Chairman of architectural firm*
Architect	*Authorized person; Hong Kong Institute of Architects Fellow Member*
Architect	*Senior architect; Working in leading architecture firm for 5 years in Hong Kong; All the projects the architect has joined are green buildings.*
Architect	*Manager, working in leading architecture firm that all the projects it did are green buildings.*
Developer	*CEO in one of leading real estate development firms in Hong Kong*
Surveyor	*Green building professional, environmental officer working in leading construction firm. Familiar with LEED and BEAM Plus.*
Surveyor	*Authorized person; Project director of consultancy firm*
Surveyor	*Director of consultancy firm*
Professor	*Over 10 years working experience in project management and building control*

Regulating for climate change related overheating risk in dwellings

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Abstract

There is broad scientific consensus supporting the link between CO_2 emissions and climate change. In cool and temperate climates such change is predicted to result in (among other impacts) warming ambient temperatures. As in recent years buildings in such locations have been increasingly optimised for heat retention (through regulations and standards), a warming climate has the potential to have a significant impact on the built environment and there is already evidence of overheating in new and recently constructed buildings.

Regulations in the built environment are largely designed to address issues of health and safety. In recent times however, such regulations have increasingly sought to incorporate issues related to energy efficiency while being used to implement national carbon reduction targets at the building scale. Arguably, building regulations remain focused on the 'point of handover' or near term performance, which given the uncertainty associated with predictions (such as climate change, occupant behaviour or technological change) is understandable. Such an approach however, in a situation where the current existing stock is seen as a major barrier to carbon reduction, risks buildings delivered today becoming prematurely obsolete due to the impacts of climate change.

Current overheating risk assessments in building regulations may not be appropriate as they are largely based on historic climate data. There remains a role however for regulations and standards that take account of the potential impacts of climate change. Building upon earlier research by the authors that demonstrates the potential magnitude of the overheating risk for UK dwellings, this paper suggests a risk based regulatory approach to overheating assessment based on climate change predictions while incorporating a requirement for adaptation planning. The approach put forward is based on semi-detached dwellings, built to new and emerging standards and regulations and aims to ensure that short term efficiency is not compromised for long term performance and comfort, thus minimising the potential for premature obsolescence related to overheating.

Keywords: Adaptation planning, Building regulations, Climate change, Dwellings, Overheating risk

1. Introduction

The built environment is responsible for a large proportion of global energy use and corresponding CO_2 emissions, with the residential sector using 18% of energy in 2011 (U.S. Energy Information Administration, 2015). In that context and with the drive to reduce such CO_2 emissions and thus mitigate against climate change, there has in recent years been a drive to make our dwellings more energy efficient. Building regulations have set increasingly ambitious energy reduction targets while other standards and assessment methods have emerged which go beyond the minimums of the building regulations (such as the Passivhaus standard). In cool and temperate climates increasing efficiency largely means optimising buildings for heat retention, with increasing levels of insulation and air tightness significantly reducing energy consumption.

Although the drive to improve efficiency, reduce emissions and minimise the potential for climate change is well founded, as noted by the IPCC (2007) a certain amount of warming is now inevitable. In cool and temperate climates there is evidence that this change may result in overheating (for example Jenkins et al., 2014a and Dodoo et al., 2014). Adaptations to alleviate overheating (Porritt et al., 2012) may help reduce the risk, however such adaptations may result in costs that some sectors of society cannot afford (Hills, 2012). In this context there is a need for building regulations to consider the impacts of predicted climate change. Furthermore, as ambient temperatures warm it is likely that occupant behaviour may become an increasingly important factor where clothing, work and lifestyle patterns may have to adjust.

This paper, which builds upon an earlier publication by the authors that sought to understand the magnitude of the potential for climate change related overheating (Mulville and Stravoravdis, 2016), presents a risk based approach for dealing with such overheating. Such as approach could form part of a regulatory framework that considers the potential impacts of climate change. The proposed approach aims to ensure that short term efficiency does not result in an unacceptably high overheating risk in the long term, thus attempting to take account of the lifetime performance of the building.

2. Literature Review

Roaf et al. (2015) suggest that the long life of buildings presents a challenge in developing *'fit for purpose'* regulations and standards in the context of climate change.

Most studies that seek to explore overheating related to climate change in dwellings do so using predictive building simulation models, considering how building specification, building type and/or location can impact on the magnitude of the overheating (for example see Peacock et al., 2010 and McLeod et al., 2013). Some studies consider the potential benefit of technical building adaptations to reduce overheating (such as Porritt et al., 2012) while others also consider the role of occupant adaptations linked to behaviour (such as Mavrogianni et al., 2014). In this context the review that follows focuses on the evidence for current and predicted overheating, how this may be avoided, how the current overheating assessment methods may contribute to this and what alternative approaches may be of benefit.

2.1 Evidence of overheating

There is evidence that new, recently constructed and well insulated dwellings may already be experiencing overheating, especially during warm summers (Dengel and Swainson, 2012). In support of this McLeod et al. (2012) suggest that highly insulated buildings in the UK, Ireland and Northern Europe may be at risk of overheating, arguably as they have been optimised for heat retention.

Going forward, the frequencies of such problems are predicted to increase. Jenkins et al. (2014a) suggest that by the 2030s, 76% of flats and 29% of detached dwellings in the UK could be at risk of overheating. Furthermore, Dodoo et al. (2014) in a study considering the potential impact of climate change on overheating risk for ‘conventional’ and ‘Passive House’ dwellings in Sweden, predicted significant increases in cooling demand by 2050 (reductions in heating load were also predicted). The research predicted a proportionately greater increase in cooling demand for the highly insulated Passive House building. In support of this Orme and Palmer (cited in Dengel and Swainson, 2012) note that increasing levels of insulation can result in increasing overheating risk. De Wilde and Tian (2012) suggest that buildings may be more resilient to climate change than expected due to the relatively short life expectancy of systems, presence of additional capacity in those systems and opportunities to install new systems. However, Peacock et al. (2010) note that an increase in installed air conditioning could result in occupant behaviour that accentuates energy consuming behaviour. A challenge in how to deal with overheating risk remains.

It has been suggested that raised temperatures in bedrooms overnight is a particular risk (Naughton et al., 2002 as cited in Peacock et al., 2010), where temperatures above 24°C have been linked to impaired sleep and health implications (Dengel and Swainson, 2012). In this context Peacock et al. (2010) suggest that where high bedroom temperatures overnight are problematic, the use of a ‘cooling nights’ metric may be of benefit.

2.2 Overheating assessment methods

Given the evidence of overheating in new and recently constructed buildings it can be argued that the current approach to overheating risk assessment may not be fit for purpose. In regulations, assessments related to overheating risk are often made using relatively simplistic steady state tools (such as SAP UK (Department of Energy and Climate Change [DECC], 2014). This may be due to the complexity and resource needed to conduct, potentially more accurate, dynamic simulation based assessments (Jenkins et al. 2013). It has been argued that the current approach cannot account for the potential impacts of a warming climate as much of the climate data used is historic (de Wilde and Coley, 2012). Furthermore, it has been suggested that the current approach to overheating risk assessment may also allow for unrealistic user adaptations, such as window opening (Mulville and Stravoravdis, 2016).

Peacock et al. (2010) note that there remains a role for policy in addressing elevated temperatures in dwellings. Jenkins et al. (2013) suggest that using an alternative approach based on overheating frequency curves derived from regression analysis of a range of climate predictions and analysed using dynamic simulation for specific buildings, may improve predictions and allow for the consideration of risk. Expanding on the proposed overheating risk curves (Jenkins et al., 2014b), it is suggested that potential user adaptations, such as opening windows and technical intervention (such as shading and the reduction of internal gains) could be included in the assessment. The approach does still require significant knowledge of the building operation and building characteristics, however it greatly reduces the amount of simulation required and may help designers to contextualise the problem (Jenkins et al., 2013). Jenkins et al. (2013) argues that any methodology used to assess overheating should be industry focused and able to include a range of building types, glazing ratios, building characteristics and locations.

2.3 Reducing overheating risk

McLeod et al. (2013) found that in highly insulated dwellings, external shading followed by adjustments to south-facing glazing ratios had the greatest potential to reduce overheating risk. Supporting this, Porritt et al. (2012) suggest that the control of solar gains (shading, shutters, glazing specification), solar reflective coatings and insulation (the study was based on dwellings with low levels of existing insulation) could also help reduce overheating risk. Furthermore, increased ventilation (Porritt et al., 2012) and higher levels of thermal mass (Gupta and Gregg, 2012) have also been shown to be of benefit although in both cases there are potential limitations. Peacock et al. (2010) note that although during the day time thermal mass would appear to have significant advantages, overnight the measured benefits may reduce as stored heat from day-time heat gains is radiated back into the spaces. This is supported by McLeod et al. (2013) who found that although overall temperatures in high thermal mass buildings were lower than in others, bedrooms in light weight buildings cooled more rapidly (in the 2080s). Where raised temperatures in bedrooms have been shown to be problematic (Dengel and Swainson, 2012) this potentially presents a risk and the perceived benefits of thermal mass in dwellings may be questionable.

Window opening may help to reduce overheating risk. However, Mavrogianni et al. (2015) suggest that window opening in urban centres may have negative health impacts, with Tong et al. (2016) highlighting the link between raised indoor air pollution and proximity to roads. This is supported by Peacock et al. (2010) who note that window opening is likely to be limited by noise, pollution and security in urban areas. In addition to the discussion about window opening behaviour there is evidence that in the future the benefits of such window opening may reduce. Peacock et al. (2010) found that although increased ventilation still had benefits this was not enough to overcome the overheating issues predicted for London in the 2030s.

Gupta and Gregg (2012) note that adaptations to reduce overheating risk could result in some increase in heating demand and suggest that phased adaptations over the lifetime of the building may be of benefit. In this context Jones et al. (2015) set out an approach to adaptation planning related to the predicted impacts of climate change. Although based on a non-domestic building, the approach suggested that where future problems were identified an adaptation plan could be developed to enable the building to be altered on a cost-effective basis when required. Where interventions in the future may prove prohibitively expensive, but predicted risk is high, enabling works to allow the future adaptation could be incorporated into the initial construction phase.

3. Methodology

As detailed in the earlier paper associated with this research (Mulville and Stravoravdis, 2016), and summarised here, this study used dynamic simulation modelling for a ‘typical’ (UK) semi-detached dwelling coupled with climate change predictions to understand the level of overheating risk. To understand how the heat retention parameters of the fabric impact upon the potential overheating risk, five standards were chosen and associated construction specifications developed to reflect these construction standards (UK Part L 2006 and 2010, ‘Good Fabric’, ‘Advanced Fabric’ and the Passivhaus standard). The construction system used was also varied to reflect a range of potential levels of thermal mass (low, medium and high options). For the purposes of this paper the analysis and results presented are based on a North-South orientation only.

3.1 Simulation approach

The ‘typical’ building was modelled using Ecotect® software (Marsh, 1996) which was then exported to Heat Transfer in Buildings 2 (HTB2) software (Lewis & Alexander, 1990) for the purpose of dynamic simulation and analysis. The models were then ‘run’ for the summer months using a range of current and probabilistic future reference years (climate files) based around the prediction of the UKCP09 weather generator and developed as part of the PROMETHEUS project at the University of Exeter (as detailed by Eames et al., 2011). For the purposes of this work the 50^{th} percentile medium scenario predictions were chosen. The results presented in this paper are based on Design Summer Years (DSYs) representing near extreme scenarios. In addition a range of possible window opening positions, where included in the modelling.

3.2 Overheating assessment approach

The adaptive comfort approach to predicting overheating as detailed by Nicol and Spires (2013) was used to determine when overheating may have occurred and to gauge the magnitude of the overheating identified. This is represented by three overheating criteria. Criteria one was based on the comfort threshold being exceeded, criteria two considered the severity of the overheating in a given day and criteria three set an absolute maximum allowable temperature. In each case the temperatures were related to a running mean of outdoor temperature and were analysed based on the outputs of the preceding modelling approach. Exceedance of any two of these three criteria, as detailed by Nicol and Spires (2013), was then considered to represent an unacceptable level of overheating. As noted in the preceding research to this paper (Mulville and Stravoravdis, 2016), there remains a debate about the most appropriate metrics to be used. As a result, additional analysis was carried out based on exceedance of specific temperatures.

4. Overheating Risk

This research sought to consider the potential impact of a warming climate on dwellings. In this case a 'typical' semi-detached dwelling was chosen and analysed using dynamic building simulation and probabilistic climate scenarios for a southern UK climate.

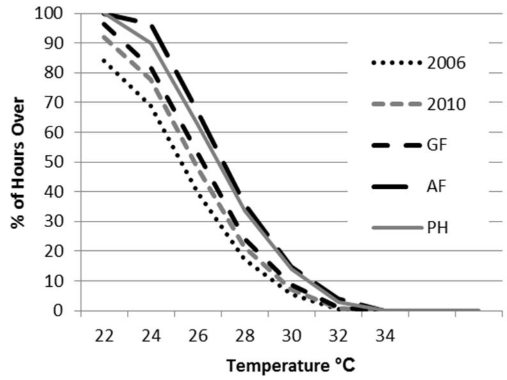

Figure 1: Temp. frequency curve – Across standards

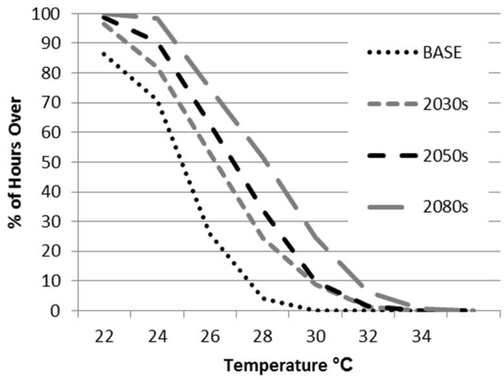

Figure 2: Temp. frequency curve – Overtime

4.1 Predicted overheating patterns

Figures 1 and 2 are based on scenarios where windows are able to be opened to the 'slightly opened' position (triggered by internal temperatures thresholds and appropriate outdoor temperatures to aid cooling) which represents one air change per hour and a medium thermal mass construction. As can be seen in Figures 1 and 2there is a general increase in temperatures and therefore overheating risk as fabric heat retention criteria increase (insulation levels, air tightness, glazing specification etc.) and the climate warms. This was also reflected in the wider analysis across all thermal mass and window opening scenarios. The Passive House standard did appear to offer some protection from overheating when compared with the 'Advanced Fabric' building, with 6.6% reductions in the 2030s, 6.8% in the 2050s and 7.2% in the 2080s observed in certain scenarios (see Mulville and Stravoravdis, 2016). This is arguably due to the greater emphasis on solar protection required by the Passive House standard and possibly a more robust overheating assessment. Thermal mass was also found to offer benefits in reducing levels of overheating with reductions of 15% observed in the 2030s, however the benefit for highly insulated options (Advanced Fabric and Passive House) may reduce between

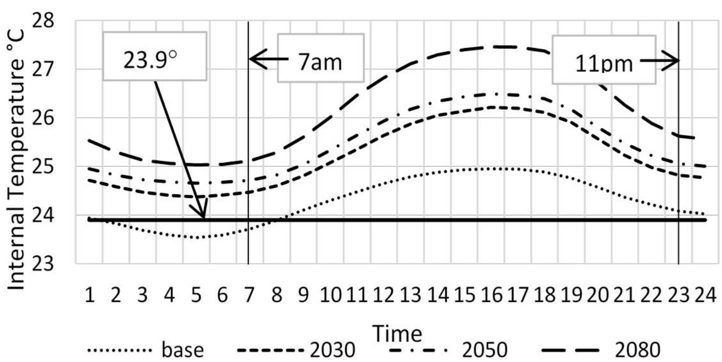

Figure 3: Daily temperature profile (HTM, Good Fabric)

the 2050s and 2080s. This could be related to a reduction in internal to external temperature differences over time, with for instance a reduction in the mean internal to external temperature difference for the Advanced Fabric building of 3.36°C observed between the base case and the 2080s. This in turn reduces the ability of ventilation air to cool the building fabric. As demonstrated in Figure 3, which is based on slightly open windows, as the temperature warms due to the impacts of climate change, night-time bedroom temperatures frequently exceed the 23.9°C threshold (as noted by Peacock et al, (2010) this is the temperature at which bedroom occupants at night may begin to feel uncomfortable and may seek to change the conditions) during peak summer. This does reduce where windows can be opened further (see Figure 4, based on 'half open' windows in the 2030s), but the issue remains. Exploring this in more detail it is found that although thermal mass can, as noted above, reduce overall levels of overheating (measured against the adaptive comfort criteria), temperatures are higher overnight for the high thermal mass solution compared to the low thermal mass solution (see Figure 4). This can be related back to the suggestion by McLeod et al. (2013) that heavy weight buildings may contribute to raised temperatures in bedrooms overnight due to the re-admittance of stored gains into the space. As demonstrated by comparing Figures 3 and 4 window opening to increase ventilation offers benefits, although as previously noted such benefits may reduce over time and concerns regarding air pollution, noise and security remain.

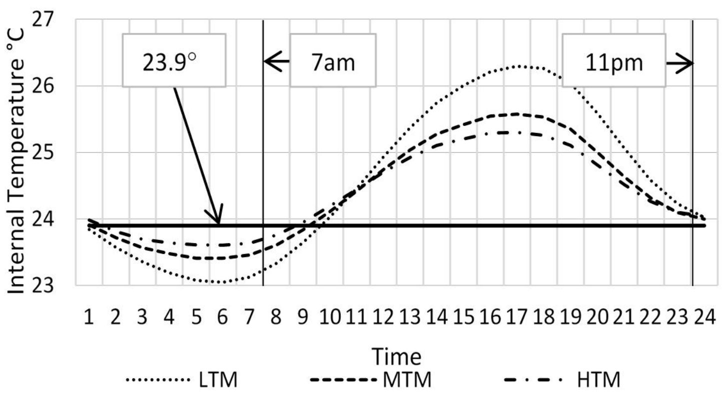

Figure 4: Daily temperature profile (Good Fabric – 2030s)

In the context of the analysis presented here, it can be argued that there is a need for more robust building regulations that take a longer term view in relation to overheating risk assessment. There is also a need to explore overheating metrics in relation to overnight bedroom temperatures.

4.2 Building overheating risk categorisation criteria

Based on the preceding discussion (and findings of the previous research to this paper (Mulville and Stravoravdis, 2016)) it can be argued that the main risk criteria related to overheating in dwellings are overall fabric heat retention parameters (insulation levels, air tightness, window specification), thermal storage parameters (mass) and opportunities for occupant adaptation (window opening). There remains questions around both thermal mass and window opening in relation to long term benefits, overnight temperatures and urban environments. In addition, building on the findings from previous studies, building configuration (semi-detached, terraced, flat etc. and orientation (including shading)) and insulation position (which could be included in the 'heat retention parameters') are also risk categories. This study did not seek to rank the relevant importance of these risk categories, but instead considered how the potential combinations of these criteria are likely to contribute to overall overheating risk (see Figure 6).

4.3 Proposed risk based assessment approach

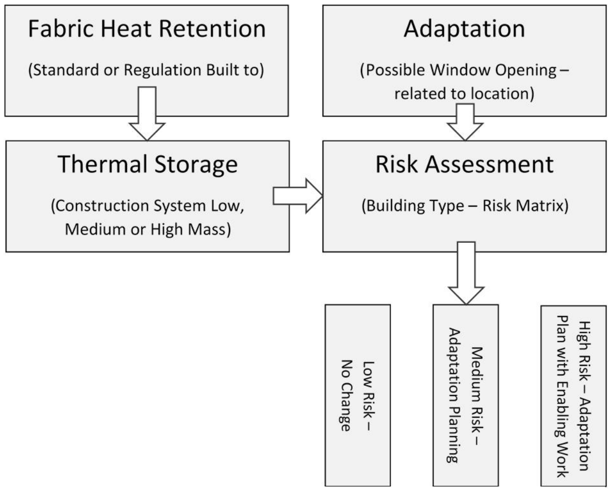

Figure 5: Proposed Approach – Flow Chart

As noted by BJM (2009) cited in de Wilde and Tian (2012) a risk can generally be stated as 'probability x consequence'. In this case the probability is that overheating risk derived from dynamic building simulation and the consequence is the impacts of that overheating. In any risk assessment the weightings of parameters used should reflect their relative importance. In this case exceedance of the adaptive comfort criteria is used to determine the level of risk. This is based on the relevant running mean of acceptable temperatures. As raised bedroom temperatures at night time have been shown to be problematic and as the benefits of thermal mass in reducing overheating during the day may reverse overnight, a debate remains regarding the most appropriate metrics to use. If raised temperatures in bedrooms overnight (above 23.9°C) was used as the overheating metric in this study the risk matrix presented in Figure 6 would be significantly different. The adaptive comfort criteria as described, coupled with the risk criteria previously noted (fabric heat retention parameters, thermal storage parameters, adaptation options and building configuration) are combined to create the risk matrix displayed in Figure 6. A flow chart of the assessment process is presented in Figure 5, detailing the steps taken to reach the appropriate point on the risk matrix. One of the key input criteria for the proposed approach is the possible window opening position. Permissible window opening positions must be linked to the location of the building and a decision made based on exposure to pollution and noise along with an assessment of potential security concerns. The risk matrix as presented considers the 2030s only, arguably a weighted matrix could also include predictions for the 2050s and 2080s. However, as noted by de Wilde and Tian (2012) longer term predictions become increasingly uncertain due to the range of assumptions association with maintenance, systems and renovations etc. As a result, in this case a shorter term assessment is presented, although longer term predictions may also have merit where the level of uncertainty can be taken into account.

As noted by Gupta and Gregg (2012) interventions made now could result in increased heating demand. In this context regulations dealing with overheating should aim to optimise lifetime building performance while minimising the risk of future overheating. An approach integrated with adaptation planning and backcasting/forecasting (Jones et al., 2015) could help to deliver whole life performance. Therefore, the output of the proposed approach is requirements for adaptation planning, adaptation planning with enabling works or a change in the approach taken based on the level of risk identified. As an example, taking a dwelling in an urban area where only slightly open windows may be possible. If built to the ‘Good Fabric’ condition with low thermal mass, this dwelling would be at high risk of overheating (see Figure 6) and would require an adaptation plan with enabling works to allow for future adaptations (such as preparations for the installation of shading). As this is likely to add cost, it may be that the designer/ developer would choose to avoid such a scenario. In that case, a change in construction system to a medium thermal mass level has the effect of reducing the risk and removing the requirement for enabling works, while a high thermal mass solution would move the building into a low risk scenario. This approach must be considered in the context of the previous comments about the potential impact of thermal mass on overnight temperatures in bedrooms. However, if appropriate overheating metrics could be assigned, the approach outlined could help to ensure that current performance is not compromised to avoid longer term overheating. The approach, as such, incentivises the designer/developer to favour a low risk scenario while accounting for a range of building characteristics (as suggested by Jenkins et al., 2013) and favouring phased adaptations (as suggested by Gupta and Gregg, 2012).

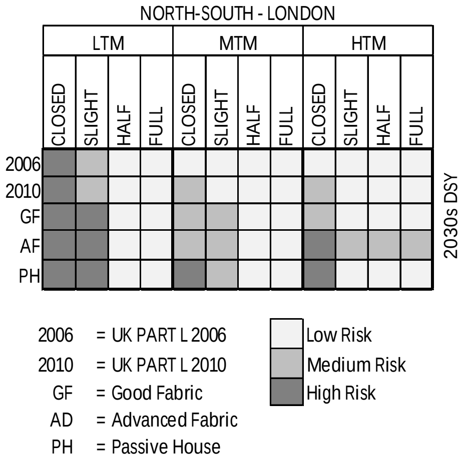

Figure 6: Risk Matrix (adapted from – Mulville and Stravoravdis, 2016)

5. Discussion & Conclusion

The overall installed capacity of artificial cooling in UK dwellings remains low (Hulme et al., 2011). However, if the potential increase in overheating as predicted is realised the installed capacity could increase significantly (Peacock et al., 2010). Although there is likely to be a corresponding reduction in heating demand (Dodoo et al., 2014) and with technological change the overall increase in carbon emissions may be minimal, increased use of artificial cooling could have a negative impact on the energy use behaviour of occupants (Peacock et al., 2010). Furthermore, if the overheating risk is not addressed a shift from winter to summer time fuel poverty could be observed, with corresponding health, wellbeing and societal impacts. As discussed, the current approach to overheating risk assessment may not be fit for purpose as it does not take account of climate change projections and may assume unrealistic adaptations.

The proposed approach to overheating risk assessment utilises the increased accuracy of dynamic building simulation modelling (when compared to steady state assessments) (Jenkins et al., 2013), while reducing the amount of resource required and presents an approach that could be applied by industry. If risk matrices for a range of building types, in a range of locations could be developed a large proportion of the ‘typical’ new stock could be represented. The requirement for adaptation planning based on the level of risk identified would help to ensure that pathways focused on long term performance can be developed for the dwellings in question. This approach could be tied to the likely major refurbishment points for the building, such as when windows etc. have reached the end of their useful life.

The findings of this research demonstrate that, by using risk based assessments implemented through the building regulations, it may be possible to take account of the potential impacts of climate change (in this case overheating) while considering the inherent uncertainty of such predictions. The implications for building regulations is a shift from a *'point of handover'* approach towards a forecasting role. Such forecasting must be approached with caution and an appreciation of risk and probability to avoid unintended consequences. Arguably, given the potential impacts of overheating on occupants, this refocuses on the traditional health and safety role of the building regulations while accounting for energy performance on a whole of life basis.

As noted, the metric used can have a significant impact on the level of risk identified. This is particularly true in relation to temperatures in bedrooms overnight, where issues related to the relevant benefit and drawbacks of thermal mass may also be important. Further research in relation to developing overheating metrics in dwellings that takes these issues into account would be of benefit. In addition, as the research demonstrated, window opening to increase ventilation can have a significant impact on reducing overheating risk. However, in some scenarios presumed window opening behaviour may be unrealistic or may result in negative health impacts related to pollution. Further research into window opening behaviour in dwellings, particularly in urban areas subject to noise, pollution and security issues would be of benefit.

6. Limitations

The approach taken in this study must be considered in relation to a number of limitations. A medium level, 50th percentile prediction was used and a wider consideration of potential climate scenarios may add depth to the assessment. In addition the building simulation approach used includes a number of assumptions related to internal gains and occupancy patterns that cannot be easily predicted. Although a range of 'typical' buildings could be addressed if this approach was expanded to include other configurations, the criteria that define 'typical' would need to be carefully developed. A range of dwellings that cannot be easily categorised would remain and these would require more resource intensive building specific assessments.

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Ten years of performance building code in Spain (2006-2016): facing the challenge of climate change

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Abstract

Spain has experienced various important changes in the first years of this century regarding the building activity. A new building act, which clearly defined, for the first time, the objectives, the sector stakeholders, competencies, responsibilities and guarantees, was followed by the approval of a performance building code. This new regulatory frame seemed a good tool to fulfil the ambitious energy efficiency goals set in parallel by the EU, but arising problems are threatening today its capacity to face the challenge, at least as a single actor.

The severe economic crisis, affecting specially the building activity, which dropped sharply from 2007, has slowed down the impact of the code. The complexity of the Spanish legal system, with shared competences between the State, the Autonomous Communities and the Cities does not contribute to set clear common criteria, methods and administrative procedures. The strong tradition of inefficient building control is based exclusively on formal document completion, but not on real performance evidence. The existing building stock, under none or very low standards, that will represent in the future a big percentage of the total, is almost out of the scope of the code. To complete the panorama, important social issues as unemployment, energy poorness and changing demographics make very difficult to progress towards facing effectively the threat of climate change.

An important change in building regulations and control is to be produced in the country in a near future, requiring a real structural change. On the one hand, diminishing regulations will help to reduce the administrative burden, allowing flexibility and saving time and money in the first steps of the process. It will simplify also the differences between the various regulatory bodies. On the other, an effective performance control at the end will help to ensure quality and act as a real driver for the different stakeholders.

Keywords: Building Regulations, Building Control, Climate Change, Building Stock, Building Performance

1. Introduction

Spain experienced a key regulatory change in 1999, when the Building Act (1999) was approved by the Parliament. For the first time, the Country had a document which clearly defined the Building Objectives (Habitability, Safety and Functionality), the stakeholders and their competencies and the guarantees for final users.

The Building Code, approved in 2006, developed the Building Act Objectives in Performance Requirements (2006). It was intended to be a well-organized normative framework to facilitate their fulfilment in harmony with European regulations. It included five Energy Saving Requirements to accomplish the objective of “a rational use of the energy”: limitation of the energy demand, efficiency of building systems, efficiency of lighting systems, minimum solar contribution for hot water production and minimum contribution of PV for electricity production.

The structure of the Code was, in fact, based on the one outlined by the Nordic Building Codes Committee in the 1970s, but it remains incomplete if compared with the more advanced scheme proposed by the IRCC. As Meacham and others (2004, 2005 and 2010) have pointed out, a complete Performance-Based Building Regulatory Framework needs to be informed with accurate data from the building, the users and the tolerable risk levels.

Unless some aspects traditionally addressed by building regulations are relatively easy to quantify, to effectively implement and to follow by the administration, others are not. On one hand there are some risks faced by the inhabitant, with immediate and evident consequences. On the other there are some potential risks, not so evident to the user. This is the case of the regulations facing aspects like fire safety or energy efficiency. The user may be aware of the risk, but he thinks he can probably manage it in some way.

Addressing the climate change through building regulations and control is a very difficult task for many reasons. It is a fragmented process where different stakeholders come into play, seems to be manageable by them and has long term consequences for the environment, not directly for the building user. It becomes therefore, as has been commented, an open gate for responsibility dilution (2013).

2. Current sector situation

Unless the Building Code was approved in a period of a very important building activity growth, the economic crisis started a year later, in 2007, and its impact in the country economy and especially in the building sector was lethal. Data offered by the Ministry of Fomento (2016), in Table 1, reveal two very important facts. The first one is the significant drop of the building activity, affecting especially the new buildings, which in 2014 represented only a 10% of the 2006 number. The second one is the growing importance of the rehabilitation works, that over passed the new ones in 2012.

Table 1: Number of Buildings according to work type 2006-2014

	2006	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
new	*230.044*	*187.147*	*93.678*	*51.744*	*44.781*	*38.973*	*28.956*	*24.052*	*22.594*
to rehabi-litate	*35.856*	*33.359*	*34.807*	*33.267*	*31.910*	*30.237*	*29.154*	*25.227*	*26.136*
to demolish	*28.480*	*26.141*	*14.573*	*7.984*	*8.084*	*7.295*	*6.941*	*5.725*	*5.279*

A third important aspect is the weight of the housing dwellings in the total property stock. According to data shown in Table 2 from the Observatory of Housing and Ground (2014), referred to September of 2013, and revealing the current number of properties in Spain (Navarre and the Basque Country not included, but specific data from these two autonomies, based on buildings and not in properties, are consistent), two thirds of the total building properties are housing dwellings (66,1%).

*Table 2: Number of properties, by use and date of construction **

	till 1980	**1981-1990**	**1991-2001**	**2002-2013**	**No data**	**Total**
Houses	*11.868.582*	*2.938.095*	*3.728.153*	*4.496.245*	*111.192*	*23.142.267*
Other Uses	*1.700.176*	*1.730.705*	*2.734.667*	*3.637.819*	*138.611*	*11.895.201*
Total	*15.521.981*	*4.668.800*	*6.462.820*	*8.134.064*	*249.803*	*35.037.468*
**Data from Navarre and the Basque Country are not included*						

The fourth critical aspect we can conclude from the same study is that a significant percentage of this building stock (51,3% of houses, 61,9% of industrial facilities, 51% of commercial and 41,3% of offices) was built before 1980. The year 1980 is very important in Spain, because the first insulation regulation was approved in 1979. It was completely prescriptive and considered mainly transmittance through walls, roof and soil with a very poor evaluation of important parameters, like thermal bridges.

The population and dwelling census for all the Country is worked out every ten years and its evolution, according to different data from the National Institute of Statistics (1981, 1991, 2001 and 2011), shows again (Table 3) that more than 58% of the housing dwelling stock was built before 1980. It also shows the important increase in the population number between 2001 and 2011, directly linked to the important construction activity till 2007.

Table 3: Number of housing dwellings and population, census 1981, 1991, 2001 and 2011

	1981 census	***1991 census***	***2001 census***	***2011 census***	***1991-2001 Increase***	***2001-2011 Increase***
Total Houses	*14.770.988*	*17.220.399*	*20.946.544*	*25.208.623*	*3.726.155*	*4.262.069*
Main Houses	*10.431.327*	*11.852.075*	*14.187.169*	*18.083.692*	*2.335.094*	*3.896.523*
Population	*37.683.363*	*38.872.268*	*40.847.371*	*46.815.916*	*1.975.103*	*5.968.545*

These four evidences: activity drop, shift to rehabilitation, percentage of houses and old inefficient stock, challenge the regulatory body, intended for a period of a building expansion activity based on new designs.

3. Social problems are knocking at the door

Building regulations and control cannot be aware of important social issues, especially if the ambitious European directives to face the climate change are to be met. Unemployment, fuel poverty and changing demographics are among the most influential.

Spain has currently the largest unemployment rate of the EU, a 20,9% according to 2015 data. Unless the evolution shows a slow improvement from the worst data of 25,77% in 2012, it is still far from the register of 8,26% in 2006. The unemployment rate depends directly on the building activity if we contrast it with Table 1.

Based on readily available statistical data sources – the Household Budget Survey (HBS) and Survey on Income and Living Conditions (SILC) – it is estimated that approximately 10% of the Spanish households (equivalent to 4 million people) were in fuel poverty as of 2010. This estimate is based on two widely recognized measuring approaches, which consider that a household is in fuel poverty when spends a disproportionate share of its annual income (more than 10%) on energy or states to be unable to keep its home adequately warm in the winter. The crisis is not only making the number of fuel poor households and unemployed people grow; it is also increasing at a fast pace the proportion of unemployed households that are in fuel poverty.

According to the Projection of the Spanish Population (2014), represented in Figure 1, if the current demographic tendency is maintained in the future, Spain will lose a million inhabitants in the next 15 years and 5,6 million in the next 50 years. The percentage of the population exceeding 65 years, actually an 18,2%, will raise to 24,9% in 2029 and to 38,7% in 2064

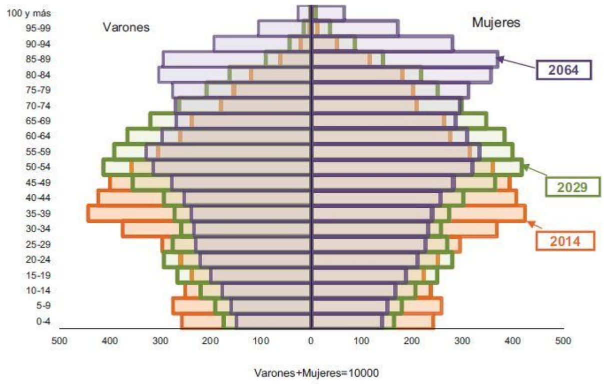


Figure 1: Projection of the demographic pyramid, 2014-2029-2064, by gender

These three problems will be important drivers in a near future. If unemployment and fuel poverty persist, there won't be money for maintenance and refurbishment and the demographic change will avoid the necessity of new structures.

4. Current regulatory situation

The Building Act picked up the six essential requirements that a building had to meet according to the European Directive of Construction Products (1988) (89/106/EEC). Between them, the "Energy economy and heat retention" requirement stated that the construction works and its heating, cooling and ventilation installations must be designed and built in such a way that the amount of energy required in use shall be low, having regard to the climatic conditions of the location and the occupants.

Starting from its first version in 2006, the Building Code, in its document "Energy Saving" (DB-HE), has been increasing the saving requirements in order to transpose the different European Directives. The last one, in 2013, has been oriented to the achievement of the European Union 20-20-20 objectives and partially transposes to the Spanish legal body the Directive on the Energy Performance of Buildings (2010) (2010/31/EU), in relation to the requirements of energy efficiency in buildings established in articles 3, 4, 5, 6 and 7, as well as the Directive (2009/28/EC) on the promotion of the use of energy from renewable sources, established in article 13 (2009).

Between other aspects, it regulates:

- The primary **consumption** of not renewable energy sources for heating, cooling and hot water production in new buildings. The energy rating for the primary non-renewable energy consumption indicator of a new building or an addition to an existing one is required to have an efficiency rate equal or superior to B. In uses different than housing, it includes lighting.
- It limits the energy **demand** for new buildings (in some climate zones, this implies a double thickness of the insulation materials than the considered in the first Code version).
- The performance of the thermal systems is improved.

- The performance of the lighting systems is improved, limiting their maximum installed power and establishing control procedures for natural light use.
- The minimum solar contribution for hot water production is required to new buildings or those where the use is changed with a hot water demand exceeding 50l/day. It is also extended to existing buildings with a hot water demand exceeding 5000l/day, if this over passes by 50% the previous demand.
- The minimum Photovoltaic contribution is extended to new or existing buildings where a global rehabilitation is carried out with a surface exceeding 5000 m2.

In 2011 the regulation laying down harmonised conditions for the marketing of construction products and repealing Council Directive 89/106/EEC was approved (2011) (Regulation (EU) Nº 305/2011 of the European Parliament and of The Council). A new essential requirement appeared: sustainable use of natural resources. According to it, the construction works must be designed, built and demolished in such a way that the use of natural resources is sustainable and in particular ensure the following:

a) reuse of recyclability of the construction works, their materials and parts after demolition
b) durability of the construction works
c) use of environmentally compatible raw and secondary materials in the construction works

This requirement is still under development as to be applied to the buildings. It is applied to products at a level of ecological labelling (environmental labels type I and III), but is voluntary.

5. Current control situation

Two are the instruments adopted to fulfil the EU objective of improving energy efficiency by a 20% by 2020:

- Energy Certification is a requirement derived from the 2002/91/CE and the 2010/31/EU Directives, partially transposed to Spain by the Royal Decree 235/2013 (2013). It is the main tool to evaluate the consumption of non-renewable primary energy, expressed in kWh/m2, and the CO2 emissions, expressed in KgCO2/m2year, and establishes the building energy performance.

- Energy Audits are regulated by Royal Decree 56/2016 (2016), which derives from the 2012/27/EU Directive. It aims to promote actions that may contribute to savings in primary consumed energy as well as to optimize the energy demand of installations, equipments or systems of big enterprises (not SMEs).

5.1 Energy Certification

Energy Certification is compulsory for new buildings, existing buildings that are sold or rented and buildings or building parts run by a public authority with a surface exceeding 250 m2 and frequented by the public.

The government has developed free computer tools for certification, both for new and existing buildings, has approved the energy efficiency certificate model and has set the label. The scale results from dividing the emissions and primary energy consumption of the building by the ones of a reference building. In the case of new structures the reference building meets the building code requirements and in the case of existing buildings it meets medium values of the existing stock. It is very complicated to offer a translation between the energy savings and the letters, because it depends on the building type, year of construction, location, etc.

The certification system lays on the reliability of the modelling tools and, for the moment, post-construction testing is not required. The reality shows a big GAP between what is simulated and the reality.

In new buildings, the certification stays at the project level and some evidence through testing should be important in the future to guarantee the calculated values. Air infiltrations, for example, may be responsible for a 30% of the consumption in a linear block typology built before 1979. They depend on the execution of the work, the joint solution between the window and the façade or the window permeability to air. Air infiltration testing could be carried out only in the more representative and critical dwelling units, taking into account orientation, floor level and exposure to wind. Thermal bridges could also be detected by using thermographic cameras.

In existing buildings, the calibration software tools allow the use of many default values, if the real ones are not known, to characterize the building envelope, allowing the GAP to be substantial. In order to reduce it, a previous energy performance monitoring campaign (temperature and humidity sensors, thermofluxometries, infiltration tests and thermographies) could help to have a more accurate diagnosis and, consequently, guarantee the effectiveness of the rehabilitation measures. Some post construction tests, like the ones in new buildings, should be proposed.

Table 4 shows the number of certified and registered buildings at 31 of December of 2014 (2015) and reveals that only one percent of them correspond to new buildings.

Table 4: Number of Energy Certificates by Autonomous Community

Autonomous Community	*Number of certificates New Buildings*	*% of certificates New Buildings*	*Number of certificates Existing Buildings*	*% of certificates Existing Buildings*
Andalucía	*1.040*	*7,91%*	*147.204*	*12,98%*
Aragón	*33*	*0,25%*	*8.863*	*0,78*
Asturias	*52*	*0,40%*	*8.474*	*0,75%*
Baleares	*268*	*2,04%*	*28.464*	*2,51%*
Canarias	*150*	*1,14%*	*16.900*	*1,49%*
Cataluña	*2.030*	*15,44%*	*332.588*	*29,33%*
C. Leon	*207*	*1,57%*	*42.912*	*3,78%*
C. Mancha	*35*	*0,27%*	*24.545*	*2,16%*
Extremadura	*3.015*	*22,94%*	*1.072*	*0,09%*
Galicia	*150*	*1,14%*	*38.413*	*3,39%*
Murcia	*221*	*1,68%*	*26.202*	*2,31%*
Navarra	*775*	*5,90%*	*16.737*	*1,48%*
País Vasco	*285*	*2,17%*	*28.454*	*2,51%*
Rioja	*59*	*0,45%*	*8.847*	*0,78%*
Valencia	*4.578*	*34,83%*	*201.586*	*17,78%*
Madrid	*239*	*1,82%*	*197.332*	*17,40%*
Cantabria	*8*	*0,06%*	*5.372*	*0,47%*
TOTAL	*13.145*	*100%*	*1.133.965*	*100%*

These data, considering the problems to characterize the existing buildings, present a crude evidence and especially if combined with the ones in Table 5, which show the amount of certificates for each rating letter.

Table5: Emissions, new and existing buildings

	A	***B***	***C***	***D***	***E***	***F***	***G***	***Total***
Emissions new	*761*	*950*	*1.489*	*4.338*	*5.406*	*66*	*135*	*13.145*
Emissions existing	*1974*	*7109*	*39.244*	*133.938*	*522.085*	*147.325*	*282.290*	*1.133.965*

The biggest percentage of certificates corresponds to existing buildings and is rated in the worst categories (E, F and G), very far away from fulfilling the B requirements.

5.2 Energy Audits

Energy Audits are compulsory for enterprises with more than 250 employees or a turnover exceeding 50 million Euros and a total balance sheet over 43 million Euros. The energy audit, every four years, has to cover at least an 85% of the final energy total consumption in the national territory.

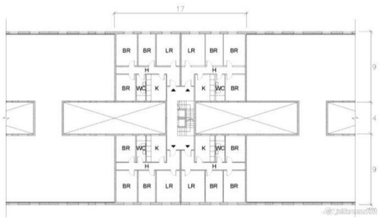
The objective of the audits is to establish a diagnosis of the building actual performance in relation to energy efficiency and to establish the improvement measures to diminish the building energy consumption. As the emissions are also considered, the type of combustible is important.

The Decree establishes that the audits should be based on up-to-date, measured, traceable operational data on the energy consumption and, in the case of the electricity, on load profiles. They have to comprise a detailed review of the energy consumption profile of buildings or group of buildings, industrial operations or installations, including transportation. They shall allow detailed and validated calculations for the proposed measures so as to provide clear information on potential savings.

6. Working with building typologies for existing buildings

Working with typologies has proved to be a good tool to understand the performance of existing buildings. A research study carried out by us selected the most common ones built between 1940 and 1980, a period of big expansion and poor energy performance. This allows establishing rehabilitation measures for building typologies with common architectural and construction features, and not for single buildings.

Through the monitoring of a representative sample, the current energy demands are simulated for the different typologies and different rehabilitation scenarios and intervention levels are proposed to diminish the demand. By doing this, data on most influential energy saving parameters are suggested (Figure 2).



ENERGY MATRIX – T2 BLOCK IN H - ENERGY RETROFITTING SCENARIOS
REDUCED DEMAND OF ENERGY (kwh/m^2·a)
COMPARATION AVERAGE SOUTH AND NORTH DWELLINGS. Option B

F2/R2/L2 Current Status	Exterior insulation in Facade rFei								Interior insulation in Facade rFii			
	ei16		ei12		ei08		ei04		ii08		ii04	
Kwh/m^2·a : 157.49 South 176.19 North	S	N	S	N	S	N	S	N	S	N	S	N
rF+W+R+L+I	37.82	46.73	40.38	49.63	45.99	55.86	57.96	69.17	52.94	63.64	67.81	80.10
rF+W+R+I	40.32	48.50	43.22	51.73	49.36	58.46	62.34	72.75	57.02	66.91	72.92	84.39
rF+W+I	53.36	61.63	56.16	64.74	60.99	70.11	72.51	82.86	68.43	78.30	82.83	94.23
rF+R+I	72.14	83.74	74.89	86.75	80.71	93.02	92.99	106.40	87.95	100.90	103.03	117.42
rF+I	85.18	96.72	87.79	99.59	92.31	104.54	103.11	116.41	99.31	112.15	112.91	127.17

Significant reduction demand: >70% — Moderate reduction demand: 40-55%

High reduction demand: 55-70% — Low reduction demand: <40%

Figure 2: Typology and decision matrix based on different rehabilitation scenarios

Typologies are useful to define usage patterns too, because they can help to characterize the users by means of their social, working or economic characteristics. This is important because there is another important GAP between what is proposed by the regulations in relation to the buildings use and the reality. In some buildings, especially in those with individual systems, the use of heating and the set point temperature differs considerably from the conditions established for calculating the energy demand.

7. Discussion

The relation between buildings and climate change is of double sense. On one hand, the buildings account for 40% of total energy consumption in the EU, therefore being one of the main contributors to greenhouse gas emissions. But on the other, they will be potentially menaced in a future by important natural threats. Temperature rising will demand for more cooling energy, air quality deterioration will ask for more sophisticated ventilation and statistically unexpected rains or winds will challenge the structures and the building systems.

Building regulations in Spain include among their objectives a rational use of the energy and fossil fuels and seem to have a performance structure capable of facing the climate change problem. However, they are emphasizing a model based on documentation fulfilment, which finally works as a prescriptive one with very poor results. The regulatory body is tough for the stakeholders with several authorities having jurisdiction involved.

Important economic and social problems added to the fact that the existing structures will continue representing, by far, the biggest percentage of the stock, will not allow having a significant percentage of energy efficient buildings if things do not change.

8. Conclusions

- The structure of the regulatory body in Spain was designed to give adequate answer to the different building objectives and essential requirements. The rational use of energy is among them and is currently addressed through certification and audits. The use of natural resources (materials), according to the seventh requirement for construction works (Regulation (EU) Nº 305/2011), under the point of view of LCA, is to be addressed as soon as possible.

- Important facts like the activity drop (and increasing rehabilitation), the existing building stock (mainly houses with very poor performance), combined with serious social problems are challenging this potentially adequate structure.

- Data on the certification process show that the system is failing, because almost all the certificates correspond to existing buildings with very poor performance rate. Their results are additionally very uncertain.

- An important change considering less regulations, more design flexibility, improving education, a real risk characterization and more emphasis on the responsibilities of private parties is to be addressed.

- The existing building stock needs to be faced specifically with different strategies and tools, not as a particular case of the new ones. Typological studies may help in this task.

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Interstitial emergence for green building: The emergence of green building practices and assessment schemes

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Abstract

The overall progress towards sustainability in the built environment has been repeatedly criticized for being slow, patchy and failing to have any significant impact. Over the past 20 years, a myriad of environmental assessment schemes have emerged to aid the adoption of green building practices in the construction industry. While these schemes have been touted as steering the drive towards sustainability the framing of the concept "green building" has been criticized for not resonating with industry professionals; with a chasm existing between practices codified in the schemes and what is technically possible and expedient. This paper sets out to explore the emergence of building environmental assessment schemes – how they are created and developed, and which actors influence the contents. The point of departure is that how assessment schemes are developed affects the content, and in turn various actors' ability and willingness to engage with them. Drawing on the field-based theory proposed by Fligstein and McAdam and the concept of interstitial emergence, we explain how green building practices have emerged in the building industry. We explain how a field/interstice for green building has appeared as industry actors engaged in various strategic actions in response to the budding green building movement. As this field emerges, and actors begin to make sense of the green building concept, various frames, templates or guidelines are developed to codify emerging new practices. The fluidity of the green building concept and the heterogeneous nature of professional practices means that actors may have varied conceptualizations of green building. The challenge in the development of schemes is, thus, the operationalization of the concept 'green building' to resonate with the various professional actors in the industry. We posit that, the development of schemes must consider issues of cognitive and normative legitimacy in order to garner the support of professional actors. We conclude by making a case for the need to empirically explore the role of industry professional and other actors in the establishment of Building Environmental Assessment Methods (BEAMs).

Key words: Green building, building environmental assessment methods, interstitial emergence, field theory

1.0 Introduction

The movement for a shift from conventional building practices, which has been labelled "green building," is an attempt to move towards a more sustainable built environment. Green building emerged in the 1990s as various industry actors - specialists, practitioners, researchers, professions, academic institutions and various other organizations – started to look for ways to decrease the impact of buildings on the environment (Cole, 1998). Since its emergence the term has become ubiquitous as a label for buildings which are deemed environmentally friendly. Some proponents have gone as far as touting the concept of green building as the future of building construction, and the way forward for the entire built environment. Its emergence is viewed as seemingly changing the underlying social structure in the building industry, and it is heralded by some as creating a shift in how buildings are designed, constructed and operated; challenging centuries-long practices in the industry (cf. Henn and Hoffman, 2013). Until recently such assertions have stood unchallenged and little research has focused on exploring if this changing socio-cultural context in the building industry is actually taking place.

With the emergence of Building Environmental Assessment Methods (BEAMs), and the stark reliance on them to set green building standards, much hope has been put on their use as instruments of change in the building industry. BEAMs have become common in the building industries of most developed countries, and are increasingly being used by policy makers and industry stakeholders to help drive sustainable development in the built environment (Schweber, 2013; 2014). In view of their widespread use as a vehicle for propagating green building practices, various research works have been carried out to ascertain how efficiently they conceptualize the concept "green building." These works have explore the technical features of BEAMs (e.g. Crawley and Aho, 1999; Cole, 1998; Cole, 1999; Cole, 2005), and have sought to compare the various sustainability indicators, weightage and the ratings of BEAMs. Some researchers have also moved on to explore whether the adoption of BEAMs is even influencing green building practices in the industry. Some of these works have investigated whether BEAM adoption influences routine green building practices in the industry; and whether it is aiding a change in, and/or influencing professionals and professional practices in the industry. Some have also explored whether the adoption of BEAMs is aiding the creation of green building awareness among industry professionals (Thomson, et al., 2010) and the effect BEAMs are having on construction projects (Schweber and Haroglu, 2014).

While this growing body of research work has investigated events after the development and establishment of schemes in the industry, an area which has received little attention in the academic literature is events at the nascent stages of green building emergence; before the establishment of BEAMs. Exploring these events will not only offer insight into how industry professionals engage with, and adopt these assessment schemes, but also how their actions contribute to the failure or success of implementing them. There is the need to understand how BEAMs are used to give content to the green building concept (Schweber, 2014), i.e. how they are developed, and industry actor's reactions to the practices codified in BEAMs. Exploring this will depend on an understanding of how green building practices emerge, and which actions are taken to ensure that practices codified in schemes resonate with industry professionals. This paper takes a cue from this argument, and going back in time to the point of origin, explore the concept of green building, its emergence in the industry, and how industry actors went about the process of 'making sense' of the concept to define which practices are 'green' and which ones are not. In so doing, we seek to add to the growing body of academic research which has begun exploring the sociological aspects of green building, employing theories from the social sciences to explicate the evolving and changing social structures in the building industry and the role of BEAMs in this process (e.g. Holmes and Hudson, 2002; Boyd and Schweber, 2012; Schweber, 2013; Schweber, 2014).

The paper draws on the concept of interstitial emergence (Morrill, 2006) and the field-based theory proposed by Fligstein and McAdam (2012). The argument made is based on the assumption that the emergence of green building can be viewed as the introduction of new institutional logic(s) in the building industry, and the establishment of BEAMs offers an example of how new action frames are introduced to reify this new logic(s) and alleviate "ontological anxiety." These frames show actors which actions are legitimate and reflects the cultural understanding of what actions make sense based on actors' subjective interpretation of green building. The following sections, first and foremost, explore the emergence and development of Building Environmental Assessment Method (BEAMs) in the industry. The concept of interstitial emergence, taken from institutional analysis, is then introduced to provide a theoretical edifice to explain the role of industry professionals in the emergence and development of BEAMs. This section explains the emergence of a common domain where actors operating in different professional jurisdictions congregate to define new standards based on their shared understanding of the concept of green building. This helps to explicate the role of actors in giving content to the concept 'green building;' and how they engage in various actions to promote practices and support the development of schemes. The paper concludes with reflections on the role of industry actors in the emergence of the green building sector and the development of assessment schemes.

2.0 Building Environmental Assessment Methods

Building Environmental Assessment Methods/Schemes or "green building guidelines" have emerged to help categorize the vast range of environmental criteria that are relevant to buildings. They provide a means for designers and builders to identify and specific environmental criteria depending on the needs of clients. These schemes have evolved out the need for a holistic comprehensive methodology to ascertain the environmental impact of buildings; providing a platform to outline green building practices. They offer a way for industry actors to objectively assess the environmental performance of buildings. Developed to set a standard for green building (Schweber, 2014), they lay down a direction for the industry to move towards environmental protection and achieve the goal of sustainability (Ding, 2008).

Aside having environmental assessment as its core functions, BEAMs may be accompanied by some form of third-party registration or certification. The certifications indicate the extended outputs from the assessment process. These typically take the form of a singular, easily recognizable designation, e.g. 'Gold', 'Excellent' or number of attained 'Stars.' The first assessment scheme, the Building Research Establishment Environmental Assessment Method (BREEAM), was established by the UK Building Research Establishment in 1990. Since its establishment, numerous assessment schemes have been developed. Aside influencing the development of LEED in the US, BREEAM has also made an impact worldwide, with Canada, Australia, Hong Kong and other countries using the BREEAM methodology to develop their own building environmental assessment methods (Ding, 2008). Most developed and rapidly developing countries now have their own domestic assessment schemes and many other developing nations are in the process of localizing existing assessment schemes for their local construction industries (Du Plessis and Cole, 2011). These schemes are constantly updated, and new version are developed to meet changing market demands and environmental expectations. For example, in response to the Copenhagen Summit in 2009, HK-BEAM Society, the owner of HK-BEAM in Hong Kong, introduced a new version of the assessment scheme – HKBEAM-Plus Version 1.1. Introduced in April 2010 (BEAM Society, 2010), and in response to the conference agenda, this version of the scheme placed greater emphasis on the importance of greenhouse gas emission reductions.

Efforts by most countries to develop they own domestic scheme is motivated by the need to encourage green building practices appropriate to specific climatic and cultural contexts. In most cases, various technical committees, advisory groups, industry experts and consultants are engaged in developing new and updated versions of schemes. Usually, they are developed to meet specific industry objectives, which are usually influenced by national sustainability goals. However, in a rapidly globalized world, the localization of assessment schemes creates complications for stakeholders, including property investors, who purchase buildings in different countries (Ding, 2008), or who are involved in the development of multi-national project. This has led to increasing use of some international brand name assessment schemes such as the US-LEED and UK-BREEAM. Their presence in the local market of some countries is largely due to the demands for 'brand recognition' in a global market and the motivation of the owners of some assessment schemes to expand the adoption of their assessment schemes abroad.

2.1 The organizational Context of Assessment Scheme

The establishment of the majority of assessment schemes (e.g. LEED, BREEAM, and HKBEAM) are defined by the current neoliberal zeitgeist that embraces government at a distance. As such they are voluntary in their application (Ding, 2008; Du Plessis and Cole, 2011), and they are mostly owned and promoted by industry or other non-state actors (e.g. NGOs). There are also a number of voluntary schemes which have been developed and are owned by the government/or state actors. For example NABERS, the Taiwanese Evaluation Manual for Green Buildings (EMGB) and the Hong Kong CEPAS. The distinction between voluntary and mandatary assessment schemes is that, unlike mandatary schemes such as the Singapore Green Mark and the Australian Building Sustainability Index (BASIX) which specify minimum certification requirements and are increasingly being used as incentives for development approval, voluntary schemes (e.g. Hong Kong BEAM and the US-LEED) are initiated and administered by industry or non-state actors who may not have the authority to impose any strict regulations regarding their adoption.

Considering the voluntary nature of majority of the schemes, the issue of how to promote their adoption and encourage engagement by industry professionals becomes key. Whereas building professionals may have no choice but to respect assessment schemes that are mandated, they are less constrained with regards to the adoption of voluntary schemes. Thus, a central argument with voluntary schemes concerns the conditions under which they are adopted or challenged by professional actors. Since these schemes promulgate a particular understanding of "green building", professional actors can challenge the content if they do not agree with how green building is conceptualized in BEAMs. The emergence of terms such as "sustainable building", "High performance building", "smart building", "environmentally friendly building", which have all become synonymous with the concept of green building (Henn et al., 2013), evoke various actors interpretation of what green building should accomplish, or the goal of green building. The challenge in the development of assessment scheme is therefore the operationalization of the concept "green building." This is because, aside the challenge of codifying the numerous environmental criteria, deciding on which practices are 'green' and which ones are not, and which indicators and weightages to use, is not an easy task. To overcome this challenge of operationalizing the concept such that it resonate with the industry's myriad actors, some schemes use open-ended language to frame practices. With such variability in the concept, the development of assessment scheme to codify green building practices is sometimes fraught with struggle over how the concept is framed in assessment schemes.

In the UK for example, increasing rejection of assessment criteria in BEAMs as authentic measures for green building has been reported (See Schweber, 2013, 2014). Professional actors criticized particular credits or categories for not adequately, or wrongfully capturing the green building concept. These concerns question the authority of developers and owners of these schemes and impedes the adoption of green building practices and the advancement of sustainability in the building industry. Considering the heterogeneous nature of professional practices in the building industry, a vital question in the development of BEAMs is how to conceptualize the knowledge of green building into meaningful practices that resonate with actors from varied professional backgrounds, with varied ideologies. And how multiple types of technical knowledge of the various experts engaged in the development of schemes can be combined to develop a scheme that resonates with professional actors operating in different professional jurisdictions and with different values and principles.

Thus, if professionals from different disciplines are to coalesce around a particular universal definition of green building and develop a shared sense of identity and purpose to help promote green building practices (Bresnen, 2013), the question is how such a united front can be forged around a single assessment scheme. And how can such a collaboration be achieved if industry professionals have different perspectives of what green building is, and which practices qualify as 'green' and which ones do not? The next section sheds some light on the heterogeneous nature of professional practices in the industry.

2.3 The nature of professional practices in the building industry

The shift towards sustainability in the built environment will require some form of engagement among industry actors in order to develop a more holistic solution. Since green building, as noted by Hughes and Hughes (2013), does not really fall into any professional jurisdictional domain, it requires a range of collaborative engagements across various professional domains in the industry. Some researchers have advocated for the development of a new sense of professional ethics (Hill, et al., 2013), and have questioned the ability of professional institutions to separately provide the needed drive to respond to environmental concerns. However, professional actors in the building industry operate in different jurisdictions (Bresnen, 2013), developing their own set of skills, knowledge base, and working on their own tasks. Actors in the building industry seldom interact, and the one-off bespoke nature of construction projects exacerbates the heterogeneous nature of professional work. This fragmentation makes promoting green building and specifically BEAMs in the industry anything but a trivial task.

Bresnen (2013) stresses the need to address competitive, collaborative and participative challenges that inhibit forging a united front to address sustainability concerns. Some researchers have argued for the need for professional actors to develop a shared sense of identity and purpose (e.g. Hartenberger, et al., 2013; Duffy and Rabeneck, 2013). Some (e,g. Twinn, 2013) have even called for building professionals to act as a united voice and use media outlets to communicate messages about green building. But as Bresnen (2013) points out, this leaves open the question as to how such a united voice might be created and mobilized. Mobilizing actors from different jurisdictions to promote specific sets of green building practices presents a variety of issues; such as which alternative practice should be promoted. Since actors will have varied perspectives on what green building is and how best to achieve it, there is always the challenge and risk of attempting to instill and impose unitary notions of accepted practices.

It follows from the above that the development and establishment of assessment schemes have to take into account how actors with varied professional backgrounds negotiate the meaning of green building and develop a shared sense of identity around a particular scheme. Addressing the issues of legitimacy of schemes also becomes problematic considering the varied technical background of professionals and the fact that each professional jurisdiction has its own institutional norms and values. Coupled with this is the presence of professional bodies who may want to preserve tried and tested ways of doing things. While preserving their exiting professional identity, these professional bodies may want to take on new professional roles vis-à-vis the emergence of green building. These observations present a challenge when one considers the voluntary nature of most assessment schemes and the fact that professional actors who do not agree with the meaning of green building may resist their propagation as genuine measure of green building (Schweber, 2013, 2014).

3.0 Conceptualization of BEAMs in the Building Industry

It is difficult, if not impossible, to provide a universal definition of Green building. It is better understood as an emergent concept. The concept is in constant flux, shifting as actors who represent different social groups or fields in the industry engage with each other to negotiate its meaning. Thus, green building practices codified in BEAMs are subject to considerable debate and simultaneous multiple meanings (Howard-Grenville et al., 2007). It follows that, at every stage in the evolution of green building in the industry, it is possible that differentially powerful actors will influence the framing of the concept, with each actor espousing and promoting different practices – practices which possibly advance their own interests in the industry (Fligstein and McAdam, 2012). The fluidity of the concept means that multiple interpretations will constantly be at play, competing for dominance as actors negotiate the meaning of green building. As stated above, the nature of professional practices means that different professional actors operating in different professional jurisdictions (see Bresnen, 2013) may hold different views about the concept 'green building.' Even professional actors in the same professional jurisdiction may have different subjective interpretations of what green building means to them or their organization. Thus, at the level of practice and implementation, the variously held subjective interpretations can translate into political contestation over the multiple meanings and means of adopting green building. Thus, the development of assessment schemes can be seen as fraught with power struggles among industry actors; as to who wins and who loses in the debate over which standards and practices become adopted (Janda and Killip 2013).

Based on this argument, assessment schemes should be viewed as the outcome of negotiated shared meanings/understandings of green building. Their emergence in the building industry should be viewed as the development or creation of a universal template that provides an interpretive frame for multiple actors situated in different professional fields in the building industry. These schemes embody the knowledge and practices of the industry. They therefore function as knowledge repositories, standardized forms and methods used to communicate across multiple fields; translating and transmitting knowledge across multiple fields. Understanding how actor, with varied interests and goals, go about the process of developing such a scheme is the focus of the theoretical position elucidated in the next section.

To make this theoretical argument, the building industry is conceptualized as a social space in which relatively large number of individuals and organizations, who may belong in different fields/jurisdictions, engage with each other. Industry actors occupy various organizational fields, with each field comprising aggregates of organizations/professionals/actors providing similar services, their constituencies, and their relevant professional bodies (DiMaggio and Powell 1983). These fields exists together with numerous other state and non-state fields and are nested within each other in a broader field environment. Industry actors operating in various fields or professional jurisdictions interact with each other on the basis of shared (but not consensual) understanding about what is at stake in the industry (in this case, the delivery of green buildings). Actors relate with each other with a shared understanding of the rules governing legitimate actions in the industry vis-à-vis green building. Through this process of engaging with each other, taking each other's actions into consideration as they produce green buildings, actors are attempting to create and sustain a social world by securing the cooperation of others. They do this not only to take advantage of emerging new ideas, by behaving strategically to advance their individual interests in the industry. Actors also consider the benefit of a collective identity, of being part of a social group – the green building field – what Fligstein and McAdam (2012) labelled as "the existential function of the social."

3.1 Interstitial emergence: The emergence of a green building field

The concept of interstitial emergence is founded on the argument that firms, organizations or industry professionals are simultaneously members of multiple, partially overlapping fields (Morri, 2006; Hoffman and Ventresca, 2002). This means that when an issue (for example, reducing environmental impact of buildings) that is of common interest to actors belonging to these multiples fields arises, there will be interstices between fields (Rao *et al.*, 2000). It is at these interstices that alternative practices of building have emerged and schemes have been developed to help reduce the negative impact of buildings on the environment. What this means is that, actors, instead of addressing environmental concerns in their own professional jurisdictions or fields by expanding on existing logics and norms in their fields, will act by bridging between multiples firms to address this issue. This interactions between multiples fields leads to the emergence of a neutral arena, an interstice – a gap in social space, where alternative courses of action will be established.

Actors do not leave their professional jurisdictions, nor ignore their position in their field and move into the emerging new field. Instead they engage deliberately with different actors from other fields who are also interested in addressing these environmental concerns. The challenge for industry actors in such a situation is to remain credible in their own field, upholding the standards and norms in their professional jurisdictions, while simultaneously building resources, new capabilities and legitimacy in the emerging field. Thus, interstitial spaces are characterized by institutional diversity as actors bring with them different institutional logics from the respective fields in which they have been historically socialized (Furnari, 2014). As a result, actors interacting in interstitial spaces are likely to have diverse and sometimes conflicting logics of action, taking on different identities as they traverse multiple organizational fields. They therefore face the challenge of managing the conflicting logics in their own fields and the new logics in the emerging field.

Morrill (2006) identified three mechanisms that leads to the emergence of a legitimate social space, i.e. a new field, for emerging new practices in interstitial spaces: 1) the development of resonant frames for the new practices, 2) mobilization of critical masses and resources in support of these frames, and 3) structuration efforts. What this means is that, before the development of any formalized script or universal template of action (i.e. BEAMs) in any industry, various alternative practices would have already started cropping up in the industry and these might have been implemented sporadically and informally on construction projects. Since actions at this stage of field emergence are informal and are not guided by any formal institutional script (cf. Rao et al. 2000), such practices may not be adopted by other actors. Practices advanced by individual actors will be based on their own ideology (Benford and Snow, 2000), infused with shared meanings reflecting their cultural beliefs and norms (Furnari, 2014). As such, practices before the development of an official assessment scheme may not resonate with other actors in different fields in the industry. A typical example could be an architect trying to communicate a new idea to the builder, or the builder trying to incorporate a new innovative technology or practice. Actors will thus act strategically, employing various social skills to convince other actors to adopt and/or accept the new practices. At this stage of the field emergence, it is possible for individual actors or groups of actors to have their own frames, templates or green building guidelines for implementing new practices in their organization, professional jurisdiction or field.

As the actions of individual actors become increasingly interrelated, based on shared interpretations of the green building concept, individual frames will coalesce into collective action frames (Benford and Snow, 2000) and trigger collective action processes. Those actors with shared collective interpretation of green building will develop schemes to codify practice and start mobilizing other actors to support these practices. Thus, at the nascent stages of green building movement, when no formal scheme has been developed, it is possible for multiple schemes or template to exist. Various actor will have different views about how best to adopt the concept, and actors will start mobilizing various resources (economic, social, political and cultural, cf. Bourdieu (1986)) at their disposal to promote and support schemes that resonate with their core values and principles, and which advance their interest in the emerging field (Fligstein and McAdam, 2012).

Thus, schemes are developed to codify practices, which are then used to mobilize support and resources. What this means is that, in order to foster adoption and engagement by other industry practitioners, assessment schemes must resonate with actors in the diverse fields in the industry. These schemes may often suffer from technical and normative stigmas as they are propagated. This can be addressed by associating with and borrowing the technical legitimacy of science, substantive findings, and expert knowledge that support the efficacy of emerging new practices. With regards to cultural-cognitive stigma, actors propagating new practices can ensure that the new practices resonate with the values and principles of other actors in the emerging field. If actors promoting a particular alternative practice are successful in developing a resonant frame and mobilize support for this scheme, a legitimate social space will then be carved for the emerging new practices. Through these mechanisms, the new practices can become a new professional jurisdiction replete with new normative, cognitive and material boundaries (Morrill, 2006).

4.0 Discussion

Green building is seemingly introducing new sets of norms and standards of practices in the building industry. Its emergence is arguably creating new professional practices, altering roles in existing ones, and rearranging traditional roles and relationships among industry actors. Terms such as ‘sustainable architecture,’ ‘sustainable engineering,’ ‘sustainable procurement’ and various other related neologisms attests to the changing landscape of professional practices in the industry. In the wake of this, professional actors in the industry face the dilemma of managing multiple logics in their existing professional roles and new logics in the emerging green building field. There is therefore the question of how actors from different professional jurisdiction can find a common ground to address sustainability goals in the built environment. There is also the question of how actors can internalize new norms and standards vis-à-vis the emergence of green building (Schweber, 2013).

The development of BEAMs, which are aimed at reducing ontological anxiety by codifying the numerous environmental criteria relevant to buildings, provide a means for actors to find a common ground to promote green building. BEAMs are developed to operationalize the green building concept and to facilitate the adoption of green building practices. However, for BEAMs to achieve this goal, practices codified in these schemes must resonate with the myriad actors in the industry. Schweber (2013, 2014) noted that the challenge of BEAM development is how multiple types of technical knowledge can be combined. The fluidity of the green building concept and the heterogeneous nature of the building industry means that actors from various professional jurisdictions may not necessary agree on alternative practices prescribed by BEAMs. Thus, developing a scheme that resonates with professional actors operating in different professional jurisdiction and with different values and principles may be a daunting task. The involvement of professional actors with knowledge about sustainability will be one way of addressing this issue. In her study of the UK construction industry, Schweber (2014, pp.157) observed that the fact that some *"professionals felt empowered to actively engage with and pass judgement on specific requirements draws attention to the distribution of scientific or technical authority across stakeholders in the assessment process."* The involvement of actors with knowledge about green building will therefore afford a degree of technical legitimacy, which is needed to mobilize support for the adoption of practices in scheme. This will also contribute in addressing issues of normative legitimacy. The involvement of actors from diverse background in the development of schemes will ensure that practices resonate with the values, assumption and principles of professionals from different jurisdiction.

In the UK Building industry, Schweber (2013, pp 141) observed that *"the greater the individual's expertise in a particular area, the less likely they are to accept the BREEAM operationalization of the concept."* The study noted that *"…sustainability minded professionals… rejected the adequacy of the scheme for the achievement of genuine sustainability."* A key finding of the research was *"the way in which tensions between professionals' own understanding of 'greenness' or 'sustainability' and the requirements of BREEAM undermined their respect for the tool as a whole."* Taking a cue from this observation, it could be argued that the tension between professionals' understanding of 'greenness' and the requirement of the UK-BREEAM could be because the practices codified in the scheme do not resonate with professionals. This is not surprising as assessment schemes are usually developed with little or no input from industry professionals. It also serves to explain, at least partially, the lack of respect for schemes by some professionals and the rejection of *"the adequacy of the tool for the achievement of genuine sustainability."* The lack of respect for scheme is shown in actors' explicit criticism of categories used to reify the green building concept (Schweber (2014). This indirectly challenges the authority of developers and custodian of the assessment scheme (i.e. the Building Research Establishment (BRE)).

From the concept of interstitial emergence, the question as to whether actors will choose to internalize new logics depends on whether practices in the new field resonate with the core values of professional actors. Furnari (2014) viewed practices as "visible enactments" of shared beliefs that define the institutions of actors in a particular field or jurisdiction. They are infused with shared meanings. The shared meanings encoded into practices are informed by wider cultural beliefs shared at the institutional field level in their professions. Thus, green building practices emerging from various jurisdictions will reflect their idiosyncratic subjective interpretations of the green building concept. Consequently, incongruence between practices outlined in schemes and actors' conceptualization of green building practices in BEAMs may not only lead to rejection of these practices as genuine operationalization of green building or sustainability (cf. Schweber, 2013), but also a conscious refusal on the part of actors to be transformed by the logics that are used to explain and define these practices.

With the increasing emergence of new professional practices, there is also the question of how existing and newly emerging professional practice domains establish clear professional jurisdictional claims (Bresnen, 2013). With regards to this, we posit that, from the perspective of interstitial emergence and the theory of fields proposed by Fligstein and McAdam (2012), professional actors may operate in multiple professional domains. Although with time actors may internalize logics in the emerging new field if those logics resonate with their core values, they maintain the logic of practices in their own field while engaging with other actors in the emerging green building field. Professional actors therefore take on different identities as they traverse multiple organizational fields. As long as logics are not congruent with actors' core value, actors will manage conflicting logics between their own professional jurisdiction and the new professional jurisdiction; contributing to a superficial adoption of logics in the emerging new field.

5.0 Concluding remarks

The foregoing argument join in the chorus of the small but growing research agenda aimed at exploring the impact of assessment schemes on professional practices in the building industry. Since assessment schemes, for example the UK-BREEAM, the US-LEED, and the HK-BEAM have emerged to reify industry actors' interpretations of the principles of sustainability, and are increasingly being promoted as templates of action and as policy instruments by national governments, concerns about their legitimacy warrants in-depth studies. In this paper, we have provided a theoretical perspective on some of the probable reasons why industry professionals and other actors may choose not to actively engage with BEAMs. Not only can this lead to a superficial adoption of BEAMs by industry professionals, but the outright rejection of these schemes as authentic assessment tools for green building. While it can be argued that it was justifiable to instill or impose unitary notions of accepted practices at the nascent stages of the green building movement, at a time when professional actors had little to no knowledge about sustainability, it may not be expedient to do so now. Increasing professional expertise in sustainability means that actors may not, willy-nilly, accept practices imposed by the state or by other powerful actors in the industry.

This observation becomes even more crucial when analyzed from a global perspective in light of the increasing importation and use of assessment schemes developed from other regions. In most developing countries, governments with no existing domestic or local assessment schemes have adopted internationally recognized schemes in their local market. Even in developed countries, there is increasing use of internationally recognized schemes such as the US-LEED and the UK-BREEAM by international multinational firms. From the theoretical argument put forward in this paper, because practices may already be emerging at the nascent stages of the green building movement in any industry, and professionals may already be developing practices unique to their culture and environment, care must be taken when importing schemes developed in different context. Actors importing internationally recognized schemes must be smart about how they introduce these scheme in their local industries, taking into consideration how these practices dovetail with professional practices in the industry. If assessment schemes are developed for use in the building industry, then they must be developed to resonate with the practitioners who are supposed to use them in their daily activities.

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Issues about moisture in residential buildings of Brazil

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Abstract

Moisture is one of the main issues in building disorders. It can lead to microorganism's growth, discomfort, material deterioration and impact on energy consumption. In Brazil, there is a lack of assessment of the moisture risk potential in a comprehensive point of view, considering that most of the country is located in a tropical climate with important moisture sources. The current paper provides an overview on the potential risk of building moisture disorders, analysing the country differences of climate, population density, building standardization, type of construction methods and cultural issues. The main drawbacks reveal that many houses are built informally with lack of professional labor. Furthermore, the building standards do not consider the important moisture loads due to the climate and do not encourage the use of innovative techniques to deal with these issues. Climate, cultural and income differences within the country indicate there is a large potential for conducting research in Brazil on this topic with the perspectives of practical applications.

Keywords: moisture risk, residential buildings, Brazil

1. Introduction

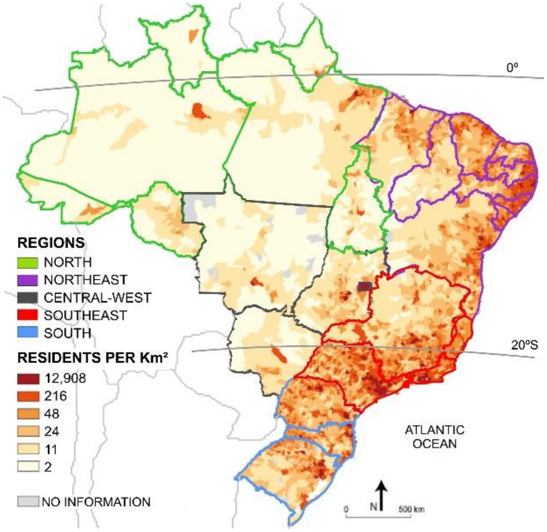
Moisture is one of the main issues in building construction. It can lead to microorganism's growth causing health problems, functional damage (corrosion, stain, decay), thermal discomfort, material deterioration, and change on energy consumption and power demand (Berger et al., 2015). The main sources of moisture are climate, capillarity, leakage, failure on construction process, and condensation. Moisture is a difficult issue to control, which may occur due to many factors such as insufficient air change rate, adsorption and desorption phenomena, leakages and presence of cracks.

Few research work about moisture in buildings are carried out in Brazil, but the majority are strictly academic restricted to a few research groups with limited funds. Construction pathology caused by moisture is a subject with a very few studies in the country; the ones found mostly have a case of study approach, not assessing the moisture risk potential in a comprehensive point of view, considering climate, building standardization, constructive techniques, and cultural issues influence.

The present article intend to evaluate the potential risk of moisture disorders in a cross-disciplinary approach, analysing the influence of climate, type of construction methods and cultural issues. Building standards, measures needed and challenges to improve moisture safety in the residential building sector are also discussed.

2. Brazil – Population and Characteristics

Brazil is located in South America, its area of approximately 8.5 million m² is divided into five geographic regions as shown in Figure 1, and with estimated population of 204 million inhabitants in 2015. The Brazilian bioclimatic zoning classifies the country into 8 zones according to Figure *2*, being the zone 1 the coldest and zone 8 the hottest. Each bioclimatic zone has relatively homogeneous climate characteristics, by considering minimum and maximum monthly average air temperatures and monthly average air relative humidity.



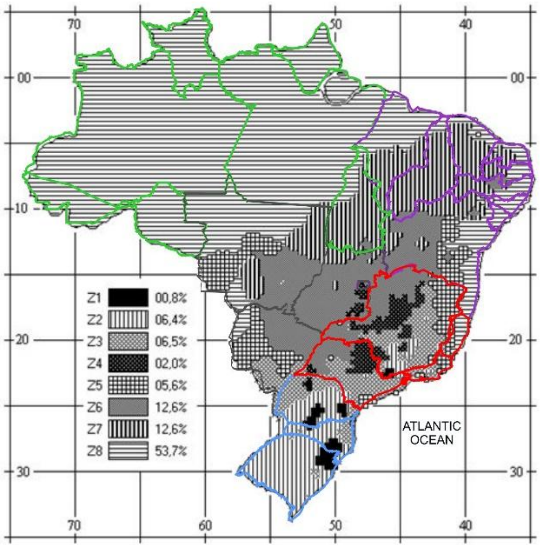


Figure 1 – Geographic regions and population density (2000)

Source: adapted from IBGE (2011)

Figure 2 – Brazilian bioclimatic zones

Source: ABNT (2005)

The major population is concentrated near the east coast, and although bioclimatic zone 8 accounts for more than 50.0% of the territory it is mostly located in the region that has the lower population density. Figure 3 exhibits a comparison of land area, population, dwellings, and average monthly income per dwelling between geographic regions.

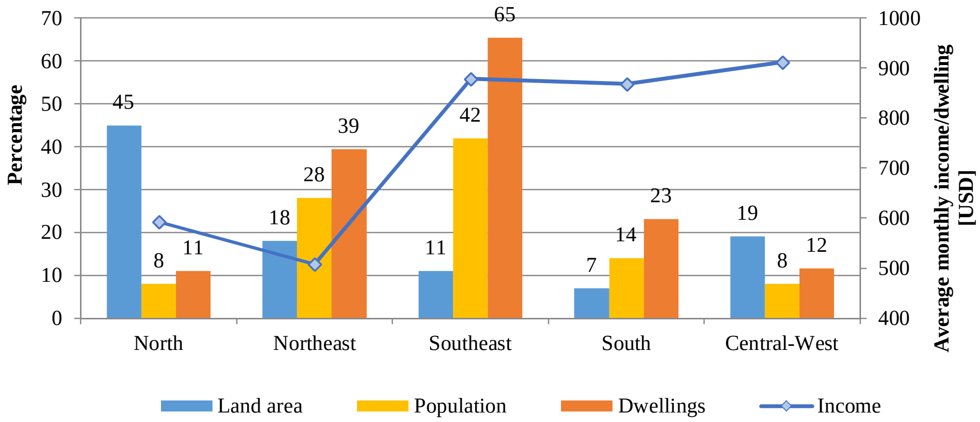


Figure 3 - Percentage of land area, population, dwellings, and average monthly income per dwelling per geographic region of Brazil

Source: adapted from IBGE (2015)

Southeast region corresponds to 11.0% of the total land area, 42.0% of the population and 65.0% of the dwellings. In contrast, the North region encloses 45.0% of land area and accounts for just 8.0% of the population and 11.0% of the dwellings. Northeast with near 28.0% of population has the lowest average income per dwelling.

To have an overview on moisture disorder risk in Brazil, climate data for 8 cities corresponding to 8 Bioclimatic Zones are presented (Table 1). Cities were chosen according to the largest population among the cities with data available. Figure 4 presents the average annual precipitation and the location of the cities representing each bioclimatic zone, and Figures 5 to 7 present their average monthly precipitation, air temperature, and vapour pressure. Figures 4, 5 and 7 show the high moisture disorder potential due to the high precipitation rate and to the high outdoor vapour pressure.

Table 1 – Bioclimatic zones cities and population

Zone	*City*	*Population*
Z1	Curitiba	1,879,355
Z2	Santa Maria	276,108
Z3	São Paulo	11,967,825
Z4	Brasília	2,914,830
Z5	Campos	483,970
Z6	Goiânia	1,430,697
Z7	Cuiabá	580,489
Z8	Rio de Janeiro	6,476,631

Source: adapted from IBGE (2015)

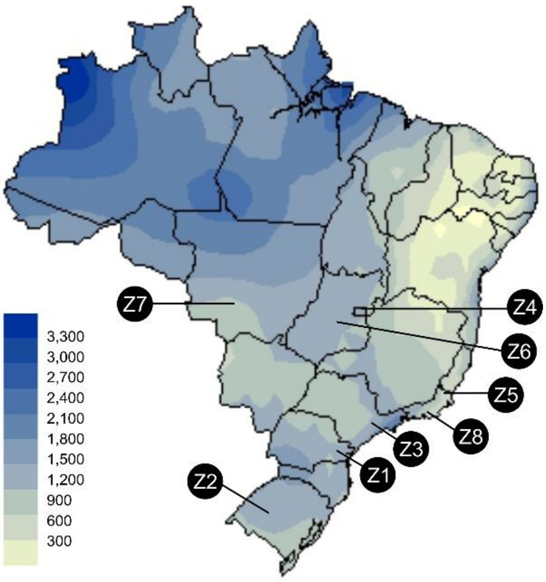


Figure 4 – Average annual precipitation (1931-1990)

Source: adapted from INMET (2016)

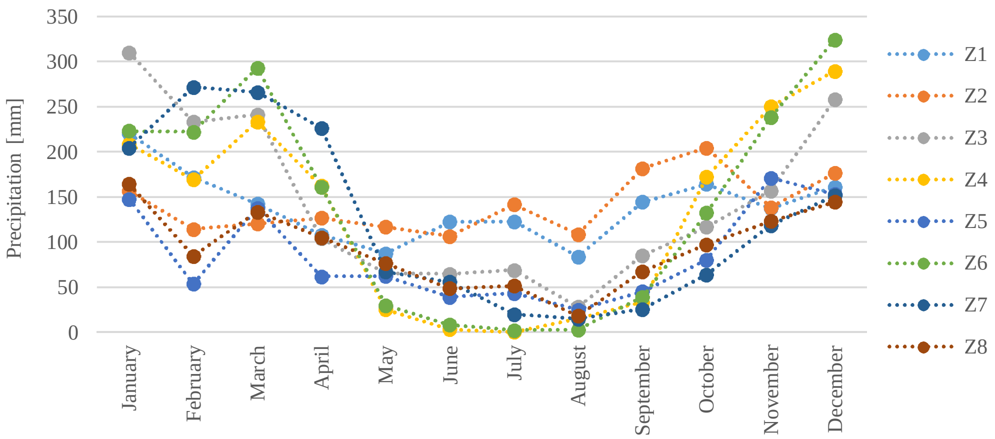


Figure 5 – Average monthly precipitation (2005-2015)

Source: adapted from INMET (2016)

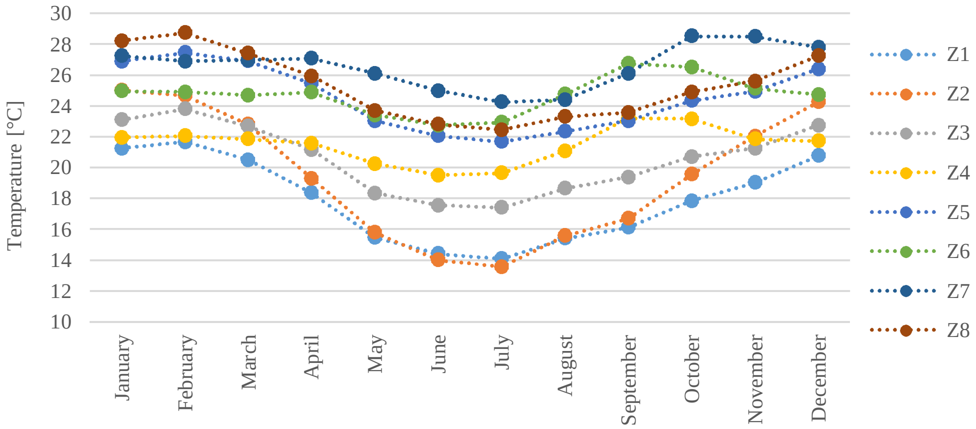


Figure 6 – Average monthly air temperature (2005-2015)

Source: adapted from INMET (2016)

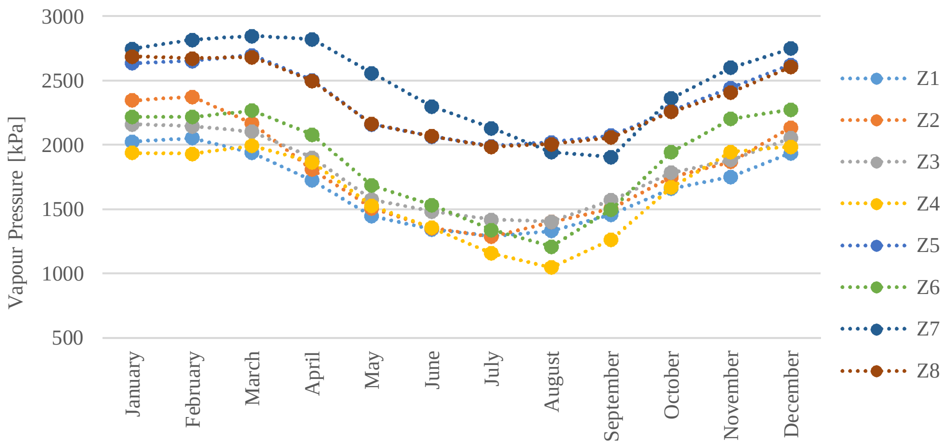


Figure 7 – Average monthly vapour pressure (2005-2015)

Source: adapted from INMET (2016)

Curitiba, which is the capital with the lowest average temperature, has the higher relative humidity values despite its high altitude. São Paulo and Rio de Janeiro, the more populous cities, have great differences between temperature but close values for relative humidity. It can be noticed that for all cities there is an outline of dry cold periods (April - September) and wet hot periods (October – March).

It can be noticed that the climate is an important source of moisture due to high precipitation rate and high outdoor vapour pressure. These climatic conditions reveal an important source of moisture that can lead to potential risks if it is not well managed. The potential mould growth risk was analysed using the isopleth limit approach (Vereecken and Roels, 2012), in which hourly outside temperature and moisture content are plotted on the psychometric diagram. The red points indicate data of temperature and humidity ratio obtained from Test Meteorological Year (TMY) weather files; the points above the isopleth curve indicate hours of mould growth risk.

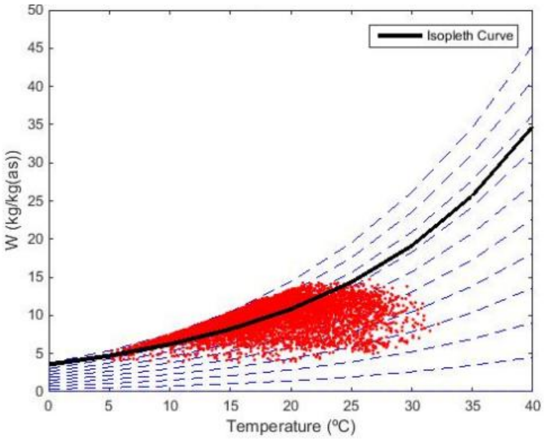


Figure 8 – Mould growth risk for Z1 (Curitiba)

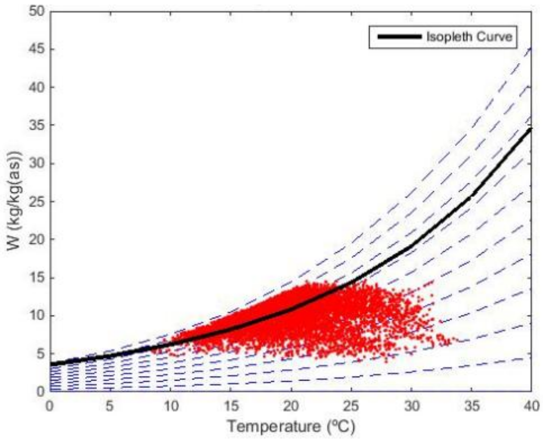


Figure 9 – Mould growth risk for Z3 (São Paulo)

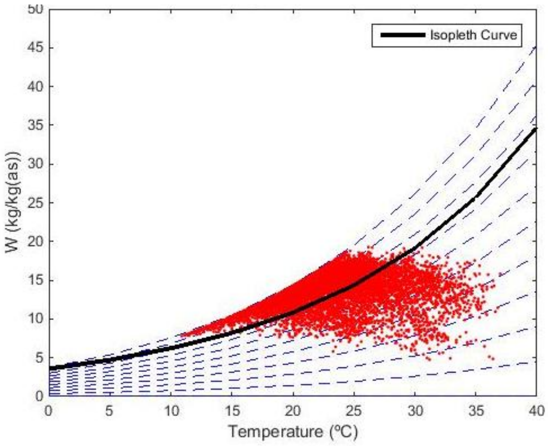


Figure 10 – Mould growth risk for Z8 (Rio de Janeiro)

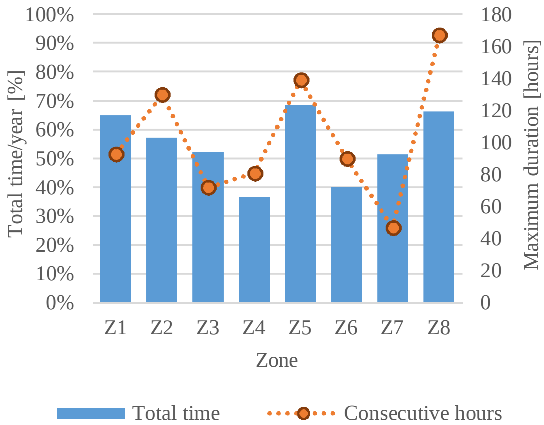


Figure 11 – Time of mould growth risk within one year per zone

With the exception of zones 4 and 6, all the others have more than 50% period of risk within the interval of one year, having zone 5 the highest value that is approximately 70%. Zone 8, in addition of having around 65% of time per year, also presents the greatest value of consecutive hours of risk (around 7 days). These data may represent an important issue considering that zones 5 and 8 encompass a significant part of Southeast and Northeast regions, the more populous ones. The outside moisture content should be managed to do not penetrate into building and lead to mould growth risk.

Despite of the geographic, cultural, and climatic differences between regions, there is few variation of constructive methods between geographic regions as presented in Table 2.

Table 2 – Construction methods main used on single-story houses according to geographic region

Region	Construction method	Amount of total single-story houses of the country	Absorptance	Thermal transmittance	Thermal capacity
		[%]	[dimensionless]	[W/(m².K)]	[kJ/(m².K)]
North, Northeast, Southeast, South, Central-West	Masonry with plaster and light colored paint	96.0	0,4	2,86	100
Northeast, Southeast, South, Central-West	Clay tile and concrete slab	62.2	0,7	2,05	238,4
North	Clay tile and wooden ceiling	28.8	0,7	2,02	26,4

Source: adapted from SINPHA (2005)

Single-story houses represent 88% of the total dwellings (Figure 3) (IBGE, 2015). Data from the construction industry relating type of financing (self, private, or governmental), amount of houses built by construction firms, and the total number of houses (given by official national census) gives a panorama of about 67% to 77% informally built houses (CGEE, 2009).

The main characteristic of the informally built house is the direct management of their owner and occupants. They acquire the land, map a building scheme without technical support, provide acquisition of construction material, agency labor (free or informally paid), and build their home. In Brazil mostly of construction labor lack professional training. Furthermore, innovative techniques faces difficulties to take place, as for instance double-glazed windows, insulation, and vapour barriers. Due to the low demand, these materials are imported, making its price high.

These issues combined – informal construction, lack of professional training and innovative techniques – may lead to this predominance of masonry wall with clay tile roof usage.

As observed, Brazil is a wide and heterogeneous country. Population is mostly concentrated in Southern regions, which have the higher average incomes; Northern regions are the less occupied and the poorest ones. This low occupation is mainly because of the amazon forest that comprises a major part of North region, which has the highest values of precipitation. Despite of the moisture disorders risk due to climate, houses use almost the same construction techniques, the innovative ones faces difficulties to take place and labor lack professional training.

3. Standards and laws – societal demands governing moisture safe construction

Considering that the vast amount of the single-story houses are informally built, means that they do not attend to Brazilian laws and standards requirements. The standards presented in this item may refer to measures directly linked to avoidance of moisture/leaking issues or to thermal properties of materials and design requirements that may affect the occurrence of moisture disorders. The presentation is according to the building lifecycle phases: design, construction, and operation. The societal demands governing moisture safe construction assessed are:

- NBR 15575 – Residential buildings – performance. The standard provides responsibilities for each agent of the chain of relationships of construction industry and it is applicable only to new buildings, not comprising retrofitting. As part of the standard the building must have a Manual of Usage, Operation and Maintenance, providing guidelines related to the operation and maintenance of the building and its equipment, in order to increase its lifecycle (ABNT, 2013)
- NBR 15220 – Thermal performance of buildings. This standard classifies the country into 8 bioclimatic zones with similar climate characteristics and formulate for each zone a set of recommendations and technical specifications in order to optimize the thermal performance of buildings (ABNT, 2005)
- RTQ-R – Labelling for energy efficiency of residential buildings. The purpose of this regulation is to classify the level of energy-efficiency of residential buildings, being the rating from A (more efficient) to E (less efficient). It is voluntary and can be applied to new and existing buildings (INMETRO, 2012)
- Local laws related to building design. In Brazil, each municipality has its own legislation related to building construction that must fulfil to federal and state laws. Local law generally defines Brazilian standards (NBR) to which design project must be accomplished.

3.1 Design Phase

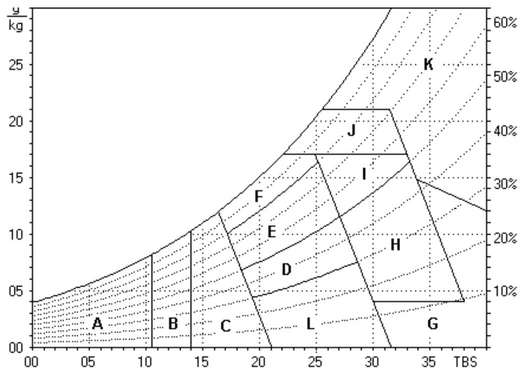
The majority of standards requirements focus on the design phase. Regarding moisture safety, NBR 15575 is the most relevant standard once it refers specifically to floor, wall, and roof systems, that in turn refer to other specific NBR standards, as presented below.

For floor systems, the main recommendation is in order to avoid rising damp. Floor systems when waterproofed must satisfy the standard NBR 9575 – Waterproofing selection and project (ABNT, 2010). Its scope establishes the requirements and recommendations related to selection criteria of materials and to waterproofing project, to attend the minimum requirements of building protection against fluid crossing, so as the requirements for healthiness, safety, and comfort of the user, to ensure the water tightness of constructive elements.

In relation to driving rain, the wall system design must indicate constructive details of interfaces and component joints to ease water drain and avoid water infiltration, considering the exposure conditions of the building during its lifecycle. Protection around the building to avoid water accumulation in the building basis should also be considered.

The roof system must avoid rainwater, incidence of moisture, and microorganism proliferation. Waterproofing systems must be executed in accordance with the standard NBR 9575 (ABNT, 2010). It also must be able to dry the maximum precipitation value for the region in which the building is located to avoid water pools or overflow, by attending the national standard for sizing rainwater systems of buildings NBR 10844 (ABNT, 1989). The project must predict constructive details to ensure the non-occurrence of moisture and its consequences in the liveable environment for at least 5 years. The standard also provides a guide for development of designing, sizing, detailing, executing and maintaining for building sanitary installations.

Brazilian Standard NBR 15220 (ABNT, 2005) presents the Brazilian Bioclimatic Zones as previously shown in Figure 2. For each bioclimatic zone, the standard provides a bioclimatic chart in which data of temperature, relative and absolute air humidity are plotted, indicating the most appropriate construction guidelines such as ventilation openings area (defined as a function of the percentage of floor area) and thermal properties for building envelope. Figure 12 presents a model of the chart.



A – Mechanical Heating zone (heating system)
B – Solar heating zone
C – Thermal mass for heating zone
D – Thermal comfort zone (low moisture)
E – Thermal comfort zone
F – Dehumidification zone (air renovation)
G + H – Evaporative cooling zone
H + I – Thermal mass for cooling zone
I + J – Ventilation zone
K – Mechanical cooling zone
L – Air humidification zone

Figure 12 - Bioclimatic Chart

Source: ABNT (2005)

However, the guidelines are considerable generic, *e.g.* do not consider the orientation of openings, use thermal-physical properties not validated by measurement and only for a reduced number of construction types, and disregard the building geometry. Computer simulation is not required and there is a lack of climatic database. There are few engineering consultants to do simulations and their prices are extremely high.

In the RTQ-R, there is no directly moisture related evaluation item, but requirements related to ventilation and evaluation of the envelope. In order to achieve level A or B, bioclimatic zones 2 to 8 require cross ventilation rates that must provide airflow between openings located in at least two different façades and in two different orientations. The requirements for envelope evaluation are in relation to geometry, thermal properties, use of insulation in cold zones, size and solar orientation of façades and openings.

Table 3 presents a comparison between the ventilation openings sizing and thermal transmittance requirements of the standards presented. It can be noticed that there is no compliance for some requirements.

Table 3 – Ventilation openings and thermal transmittance requirements

Requirement		**Standard**	**Bioclimatic Zone**							
			Z1	**Z2**	**Z3**	**Z4**	**Z5**	**Z6**	**Z7**	**Z8**
Ventilation openings (V) [% of floor area]		*NBR 15220*	$15<V<25$	$15<V<25$	$15<V<26$	$15<V<27$	$15<V<28$	$15<V<29$	$10<V<15$	$40<V$
		RTQ	$V \geq 8$	$V \geq 8$	$V \geq 8$	$V \geq 8$	$V \geq 8$	$V \geq 8$	$V \geq 5$	$V \geq 10$
Thermal transmittance (U) [W/m²k]	*wall*	*NBR 15220*	$U \leq 3.00$	$U \leq 3.00$	$U \leq 3.60$	$U \leq 2.20$	$U \leq 3.60$	$U \leq 2.20$	$U \leq 2.20$	$U \leq 3.60$
		RTQ	$U \leq 2.50$	$U \leq 2.50$	$U \leq 3.70$	$U \leq 3.70$	$U \leq 3.70$	$U \leq 3.70$	$U \leq 3.70$	$U \leq 3.70$
		NBR 15575	$U \leq 2.50$	$U \leq 2.50$	$U \leq 3.70$	$U \leq 3.70$	$U \leq 3.70$	$U \leq 3.70$	$U \leq 3.70$	$U \leq 3.70$
	roof	*NBR 15220*	$U \leq 2.00$	$U \leq 2.00$	$U \leq 2.00$	$U \leq 2.00$	$U \leq 2.00$	$U \leq 2.00$	$U \leq 2.00$	$U \leq 2.30$
		RTQ	$U \leq 2.30$	$U \leq 2.30$	$U \leq 2.30$	$U \leq 2.30$	$U \leq 2.30$	$U \leq 2.30$	$U \leq 2.30$	$U \leq 2.30$
		NBR 15575	$U \leq 2.30$	$U \leq 2.30$	$U \leq 2.30$	$U \leq 2.30$	$U \leq 2.30$	$U \leq 2.30$	$U \leq 2.30$	$U \leq 2.30$

Source: adapted from ABNT (2005), INMETRO (2012), ABNT (2013)

Some additional laws can be imposed on the design phase of the building. For instance, for the city of Curitiba (Z1), there is no law directly related to moisture avoidance, but conditions that the building must meet such as minimum requirements to floor area, natural lighting, natural ventilation area and source, and type of internal finishing. The sizing of openings is a proportion of the floor area.

For São Paulo (Z3), the building law requires waterproofing for every slab with ground contact and refers to related standards NBR 9575 (design) and NBR 9574 (ABNT, 2008) (execution). Walls with ground contact and/or south oriented also require waterproofing. Sizing of lighting and ventilation openings is according to the use and the geometry of the building.

The building law of Rio de Janeiro (Z8) have many requirements related to light well and airshaft, considering is an old city with narrow building lots and many existing semi-detached buildings, this is a main concern. However, it does not consider the high rates of air conditioning use in the city, one of the biggest of the country. Sizing of openings have a similar approach to Curitiba, a proportion of the floor area of the compartment. There is no specific moisture related demand, just general recommendations in order to ensure the sealing of the building.

In order to obtain a building permit, the city hall competent body must inspect the building design. However, the attendance of the standards required by the local law is normally a responsibility of the architect/engineer, but there is no organization to proper control the attendance of these standards.

3.2 Construction Phase

For construction phase, only NBR 15575 presents related requirements for wall, floor, roof, and sanitary systems, which in turn cite other specific NBR standards. Floor systems when waterproofed must satisfy the standard NBR 9574 – Execution of waterproofing – Procedure (ABNT, 2008). For wet areas, the floor must not permit the occurrence of moisture. The bottom surface and the joints with walls and adjacent floors that delimit the floor must remain dry when submitted to a water blade of 10mm for 72h.

For envelope sealing considering driving rain there are two types of tests. The specimen must accurately represent the design with its construction characteristics of vertical sealing and its components joints. The first test option consists on submitting during a predicted amount of time the outer surface of a specimen to a water flow, creating a homogeneous film with a simultaneous application of a pneumatic pressure. The standard presents the test conditions of water flow and static pressure according to the wind velocity regions of the country. The second test option is according to the standard NBR 10821 (ABNT, 2000) that provides requirements for water tightness of windows and the elements in which they are fixed. For sealing of surfaces subjected to direct water incidence, the test consists in submitting part of a wall to water presence with constant pressure and the amount of water infiltration must not exceed $3cm^3$ for a 24h period.

For roof systems the evaluation through laboratory test consists in submitting a specimen to a water flow under a condition of static pressure difference, being accepted the occurrence of stains if it does not exceed 35% of the area. Barriers for solar protection must proceed to emissivity limit of ε=0.2; thermal insulation must proceed to at least 90% of the thermal resistance informed by the manufacturer; and for vapour must proceed to vapour permeability equal or lower than 11.4x10-8 g/Pa.s.m^2. Waterproof slabs must be executed according to the NBR 9575 (ABNT, 2010) and resist the water line test for at least 72 hours.

The criteria for the sanitary installations is that pipe system must not present leakage when submitted, for one hour, to hydrostatic pressure of 1.5 times of the value predicted in project. For sewage and rainwater, pipe system must no present leakage when submitted to the static pressure of 60 kPa during 15 minutes.

However, these tests need properly equipment and laboratory to be conducted, that are not always accessible. The country also lack training course for construction workers, which is not required by most companies. In addition, there is no engineering consultant specialized on the building energy efficiency that could assist the building workers. For instance, there is not consultants to perform airtightness tests in Brazil.

3.3 Operation Phase

For the operation phase, NBR 15575 recommends that sealing surfaces in contact with wettable areas, which are those subjected to splashing water (bathrooms, kitchens, laundries, sidewalks), it must not have perceptible presence of moisture in the adjacent rooms, respecting the occupation and maintenance conditions predicted in project.

Regarding indoor microorganism’s proliferation, it must be ensured healthiness considering the moisture and temperature inside the building herewith the construction methods used. In relation to the presence of pollutants in the interior atmosphere, the standard establishes that equipment and systems must not release products such as carbon dioxide and aerosols that lead to a worsening in the interior air quality.

For the operation phase, the accordance verification is restricted to formal construction, for whose the companies must ensure the minimum period of 5 years of guarantee.

4. Research on moisture carried out in Brazil

The birth of post-graduate programs in Brazilian universities in the seventies contributed to promote the formation of building research groups in the country working on software application and theoretical aspects of building physics.

In the early eighties, a group of researchers at the Department of Mechanical Engineering of Federal University of Santa Catarina (UFSC), concerned with the petroleum crisis, begun a series of studies on how the energy consumption in the built environment could be reduced. The Passive Thermal Systems Laboratory (SITERPA), as the group was called at that time, developed some moisture related research regarding the heat and mass transfer phenomenon in porous building materials (Souza and Philippi, 1985, Silveira Neto and Philippi, 1986), convection (Biage and Philippi, 1985), and building simulation (Philippi, 1985, Souza and Philippi, 1986, Abreu, 1986, Cunha Neto et al., 1988). By that time, the severe lack of data made them turn their attention to the measurement and prediction of hygrothermal properties of porous building materials. Some research projects were dedicated to develop instruments, procedures, and equipment to thermal property measurements (Guths et al., 1990, Fernandes et al., 1990b, Fernandes et al., 1990a). At the same time, the study of heat and mass transport processes, which take place in the microstructure of porous building materials, have been undertaken to predict thermal properties required for thermal simulation, using microstructural description of the porous medium (Perin et al., 1987, Quadri, 1988, Quadri and Philippi, 1988, Quadri et al., 1988, Fernandes et al., 1989, Fernandes et al., 1990b, Fernandes et al., 1990a, Guths, 1990, Fernandes, 1990).

In the nineties, with the continuous growth of the research domain, the group has been divided into three new laboratories, each one attached to a different University department but still working in cooperation: LMPT- Laboratory of Porous Media and Thermophysical Properties at Mechanical Engineering department (LMPT, 2016), LabEEE - Building Energy Efficiency Laboratory (LabEEE, 2016) at the Civil Engineering department, and LabCon – Environmental Comfort Laboratory (LabCon, 2016) at the Architecture department. LMPT concentrated its research efforts in transport properties of porous materials including concrete, mortar and wood (Souza et al., 1991, Philippi, 1991, Philippi, 1993). In those works, numerical and experimental approach have been used (Cunha Neto and Daian, 1993, Bueno et al., 1994, Guimarães et al., 1995, Philippi and Souza, 1995, Guimarães et al., 1997, Mendes, 1997, Mendes et al., 1999, Mendes et al., 2000). Mendes (1997) in collaboration between UFSC/LMPT and the Simulation Research Group at the Lawrence Berkeley National Laboratory (LBNL), in California – USA, developed mathematical models for estimating material properties and predicting heat and moisture transfer through porous building elements and elaborated the DOS version of the UMIDUS program.

In 1998, a new research space called Thermal Systems Laboratory (LST, 2016) was established at the Pontifical Catholic University of Parana (PUCPR) and a Windows version of the Brazilian software UMIDUS (Mendes et al., 1999) was developed to predict heat and moisture transfer through porous building elements with cooperation with UFSC/LAbEEE-LMPT. Also In collaboration with UFSC/LMPT, a new method to solve highly coupled equations of heat and moisture transfer through porous building materials have been developed (Mendes et al., 2001b, Mendes et al., 2003, Mendes and Philippi, 2004, Rode et al., 2004, Mendes and Philippi, 2005), allowing to perform the whole building hygrothermal prediction

Also in late nineties, an OOP building simulation program called DOMUS (Mendes et al., 2001a, Mendes et al., 2008) started to be developed at LST, integrating the UMIDUS capabilities and allowing DOMUS to perform the whole-building hygrothermal simulation. In 2003, (Santos and Mendes, 2003, dos Santos and Mendes, 2004) presented the software Solum to predict 3-D profiles of temperature and moisture content in soils under buildings and some research concerning moisture in soils was carried out numerically (dos Santos and Mendes, 2006, Dos Santos and Mendes, 2005) and experimentally (Olukayode and Nathan, 2007, Akinyemi et al., 2007, Mendes et al., 2012). Moisture rising damp related problems are commonly found in Brazilian constructions.

Grigoletti and Sattler (2007) developed a method to evaluate the hygrothermal performance of low cost single-story houses in the city of Porto Alegre, South of Brazil. It is mentioned the fact that the existing standards of Brazil do not consider items such as solar orientation of the openings, geometry of the building, superficial temperature of the surfaces to avoid water condensation, ventilation for indoor air quality nor heterogeneity of the superficial temperatures (that may lead to thermal bridges).

Dos Santos and Mendes (2009a) presented a new model to compute temperature, vapor pressure and air pressure profiles in porous elements. The same model was used to compute 2-D simulation in hollowed porous elements and thermal bridges (dos Santos and Mendes, 2014, Coelho et al., 2009, dos Santos et al., 2009, dos Santos and Mendes, 2009b) and roofs (dos Santos and Mendes, 2013). As insulations materials are not really used in the country and we see a large potential to their use underneath the roof, we believe a research focus and elaboration of guidelines are needed to reduce moisture problems in roof systems.

LST has also performed simulations using the moisture model of EnergyPlus and carried out a study on sensitivity and uncertainty analysis applied to combined heat and moisture models (Goffart et al., 2015). More recently, some 2-D and 3-D research on moisture models was integrated to the whole-building simulation code Domus and has been presented in Berger et al. (2016). Other two on-going PhD thesis are very focused on this topic, creating a plug-in in a commercial software to be fully integrated into Domus.

Related to moisture buffering effect, an 8m³ experimental test cell was created at PUCPR/LST in order to evaluate the effect and also to validate heat and moisture transfer models (Meissner et al., 2010). In addition, an on-going thesis is carried out in collaboration with University of Savoy on the development of new materials with a high moisture buffer capacity.

As examples of moisture disorder in buildings with case study approach, Sobrinho (2008) analysed the presence of fungi in the mortar of social houses in the countryside of São Paulo, Southeast of Brazil. According to this study, one of the main issues that occur in social houses is rising damp in the mortar due to lack of waterproofing between the floor slab and the soil. Oliveira (2013) studied the main causes that lead to construction disorders in residential buildings. In the construction company, the disorders occurred mostly in the execution (52%) and design (18%) stages. Hydraulic installations, facades and waterproofing sum 49.3% of the requests of technical assistance in the post-occupation period.

The influence of driving rain and of the architectural elements in front of deterioration of the façades were assessed for multi-story residential buildings in the city of Goiania, located in the Central West of Brazil (Júnior and Carasek, 2014). The study verified that moisture from rain deteriorate facades mostly on platbands, windowsill, and drip pans. However, stains occur not only due to facades elements, but also by condensation in masonries, mainly in the South façade, what can lead to microorganism growth.

Therefore, some research work in Brazil has been carried out about moisture in constructions since 80's, but still strictly academic or in a case study approach such as exampled above.

As building design in Brazil has been pushed towards energy efficiency due to the recent establishment of regulations and standards, attracting professionals, consultants and the building sector to the theme, we believe a similar effect might happen with moisture, especially with the possibility of decreasing the overall heat transfer coefficient of roofing systems.

5. Discussion

Despite the fact that Brazil is a large country with very different climates, income inequalities and cultural differences, the majority of the houses use quite the same construction techniques. The standards and laws have different requirements and most of the time are not respected somehow due to the lack of control. Some of them do not take into account the climate as it was shown in section 3, although it represents an important source of moisture with potential risk of mould growth.

None that handles with thermal performance (NBR 15575, NBR 15220, RTQ-R) considers moisture as an evaluation requirement, regardless of its importance. As shown by Mendes et al. (2003), the effects of moisture on conduction loads in walls may lead to oversizing HVAC equipment (especially in dry climates) and to underestimating energy consumption (especially in humid climates), indicating the importance of considering both moisture and weather when dealing with building thermal performance.

Even for constructions with building permits, standards requirements are not always met, as it depends on local laws and supervision. Standards tests require laboratory and equipment that are not always accessible, as they are most of the times located into Universities, which turn their meet more difficult.

There is a cycle between construction methods and standards: the same construction techniques are widely used for years and the standards mainly refer to these type of techniques. Government do not encourage the evolution of new techniques due to the absence of standard new materials. Bureaucracy also plays a role on this difficulty in changing construction methods – if it is not standardized it cannot be used, especially for large buildings that depend on external financing (in Brazil the major funding entity for residential construction is a federal bank).

Mjörnell *et al.* (2011) presented a validated method associated with some tools to be used in order to manage moisture safety in the building process that includes routines, templates and checklists for all parties concerned in all stages in the building process. However, these method and tools assume that there is a project management, with a design phase, a constructor and a building operator. Thus, it does not suit with Brazilian typical construction, as mentioned that over half of the single-story houses are informally built. Even constructions with building permit are not build with professional workers, as in Brazil construction labor it is not a regulated profession.

There are a few tools for moisture control in the building process. One important lacking task is to formulate this knowledge so that it can be applied in all stages and by everyone involved in the design, construction, and operation phases of a building lifecycle.

6. Conclusions

Climatic conditions – high outdoor water vapour pressure, high precipitation rate, driving rain – and low construction quality – great amount of informally built houses, difficulty on attending standards requirements, standards failure on considering moisture and climate, lack of professional labor, cultural and income differences within the country – put the populous country in a position of high attention to the risks of moisture disorders. However, instead of being a recurrent issue in building pathology, moisture is commonly neglected by researchers and building owners in Brazil.

Probably due to cultural issues and to the great amount of informal construction, moisture disorders are currently faced as something unavoidable, particularly for condensation and mould growth that are not necessarily related to execution failure.

Although there is a significant research related to moisture around the world, it is mainly in cold climate countries, for whose moisture represent a major issue once it directly affects thermal performance, deterioration of building envelope and the already high energy consumption. Moisture research in Brazil started in the early eighties and it is still mainly concentrated in universities with very modest application with the building industry. Some difficulties are related to absence of legislation and lack of a database of hygrothermal properties. Nowadays, no laboratory is carrying on measurements to determine moisture related properties.

Nevertheless, the issues presented indicate there is a large potential for conducting research in Brazil on this topic. So far there is no study in the country that assesses the influence of moisture on building energy performance, material deterioration and pathology.

As it has been noticed, since the nineties there is in the country an expressive growth related to building energy efficiency, especially after the creation of standards NBR 15575 and regulations RTQ-C and RTQ-R. We also believe in a similar positive future for the development of moisture research and real application in the building sector in this beginning of the 21st century, especially with the trends of decreasing the overall heat transfer coefficient of roofing systems in residential and commercial buildings.

Suggestions for further work are the accurate assessment of potential risk for mould growth in the different bioclimatic zones (considering building construction), use of simulation to analyse the influence of moisture on energy efficiency considering the Brazilian building type construction, providing guidelines on how to propose robust retrofit in relation to moisture issues and database of building materials commonly used in the country.

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ByggaF - A Method to Include Moisture Safety in the Construction Process

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Abstract

ByggaF is a methodology for including moisture safety in the construction process that was developed and presented in 2007. ByggaF comprises methods to secure, document and communicate moisture safety throughout the construction process, from planning to management. The methods involve a standardized way of working designed to meet the demands of society and the client's requirements for moisture safety. On request from the Swedish construction sector, ByggaF has been transformed into an industry standard. Since then, ByggaF has been used in a number of Swedish construction projects. One reason for the broad implementation of ByggaF is that the Swedish environmental assessment tool Miljöbyggnad demand for using ByggaF in order to reach "silver level" or "gold level". Another reason is that more than 100 moisture experts have been trained to use ByggaF to assure a moisture safe building process. There has also been interest in using ByggaF expressed from other countries. The industry standard has been translated to English but it needs to be adjusted to country specific conditions, such as regulation and building practices in order to be applied in other countries. In Finland, the Swedish version of ByggaF has been adapted to Finnish regulations and used for including moisture safety in construction of a school at Bergö. There have also been attempts to adjust ByggaF to suit specific applications such as construction of prefabricated single family houses and renovation of multifamily houses.

Keywords: Moisture safety, moisture experts, industry standard, construction process

1. Introduction

Moisture damage affecting our buildings is a major problem and involves major costs for repair. Despite today's modern construction methods, the trend is not declining for this type of damage. Moisture damage may cause bad indoor environment, which in turn can have an adverse effect on human health. For home-owners, moisture problems often cause major unexpected expenses. The reasons for moisture damage arising in buildings are due to a number of different factors. This could be an unclear allocation of responsibilities, ambiguous requirements, scanty follow-up and monitoring, unrealistic time schedules, lack of communication between the stages, inadequate skills and insufficient procedures for assuring moisture safety. It could just as well be due to introduction of new types of structures, materials and components without a proper verification of moisture resistant properties. This may lead to degradation in the presence of moisture, with emissions, microbial growth and stability problems as a result. It is therefore extremely important to design moisture-proof structures composed of materials that can withstand the moisture loads that the structure is expected to be exposed to during its service life, and to ensure a suitable environment for the building both during the construction stage and the operational stage. Requirements for moisture safety may often conflict with other requirements such as accessibility, architectural and design requirements as well as energy requirements. These conflicts need to be addressed and resolved throughout the entire construction process.

In order to put more focus on the moisture issues and to work with a structured approach in the construction process, ByggaF – A methodology for including moisture safety in the construction process was developed and presented in 2007, ByggaF (2007) and Mjörnell et al (2012). The methodology was then introduced to the Swedish construction sector and is today widely used by building owners (here referred to as clients), designers and contractors. In 2013 ByggaF was made into an industry standard.

The purpose of ByggaF is to highlight moisture issues at an early stage in new construction, renovation and refurbishment projects and to document the activities and actions that are required and performed in a structured way to ensure a moisture-proof building. By early formulating and setting moisture requirements and requirements for the activities, these can be incorporated into the program documents, system documents, construction documents and control plans, etc. This means that the important choices of systems and designs as well as of materials and production methods that will impact the moisture safety of the building can be made from the beginning. There have though been doubts about what parts of the ByggaF methodology are compulsory and what parts are optional. Therefore, the methodology was developed into a Swedish industry standard for the construction sector in 2013, Mjörnell (2013). The aim with this paper is to disseminate awareness and knowledge about the Swedish industry standard ByggaF to make it available for other countries to apply in their quality management work. The aim is also to give a picture how ByggaF is used today in Sweden and partially in Finland as well where is was used for construction of Bergö school, and how ByggaF has been further developed and adapted to other uses such as prefabricated single-family houses and renovation, (Johansson and Bengtsson, 2015) and (Olsson and Tjäder, 2016).

2. The Method ByggaF

Industry standard ByggaF includes a method that secure, documents and communicates moisture safety throughout the construction process, from planning to operation of the building. The method involves a way of working designed to meet the demands of society and the client's requirements for moisture safety. The full industry standard written in Swedish is available at the website of Swedish moisture centre, www.fuktcentrum.se, where there is also a direct translation of the standard into English. This paper only describes the outlines of the ByggaF method. For a detailed description we refer to the industry standard.

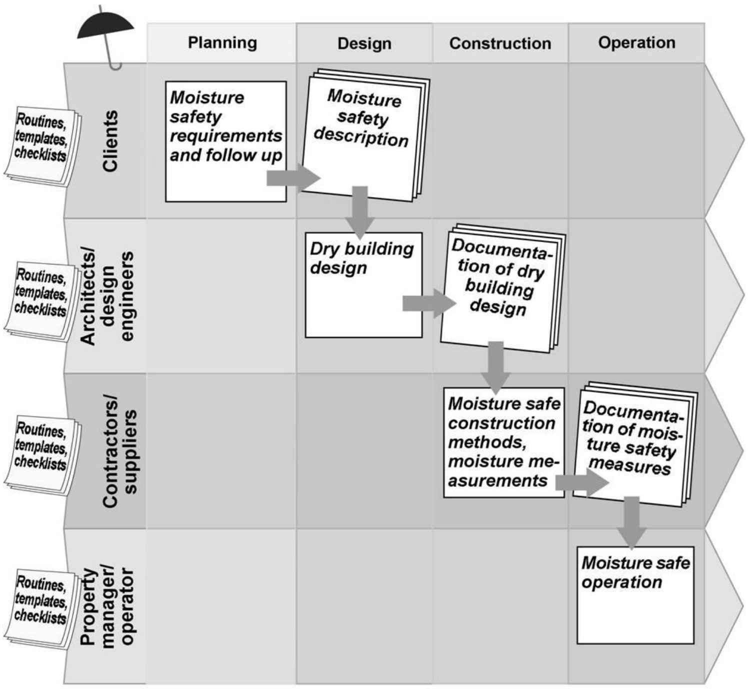

Figure 1 Overall picture of the ByggaF method.

The industry standard is designed to follow the stages in the construction process and covers the activities to be carried out at each stage. In line with how the Swedish building regulations are written, the industry standard has both "must-have requirements" that must be met and in addition, there is a guidance text that can clarify, explain or give examples of what the "must-have requirement" means. The guidance may also contain advice.

2.1 Who is responsible for what?

According to The Planning and Building Act, PBL, the client is the one who performs or fails to perform the planning, construction, alteration, renovation, demolition or excavation work. In order for the building to be planned and designed correctly, the client should engage the appropriate skills for the different work tasks. In many cases, the client hires a project manager as an extended arm in the construction process. However, the client is still responsible for compliance with the laws and regulations such as PBL and BBR. The client does not always possess enough knowledge or time to pursue and monitor the moisture safety work in the project. It can be very helpful for the client to hire a person who is an expert in moisture safety, a moisture expert. The moisture expert can help the client to set requirements for moisture safety and to monitor compliance of the requirements. However, the practical moisture safety work is performed by all participants, planners, designers, contractors, suppliers and operators. The allocation of responsibility for different moisture safety activities at different stages may vary with different forms of construction contracts. Depending on the contract form, the responsibility boundaries are moved between systems planning, detailed planning and production. In the forms of contracts where the contractor also has the role of designer, the contractor must also take responsibility for what in this document are called designers' activities and responsibilities. In design and construct contracts, the responsibility for continually monitoring the moisture safety work lies with a coordinating moisture safety manager (MSM) for the production stage.

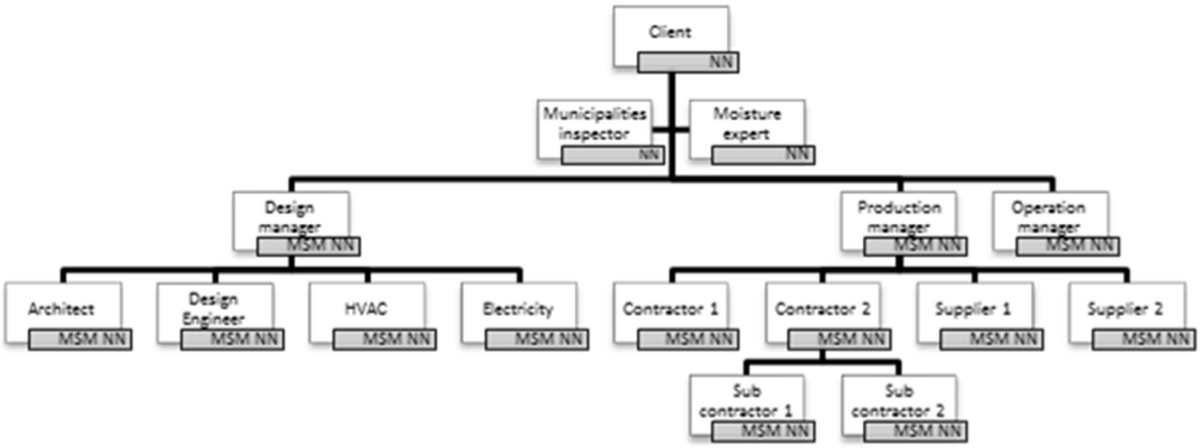

Figure 2 Responsibilities for the moisture safety work in the project organisation.

2.2 Moisture safety in the planning stage

The first thing the client should do is to appoint a moisture expert. Our experience is that involving a moisture expert following up the moisture safety work in the project is of crucial importance for the result. To start with the moisture expert will support the client making the early moisture risk analysis which he or she is responsible for. By making an early risk analyses before the mayor decisions about the buildings location, foundation practices, principles for handling rainwater, drainage systems, supporting framework, construction methods etc. are made, moisture critical constructions and designs could be avoided, which will save time and money in the long run. The moisture expert may also help the client to decide on the moisture safety requirements to be set in the project. It must be possible to verify and monitor the moisture safety requirements. The requirements must include both technical requirements and requirements for activities and skills.

2.3 Moisture safety in the design stage

Already in the procurement and contracting of planners and designers it is important to inform them about the moisture safety requirements and the methods that will be used to monitor compliance of the requirements. Each participant involved in the design stage, designing materials, building elements or installations that affect the moisture safety of the building must follow the procedure for moisture safety design. To start with, all structures and materials sensitive to moisture and moisture critical work operations must be identified. The next step is to estimate the moisture condition that the various building elements and materials as well as combination of materials will be exposed to and describe how they vary in time. Then the estimated moisture conditions are to be compared with the permitted moisture conditions in order to evaluate the probability of damage to occur.

2.4 Moisture safety in the production stage

Ahead of production, the moisture expert supported by project planners and designers must notify the main contractor of the result of the moisture safety planning and motivate their choice of construction and designs and can also answer questions regarding the drawings and technical descriptions. This is also an opportunity for feedback on the planning and design process.

Firstly, moisture-sensitive elements, structures and installations that are important in production are identified. Secondly, a moisture safety plan is prepared that describes the moisture safety measures to be undertaken in order to protect the building and construction materials from damaging moisture during production and must also include the control points identified during the planning stage. The moisture safety manager for production must ensure the implementation of the activities in the moisture safety plan as well as implementation and documentation the measurement and inspections according to the moisture safety plan. Moisture inspection rounds at the construction site are performed by the moisture safety manager and the moisture expert throughout the construction process.

In the end of the construction process, the moisture safety manager collects data for operation and maintenance instructions for moisture safety from subcontractors and suppliers as well as data from the moisture safety work carried out by subcontractors and suppliers, and submits this to the moisture expert, who in turn compiles the moisture safety documentation from planning and production and submits it to the developer.

2.5 Moisture safety in the operation stage

In the commissioning stage when the building is handed over to the building owner, the developer’s moisture expert and the moisture safety manager for production go through the moisture critical structures of the building and the measures to be carried out to ensure that moisture safety is maintained, with the responsible administrator and operations manager. During subsequent management of the building, the operation manager, on behalf of the building owner, is responsible for carrying out recurrent operational inspection rounds, in which moisture safety is one of many aspects to be considered.

3. Experiences from using ByggaF

In order to get an idea on how frequently ByggaF is used in the construction industry today and to get feedback on the field of application, usefulness and suggestion for improvements, 25 deep interviews were conducted. The interviewees were selected partly from the lists of moisture experts holding a diploma from Swedish moisture centre, partly from moisture experts who have been involved in projects that have received “gold level” in the Swedish environmental assessment tool Miljöbyggnad, a certification system for buildings, based on Swedish construction rules and regulations such as BBR, which implies working according to ByggaF.

The results from the interviews indicate that many of the users are concerned with the paper work originating from the requirement of documentation of requirements, moisture safety design and moisture safety activities during production. They ask for shorter documents summarizing the most important issues to be communicated. The documents aimed for the building owner are less frequently used and moisture experts are engaged at a later stage in the process. The interviewees are also concerned about insufficient knowledge and engagement on the part of the building owners. Another concern is the building owners unwillingness to spend money on moisture safety expertize in the beginning of the project when it would be easier to form the basis of a moisture safe design and construction, rather than to be involved later in the process to manage moisture safety issues when conditions for assuring moisture safe building are bad or even when things already have gone wrong. Critical decisions influencing the moisture safety of the building are taken early in the construction process. Another concern is that too much time is spent on meetings, rather than on constructive work.

Yet another concern is that architects and design engineers’ levels of ability vary when it comes to moisture safety design. There is also a lack of practice to document the moisture safety design and an uncertainty how to perform risk analyses. Today, risk analyses are done based on earlier experience from damages which is not sufficiently enough. In some cases the risk analyses has been disregarded. The competence among the contractors is also low and there is insufficient information and communication between employee and workers.

The moisture inspection round is an appreciated and frequently used activity and the template for documentation is widely used. However, some companies have slightly adapted the template in order to make it easier to include pictures taken during the rounds. There are also attempts to make a digital tool for the moisture inspection round. The application is however not yet launched on the market.

Many ask for a less comprehensive version of ByggaF and some companies have adjusted the documents, such as the moisture safety description, moisture design and risk evaluation, moisture safety plan and moisture round protocol, to make them easier and more suitable for their own work processes.

Among the things the interviewee asked for is a certificate affirming that the ByggaF has been used in the building process and an adjustment of ByggaF to small projects. They also stress on the importance to bring up moisture issues and moisture risks early in the building process before the procurement documents are sent out.

4. Adjustment of ByggaF to other uses

As a result of the relatively wide use of ByggaF, there have been inquiries to adjust ByggaF to specific construction processes such as construction of single family houses as well as renovation. Such attempts have been made by students in the form of two diploma works. The aim with the first study was to adapt ByggaF into a modified method ByggaF- PST applicable to the industrialized manufacturing process of single family houses with timber frame, in order to assure that is fulfills the moisture requirements specified in the buildings regulations. This work was done in collaboration with the housing industry.

The prefabricated manufacturing building process requires adjustments in ByggaF because the building process involves construction of modules and elements in a factory. For this reason ByggaF-PST includes a new stage; manufacturing of modules in factory. Another difference is that the client in most cases chooses a house from a catalogue. This means that the house already is more or less planned and designed when the client gets involved in the project. The house consists of prefabricated modules manufactured inside a factory, delivered to the building site where they are put together. For this reason there is an essential difference between the prefabricated and an ordinary building process. This affects the activities, stages, and parties involved in the presented method ByggaF-PST.

Since the client comes in late in the process, after the design is decided, and generally would not have the knowledge or the competence of setting requirements or following up moisture issues, the role as the moisture expert is delegated to the house supplier. The checklists for design as well as the risk evaluation are adapted to the most common design of prefabricated single family house modules. Another difference is that the production stage is divided into two; production of modules in factory and erection at the building site. (Johansson and Bengtsson 2015)

The aim of the second study was to adjust ByggaF to the renovation process. As a first stage interviews were conducted asking the users how ByggaF needs to be adjusted to better suit the renovation process. There was a concordance among the interviews that the most important document to further develop is the routine and checklist for inventory and investigation prior to renovation. There is also a need to adjust the procedure and template for moisture risk evaluation to suit constructions most critical in the process of renovation. The work is ongoing and not yes published. (Olsson and Tjäder, 2016)

5. Administration and training in ByggaF

The industry standard ByggaF is administrated by the Swedish moisture centre. Every year Lund University together with SP Technical Research Institute of Sweden arrange training for moisture experts. It is a 10 days of lectures (compulsory), a number of assignments to work with at home between the training occasions and a written examination in the end. When all training requirements are fulfilled the attendees get a diploma. Until know, approximately 220 persons have attended the training and 100 persons have get the diploma.

Every year, a regathering for all the attendees is arranged. The aim of this meeting is to exchange experience how ByggaF is used in the construction industry, feedback on specific drawbacks and suggestion for improvement and to inform each other of new types of moisture safety problems in general but also on new research and regulations concerning moisture issues to be better prepared for the commission as moisture experts.

Additionally, ByggaF is introduced to the students at Lund University as well as at Chalmers University.

6. Discussion

The extensive use of ByggaF may partly be explained by an advice in the Swedish building regulation BBR but also due to the fact that ByggaF must be used in order to achieve gold or silver level in the Swedish environmental certification system Miljöbyggnad. However, we have very little knowledge to what extent the different parts of ByggaF is used since it is not required to report this in detail for achieving the certificate. The results from the interviews indicate that many of the users are concerned with the heavy paper work originating from the requirement of documentation of requirements, moisture safety design and moisture safety activities during production: It is however important to keep track of activities and decisions done and a comprehensive documentation is indispensable if a retrospect is needed. The ByggaF users ask for shorter documents summarizing the most important issues to be communicated. This is something that will be considered in the further development of ByggaF. Even though the results from the interview study point out a demand for higher competence levels among the actors, the situation is much better than a couple of years ago but of course the competence levels among all actors need to be increased. Training courses suited for different actors such as clients, moisture experts, contractors and design engineers have been developed and arranged by the Swedish moisture centre at least ones a year.

7. Conclusions

The industry standard ByggaF includes a method that guarantees, documents and communicates moisture safety throughout the construction process, from planning to management. The industry standard involves a standardized way of working designed to meet the demands of society and the developer's requirements for moisture safety. The purpose of the industry standard ByggaF is to highlight moisture issues at an early stage in new construction, renovation and refurbishment projects and to document the activities and actions that are required and performed in a structured way to ensure a moisture-proof building. By formulating and setting moisture requirements and requirements for the activities, these can be incorporated into the program documents, system documents, construction documents and control plans, etc. This means that the important systems and material selection and production methods that will impact the moisture safety of the building can be made from the beginning. The aim is to make it clear and easy for the building owner to work according to the methodology and support him or her in the formulation and following up of moisture requirements during the different phases in the construction process. The industry standard has been developed in collaboration between researchers, building owners, contractors, design engineers and authorities. It is an open access standard available to down load at www.fuktcentrum.se. The English version makes it possible to use the industry standard not only in Sweden but also in other countries and in international construction projects. The requirement part of the industry standard must however be adapted to national conditions and regulations.

An interview study was conducted to get knowledge about to what extent ByggaF is used by the Swedish construction industry today and what the users views and experience from using ByggaF as well as suggestions for further development and adjustment. The conclusion is that parts of ByggaF are widely used but the users express concerns about the low level of competence in moisture issues among both designers and contractors. There are also concerns about the heavy paperwork and a wish to make that less extensive.

Until now there have been two attempts to further develop and adjust ByggaF to suit specific needs such as the construction of prefabricated single family houses and renovation of multifamily houses have been conducted in the form of diploma works.

Swedish moisture centre is responsible for administration and training in ByggaF. Up to now, approximately 220 persons have attended training for moisture experts and a little more than 100 persons have received a diploma.

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The Planning and Building Act, PBL, National board of housing, building and planning.

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Moisture Management in the Building Construction Process in Japan

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Abstract

In Japanese buildings, moisture-related problems such as water leakage and condensation are common. Although the Japanese have extensive experience with various countermeasures, numerous problems need to be solved to guarantee a durable and energy-saving building without moisture problems. For this purpose, the Building Code for Promoting Qualified Residential Building (hereafter referred to as "Hinkakuho") was enacted in 1999. The purpose, structure, technical standard, evaluation method, and guarantee system of this building code are briefly explained in this paper. In addition, recent research results related to vented wall cavities, attic ventilation, and condensation in spandrels of office buildings are explained.

Keywords: monsoon climate, Building Code for Promoting Qualified Residential Building (Hinkakuho), vented wall cavity, attic ventilation, condensation in spandrels.

1. Moisture Management Issues in Japan

1.1 Weather conditions in Japan

(1) Large amount of precipitation Because Japan is located in the boundary region of the monsoon climate and is surrounded by water, it receives a large volume of precipitation. The annual precipitation in Japan is approximately twice the world average (Fig. 1), which is one of the main reasons for the common occurrence of moisture-related issues.

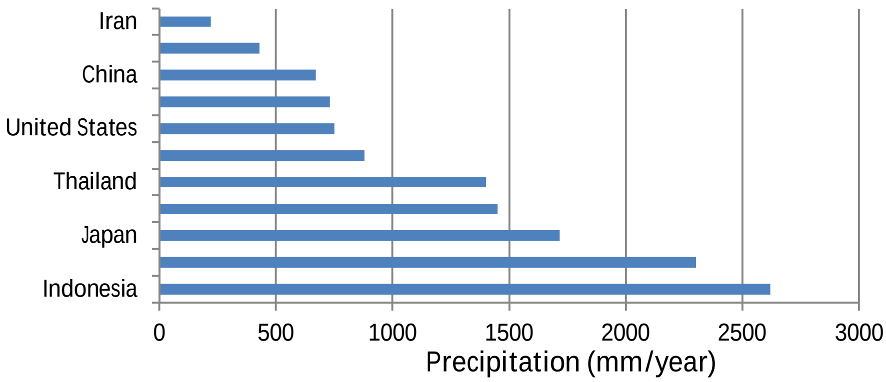


Fig. 1 World average of annual precipitation.

a) **Various moisture-related problems** Because the buildings in Japan are subjected to rain and snow throughout the year, suitable flashing such as roof waterproofing structures, eaves (including window eaves), rain gutters, sliding shutters, raised floors, adequate building ventilation, and crawl space are incorporated into a building structure. Nevertheless, numerous problems remain to be solved. A few of those are mentioned below.

・Deterioration of roof materials due to rain or snow: decay of wood, frost damage on roof tiles.
・High humidity, decay of wooden elements, condensation during summer due to ventilation, and termite breeding in crawl space because of high groundwater level and soil water content.
・High indoor humidity.

b) **A large number of wooden buildings** The number of wooden buildings and amount of wood used per person in Japan are high. Wooden buildings in Japan have not been constructed air-tight, which might be a result of prioritizing comfort during hot and humid summers over comfort during cold winters.

(2) Four seasons and large regional differences

Because Japan is an archipelago extending toward north and south, where its east and west sides face the Pacific Ocean and the continent of Asia across the Sea of Japan, respectively, local differences in the climate are rather large. Although the Japanese climate is regarded as mild, the contrast of hot, humid summers and cold, dry winters is clear and the differences between the four seasons is substantial. These seasonal and local differences cause different kinds of moisture problems.

1.2 Indoor conditions and lifestyle

Because open-type heating devices such as oil or gas combustors were previously used extensively in Japan, moisture problems such as condensation, mold growth, and decay of wooden building elements are quite common. By contrast, along with the proliferation of heating devices that do not operate on combustion, such as heatpump and insulated buildings, dry indoor climates and shrinkage of flooring and condensation due to the use of a humidifier have appeared as new moisture-related issues. Local heating and cooling is quite common even now, and it causes temperature and humidity differences in a building, followed by condensation or mold growth. In addition, wooden buildings with numerous cracks are likely to be damaged by interstitial condensation due to air leakage or vapor diffusion.

2. Building standards and norms in Japan for moisture-safe construction

2.1 Quality assurance systems in Japan: residential buildings

(1) Building Code for Promoting Qualified Residential Building ("Hinkakuho")

Most of the building standards and norms related to moisture-safe construction in Japan are specified in the "Building Code for Promoting Qualified Residential Building (1999)" published by the Ministry of Land, Infrastructure, and Transport.

http://www.mlit.go.jp/jutakukentiku/house/jutakukentiku_house_tk4_000016.html

This code was renewed 2009. Afterwards, the "Housing Performance Display System (HPDS)" was reviewed, and the "Japan Housing Performance Display Standard (JHPDS)," the "Evaluation Method Standard (EMS)," etc. were revised and promulgated February, 2014. Since then, the renewal of the Building Code (June, 2014), EMS, etc. were reviewed and promulgated

2015. HPDS was then reviewed again, and the JHPDS, EMS, etc. were revised and promulgated January, 2016, and were put into effect April, 2016.

(2) Background and objective of Hinkakuho

The following problems are serious considerations for a person intending to acquire a house:

- Because no common rule exists for displaying housing performance, a suitable comparison is difficult.
- The method of evaluating housing performance is not reliable.
- No professional management system exists for dealing with troubles regarding housing performance; consequently, a large amount of labor is required for solving problems.
- When acquiring a newly built house, the warranty period of the contract is usually one or two years.

By contrast, the following problems are serious considerations for housing suppliers:

- Because no common rule exists for displaying housing performance, the incentive for competing housing performance is weak.
- Educating the consumer such that they understand the housing performance is not easy.
- A large amount of labor is required for handling complaints regarding housing performance.
- When acquiring a newly built house, a warranty period longer than 10 years is impossible.

From the standpoint that a new framework guaranteeing housing performance from production to after-sales service stages is essential to solve these problems, this new code, Hinkakuho, was established with the following objectives:

- To promote guaranteeing of housing performance;
- To protect the purchaser’s interests; and
- To provide quick and fair solutions regarding housing problems.

(3) Framework of Hinkakuho

Given such background and objectives, the framework of Hinkakuho is outlined as follows.

- Establishment of housing performance display system
  - ・By a common rule (“Display Standard” or “EMS”) that guarantees the fair display of housing performance (structural strength, acoustic insulation, and energy conservation), the purchasers can compare the housing performance of different houses.
  - ・A fair evaluation regarding housing performance by a trusted third party can guarantee reliability of the evaluation.
  - ・The displayed performance can be achieved on the basis of the principle that the housing performance stated in an evaluation document can be a contract.

② Development of management system dealing with housing performance problems

③ Exception of defect liability

- ・In the contract when buying a newly built house, a warranty period of 10 years is required regarding the basic structural components.
- ・In the contract when buying a newly built house, a warranty period up to 20 years could be possible, including parts other than the basic structural parts.

Notably, whether the Housing Performance Display System is used or not can be decided by a housing supplier, a person intending to acquire a house, or a dealer of existing houses.

(4) Japan Housing Performance Display Standard (JHPDS)

The JHPDS is the standard specifying items to be displayed and conditions for display regarding housing performance (structural safety, indoor air environment, care for the elderly, etc.). Fig. 2 shows an image of a housing performance display. It includes 10 fields covering 32 items for a newly built house, where two fields, ③ reduction of degradation and ⑤ thermal environment and energy consumption, are related to moisture management.

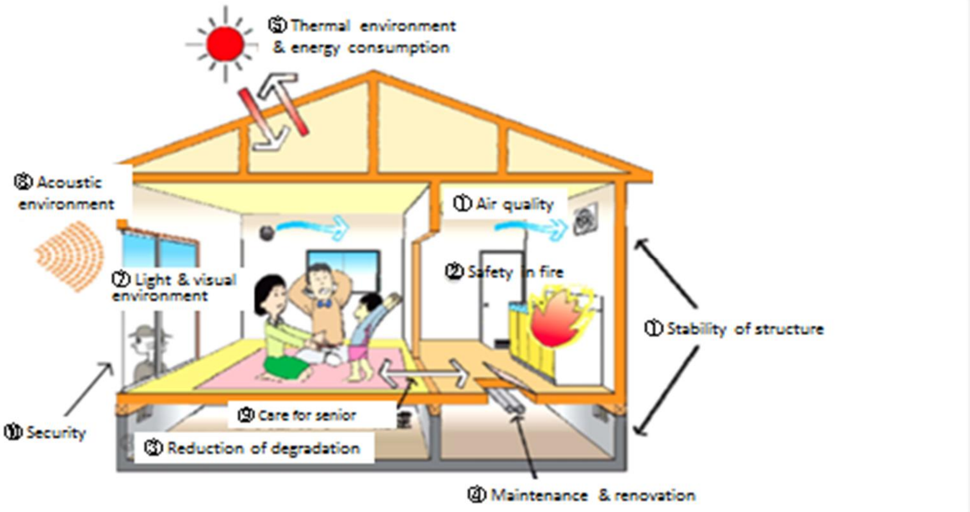


Fig. 2 Image of a housing performance display.

(5) Evaluation Method Standard (EMS)

This standard specifies an evaluating method for design documents and inspection methods regarding housing performance required by the Japan Housing Performance Display Standard (JHPDS). Existing houses were added as subjects in August, 2002.

(6) Evaluation of housing performance by registered institutions

(7) Management system dealing with problems regarding housing performance

(8) Exception to warranty

2.2 Evaluation Method Standard (EMS)

(http://www.mlit.go.jp/common/001119167.pdf)

Moisture-related issues are specified in two chapters (fields), "③ reduction of degradation," (hereafter "3-Degradation") and "⑤ thermal environment and energy consumption" (hereafter "5-Energy"). In the following sections, more details will be given. In this standard, "degradation" refers to the following:

- ・Wooden house: degradation of wood by decay and termites
- ・Steel-framed house: defects in cross sections of steel members due to rusting
- ・Reinforced concrete house: rusting of reinforcing bars due to neutralization of concrete and deterioration of concrete caused by freezing and thawing

In the following sections, only the contents related to the third-level measures will be described. Here, "third level" refers to the measures required to prevent deterioration within 3 generations, where one generation corresponds to approximately 25 to 30 years.

(1) **External wall and roof** In 3-Degradation, only the treatment of termites is described. In 5-Energy, the following measures are specified for preventing condensation:

・When a fibrous insulation material such as glass-wool or cellulose fiber, or a plastic insulation material with small water vapor resistance is used, a vapor barrier must be installed to the building element connected to the outside (p. 98).
・Nevertheless, a vapor barrier is not required if the sum of vapor resistances from the outer side of the insulation to the inside air, divided by the sum of vapor resistances from the outer side of the insulation to the outside air, is larger than the specified value (p. 99).
・If the roof or external wall is insulated, installation of a vented air layer or any other measure effective for ventilation must be taken to the outer side of the insulation (p. 99).

(2) **Attic space** Necessary number of ventilating openings and area are specified in 3-Degradation (p. 67) as follows:
・Behind the eaves, ventilating openings more than two must be installed at the positions effective for ventilation, and furthermore the effective opening area must be more than $1/250^{th}$ of the ceiling area.
・To the external walls of attic space, ventilating openings more than two must be installed at the positions effective for ventilation; furthermore, the effective opening area must be more than $1/300^{th}$ of the ceiling area.

(3) **Crawl space** The following are specified in 3-Degradation (pp. 66–67):
・The ground surface must be covered by reinforced concrete thicker than 60 mm, a vapor barrier film thicker than 0.1 mm, or another material with equivalent vapor resistance.
・At external walls of the crawl space, ventilation openings must be installed with an effective area greater than 300 cm^2 every 4 m of wall length.
・However, this is exemplified in the case of thermal insulation foundation if the ground surface is covered by reinforced concrete thicker than 100 mm, a vapor barrier film thicker than 0.1 mm, or another material with equivalent vapor resistance and if the thermal resistance of the foundation is appropriate.

(4) **Bathroom and dressing room** 3-Degradation (pp. 65–66) requires that frameworks of walls and floor of bathroom and dressing rooms and the ceilings of bathrooms must be finished with effective water proofing and that the bathroom be composed of a bath unit specified by JIS.

(5) **Living space** There is no regulation.

2.3 Moisture related regulations to non-residential buildings

(1) Indoor humidity "The management standard of environmental sanitation for buildings"*[1] in "Law for Maintenance of Sanitation in Buildings"*[2] specifies that the relative humidity in living spaces should be maintained between 40 and 70% in air-conditioned buildings.

*[1]http://www.mhlw.go.jp/bunya/kenkou/seikatsu-eisei10/

*[2]http://www.mhlw.go.jp/stf/seisakunitsuite/bunya/kenkou/seikatsu-eisei09/index_1.html

(2) Humidity in schools Regarding schools, "Standards of environmental sanitation at schools"*[3] specifies that relative humidity between 30% and 80% is desirable.

*[3]http://www.mext.go.jp/component/a_menu/education/detail/__icsFiles/afieldfile/2010/08/06/1222311_001.pdf

(3) Regulation on moisture management There is no regulation on humidity regarding non-residential buildings, although thermal insulation is required from an energy-saving view-point as PAL*[4] (Perimeter Annual Load). *[4]http://www.kenken.go.jp/becc/

3. Quality assurance systems in Japan

3.1 System guaranteeing housing performance satisfying standards

A system guaranteeing housing performance satisfying standards is composed of the following items, as specified by Hinkakuho:

- Establishment of trusted third parties who give fair evaluations regarding housing performance and guarantee of reliability of the evaluation.

  The housing performance evaluation organization of registered houses (registered by the Minister of Land, Infrastructure and Transport) can evaluate housing performance at applicant and issue an evaluation document of housing performance (evaluation document with label, Fig. 3).

Fig. 3 Example of label evaluating performance.

- By making use of a principle that the housing performance displayed in an evaluation document can serve as a contract, the displayed performance can be realized (Fig. 4).

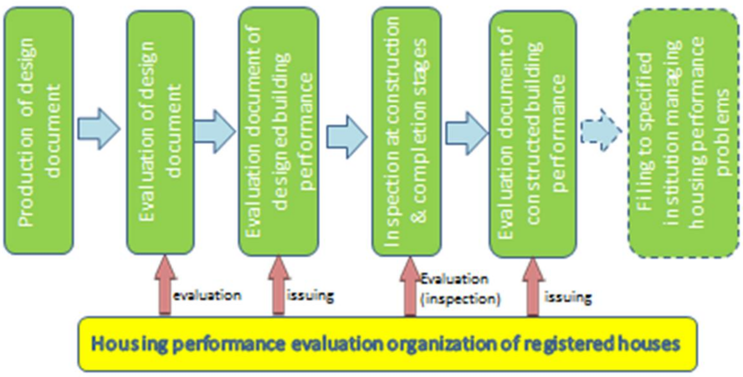


Fig. 4 Flow chart of evaluation process of housing performance (newly built house).

- Establishment of management system dealing with problems regarding housing performance.

3.2 Exception to warranty

The important point of exception to warranty is that, in the contract when buying a newly built house, a warranty period of 10 years is required regarding the basic structural components and a warranty period up to 20 years and including parts other than the basic structural components should be possible.

4. Recent research for improving moisture safety in the building process

4.1 Moisture damage in vented air space of exterior walls of wooden houses (Umeno, 2011)

(1) Background Most of the exterior walls of wooden houses in Japan have a vented air layer between the exterior cladding and the insulation. This vented air layer is designed to dehumidify exterior walls by discharging humidity to the outside and allowing outdoor air to enter, thereby decreasing the risk of condensation on the exterior wall during winter. The source of this moisture is assumed to be the indoor air; that is, the outdoor air is assumed to be drier. However, the outdoor air is often highly humid during the rainy season and may become a source of moisture. The vented air layer also allows rainwater to drain away. Any rainwater penetrating through the exterior cladding is drained away through the vented air layer. However, rain can also enter the vented air space through the air inlets. Water might accumulate in the vented air layer and produce high humidity in the exterior wall. This section describes a case of moisture damage where lye appeared on the outer surface of a plywood wall.

(2) Moisture damage to an exterior wall with a vented air layer: Lye from plywood

Figure 5 shows a case of moisture damage in the vented air layer of an exterior wall in a 4-year-old wooden residential building. Reddish-brown water was observed flowing between the plywood and the house wrapping sheets. This reddish-brown water was determined to be lye from the plywood. Lye generation was mainly observed at the contact points between the plywood and the house wrapping sheets. Furthermore, staples in the plywood had rusted.

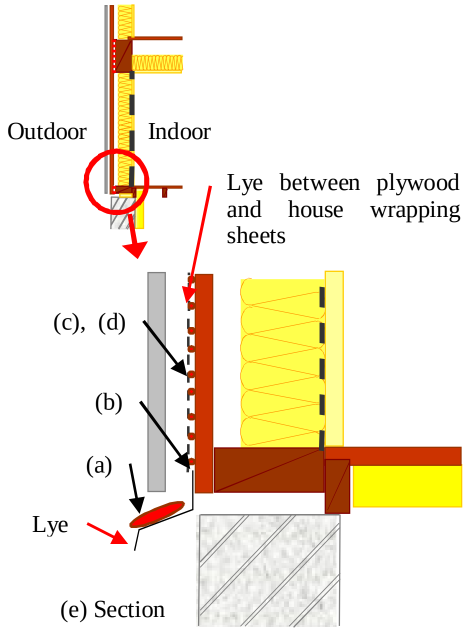
There was no evidence of condensation on the inner surface of the plywood, on the insulation, or on the posts and beams. Lye typically appeared in houses with a thin vented air layer, and was mainly found in east-facing walls. The lye was usually observed during the rainy season or in summer. Because the lye was distributed all over the surface of the plywood, condensation likely occurred on the outer surface of the plywood. The moisture source for the condensation could be either rainwater or outdoor air (or both). Because humidity increases readily in spaces with a small volume and low ventilation rate, the lye tends to appear in walls with a thin vented air layer.

(a) Lye on the flashing

(b) Bottom edge of house wrapping sheets

(c) Outside of house wrapping sheets

(d) Inside of house wrapping sheets



(e) Section

Fig. 5 Lye generation in a vented air layer.

(3) Experiments simulating lye generation

Experiments designed to simulate lye generation were performed in climate chambers. An external test wall consisting of a wooden post-and-beam framework covered in plywood and house wrapping sheets was constructed between two climate chambers. The temperature and humidity of climate chamber 1 were controlled to simulate the vented air layer, and chamber 2 was used to simulate the external surface of the insulation layer of the external wall. Experiments were then performed using three temperature and humidity combinations based on temperature and humidity measurements taken during the rainy season in Japan (Table 1). Each experiment was performed for one week. The condition of the test wall was observed visually.

In case 1 and case 2, neither condensation nor lye generation were observed on the plywood surface. In case 3, under the severest test conditions, a small amount of condensation was observed on the plywood surface immediately after the start of the experiment. The amount of condensation increased over time. After 24 hours, reddish-brown water was observed on the flashing. Figure 6 shows the change in the appearance of the test wall during the experiment in case 3. After one week, mold was observed on the plywood surface and rust was observed on the staples of the house wrapping sheets (Fig. 6 (b) and (c)).

(4) Analysis of condensation in the vented air layer The hygrothermal characteristics of the vented air layer were evaluated using numerical analysis, and the possible causes of condensation in the vented air layer were investigated. Outdoor airflow into the vented air layer could not be the cause of condensation leading to lye generation on the plywood. Instead, rain penetration through the exterior cladding was a more likely cause of lye generation.

Table 1 Experimental conditions.

	Case 1	Case 2	Case 3
Vented air layer	30 °C, 70% RH	35 °C, 70% RH	40 °C, 70% RH
Insulation layer	20 °C, 55% RH	24 °C, 55% RH	26 °C, 55% RH
External surface of plywood	26 °C	30 °C	34 °C

(a) Lye on the flashing (b) Mold on plywood (c) Rust on a staple

Fig. 6 Change in appearance of the test wall in case 3.

4.2 Hygrothermal conditions in attic spaces of wooden houses with eaves ventilation (Matsuoka, 2015)

(1) Introduction In Japan, roofs are generally constructed with plywood sheathing boards as an anti-earthquake measure. Consequently, the moisture in the attic space cannot be easily discharged outside and condensation often occurs on the sheathing roof board surface in winter in the attics of wooden houses whose ceilings are insulated. The governmental organization Japan Housing Finance Agency ("JHFA"), which finances end users for purchasing a house, plays an important role in improving the quality of Japanese houses. A general specification published by the organization provides a standard area for ventilation openings in attic spaces (JHFA). However, a rationale for this standard cannot be found in the literature in Japan. In response to new standards for energy saving, the insulation and air tightness performance of recent Japanese houses has been improved. The installation of a high vapor barrier in the ceiling, for example, decreased the moisture flow from the room to the attic space compared to houses built before the Agency Standard was implemented. From these viewpoints, the formulation of a guideline for an attic's necessary ventilation opening area that depends on the local climate is needed.

(2) Experiments A mock-up, one-story test house (3.64 m × 3.64 m floor area and a 2.54 m ceiling height) with eaves ventilation (Photo 1) was built in a suburb of Tokyo. The ceiling comprised two-layered glass wool insulation with a density of 10 kg/m^3; the insulation was 100 mm thick and was packed in polyethylene bags. On the indoor-facing side of this insulation material, a polyethylene film was attached to prevent the fibers from being scattered and to prevent condensation. The measurements were performed from February 2014 to April, 2014. The room temperature was controlled to approximately 21 °C using an air conditioner and humidity was controlled to approximately 50% to 60% using a humidifier.

Hygrothermal fluctuations in the attic space. The measured results are shown in Figs. 7–9. The relative humidity of the attic space tended to be high during early mornings. Condensation was likely to occur on the sheathing roof board every day (Fig. 8). The absolute humidity increased until early afternoon, decreased during the evening, and was almost constant during the night (Fig. 9). The absolute humidity was sometimes lower in the attic space than that in the outdoors during the night (encircled in Fig. 9).

Photo 1—Eaves vent of the experimental house (north side).

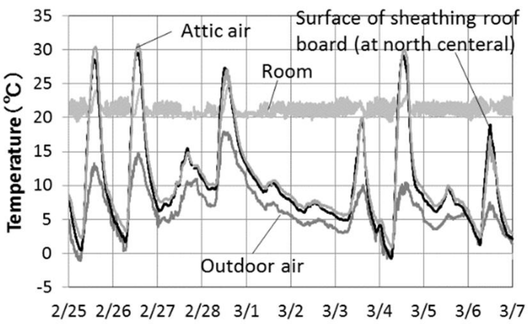


Fig. 7 Temperature in the test attic space.

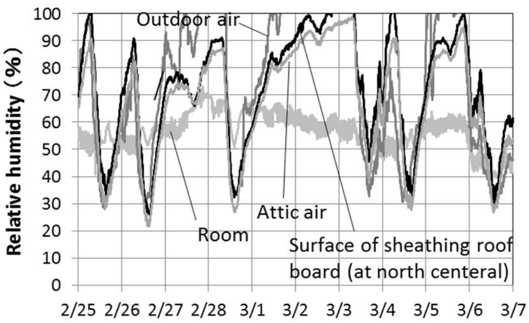


Fig. 8 RH in the test attic space.

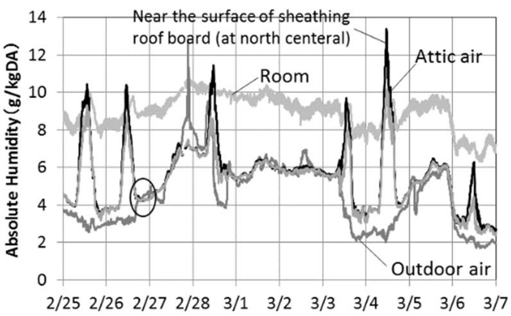


Fig. 9 Absolute humidity in the test attic space.

(3) Airflow rates through the building elements enclosing the attic space

Figure 10 shows the estimated daily average of the incoming/outgoing flow rates through the vented eave cavities, and Fig. 11 shows the flow rate through the vented wall cavity. The average ventilation rate of the attic was 10.5 times/h through the eaves ventilation opening and 1.6 times/h through the vented wall cavity. The airflow rate through the ventilation opening (north) was substantial mainly because of the location of the experimental house and the climatic conditions. The amount of upward flow through the vented wall cavity was approximately the same for the north and south walls and most of it flowed into the attic space. In the case of the flow rate through the vented cavity in the southern wall, the ratio among the upward airflow into the attic space, upward airflow into the eaves ventilation opening, and downward flow was approximately 5:1:4. Given that 20% of the upward airflow through the vented wall did not contribute to ventilating the attic, the eave space should be incorporated into the simulation model to investigate the proper size of the attic ventilation opening.

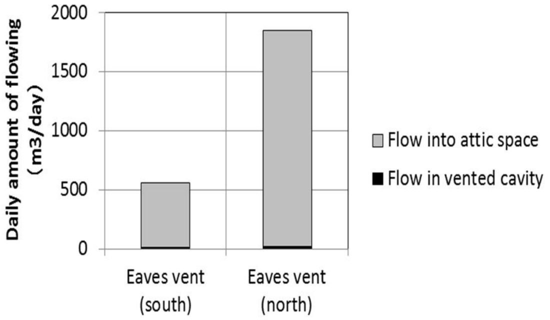


Fig. 10 Flow rate through the eaves vents.

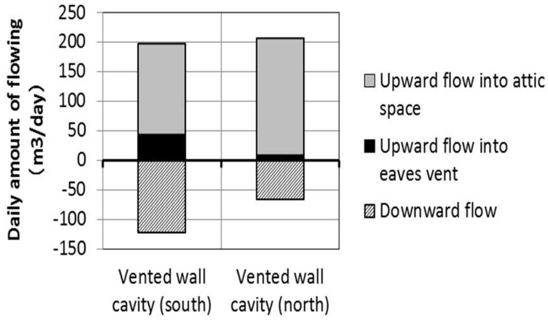


Fig. 11 Flow rate through the vented wall cavity.

(4) Hygrothermal analysis of the attic space The attic used in the simulation is shown in Fig. 12. The simultaneous transfer of the heat and moisture in the hygroscopic regime was analyzed (Matsumoto, 1971). The calculated relative humidity of the sheathing board's (north) surface was in good agreement with those measured (Fig. 12). The calculated attic temperature, attic absolute humidity, absolute humidity of the eave space, and other temperatures and humidity (omitted) were also in good agreement with the measured values.

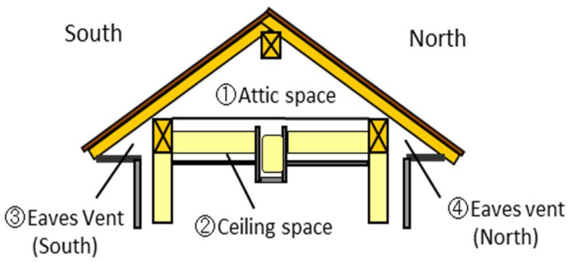


Fig. 12 Calculation model.

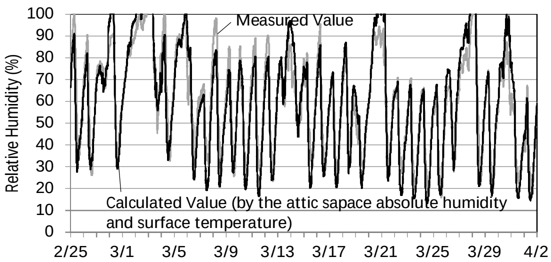


Fig. 13 RH at the sheathing roof board surface (north, inner side).

(6) Dehumidification of the attic space by building elements (daily average). The daily average of the dehumidification in the attic space by the building elements during the experimental period is shown in Fig. 14. The amount of dehumidification through the ventilation opening (north) was substantial. The amount of moisture desorption and absorption by the wooden materials in the attic was approximately the same, and the humidification due to advection vapor flow

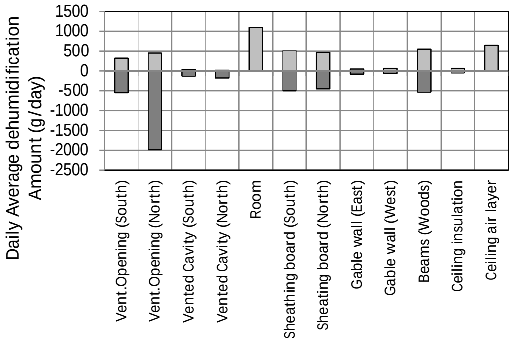


Fig. 14 Daily average dehumidification amount.

the ceiling air layer was approximately the same as that by each of the north and south sheathing boards. These results indicate that the existence of the wooden materials in the attic space, air tightness of the ceiling surface, and method of constructing the ceiling insulation are essential when examining the moisture balance of an attic space.

4.5 Prevention of condensation in the spandrel of glass curtain walls (Gondo 2011)

(1) Introduction In recent years, glass curtain walls have been increasingly used for the entire walls of office buildings in Japan because of their aesthetic appeal. At the same time, demand has been strong for maintaining suitable humidity in buildings in winter from the standpoint of enhancing the comfort and health of people indoors. Under this humidity condition, condensation in spandrels (Fig. 15) of glass curtain walls occurs from time to time. This condensation is considered to occur because of the entry of warm and humid indoor air into the spandrels and/or because of desorption of moisture from the refractory boards (calcium silicate boards) installed to prevent a fire from spreading to the upper and lower floors. Spandrel mock-ups were constructed and experiments were carried out to investigate the influence of various factors such as indoor interstices, outdoor interstices, moisture content, and type of calcium silicate board on condensation.

(2) Experiment on condensation without solar radiation (Experiment I)

To understand the influence of the indoor temperature and humidity, the interstices around calcium silicate boards, etc., a mock-up glass curtain wall spandrel was installed (Fig. 16) in a climate chamber. The experimental cases are presented in Table 2, with Case 1-1 as the standard case. The calcium silicate board used was a 20-mm-thick tobermorite-base.

With an increase in indoor humidity, the dew point of the cavity increased compared to the standard case, Case 1-1 (Fig. 17). Even when the indoor humidity was increased to 35% and 45%, the dew point inside the cavity did not increase under airtight conditions (Case 1-5). The amount of condensed water on the glass surface and the dew point in the cavity at an indoor RH of 45% are shown in Fig. 18. Insulating the indoor side of the calcium silicate board and providing a hole for ventilation of room air should be avoided.

(3) Experiment on condensation with solar radiation (Experiment II)

The influence of the liberation of moisture from the calcium silicate board was investigated under solar radiation. Infrared radiation was applied for approximately 7 hours to simulate the temperature rise induced by solar radiation. The results of the experiment with the indoor-side interstices sealed under solar radiation showed that, when interstices are provided at the outdoor side, the cavity is ventilated and the amount of condensed water decreases. The influence of the calcium silicate board type on condensation on the glass surface was observed to be important, and when a calcium silicate board with low moisture content was used or when the board was

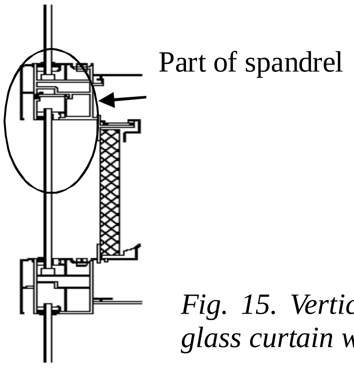


Fig. 15. Vertical section of glass curtain walls.

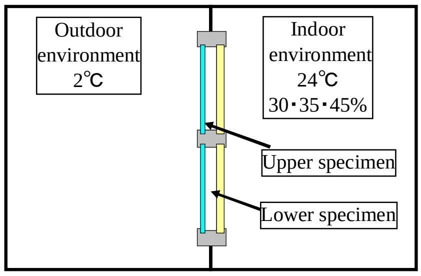


Fig. 16. Experimental equipment in a climate chamber.

Table 2. Experiment cases in Experiment I.

Case	Indoor-side interstices: Condition	Indoor-side interstices: Equivalent opening area [cm^2]	Outdoor-side interstices: Condition	Outdoor-side interstices: Equivalent opening area [cm^2]	Refractory board moisture content (wt%)	Inside insulation
1-1	Standard	55.09	Condensate drain valve at bottom 10 ϕ ×2	0.06	normal (18.0)	none
1-2					low (6.0)	
1-3					normal (12.8)	urethane 30㎜
1-4	Closing vertical interstices	25.81			low (8.2)	none
1-5	Air tight	1.5			normal (16.9)	
1-6	Vent hole	75.58			low (8.8)	

*Every refractory board was a tobermorite-based calcium silicate board

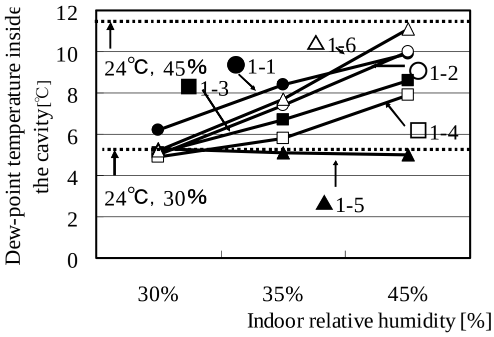


Fig. 17. The dew-point inside the cavity.

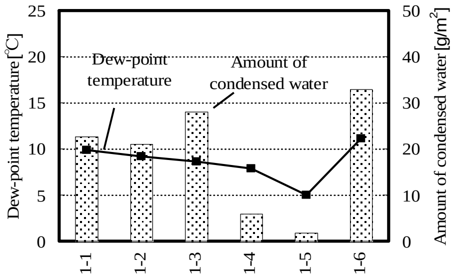


Fig. 18. The amount of condensed water on the glass surface and the dew point in the cavity at an indoor relative humidity of 45%.

covered with a metallic sheet on the surface, the amount of moisture desorption into the cavity decreased and hardly any condensation occurred. When urethane was sprayed onto the entire interior surface, the extent of moisture desorption was substantial and condensation occurred even when a calcium silicate board with small moisture content was used. A certain time is required for the calcium silicate board to reach equilibrium.

5. What challenges is the construction sector facing in Japan?

1. Technology development.
2. Change in lifestyle: concentration of population in urban areas and population aging.
3. Mutual understanding between technology and design: design education.

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Moisture and building processes in Finland

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Abstract

Moisture management is crucial to achieving good construction quality in the Nordic countries, for avoiding moisture safety risks and for reducing energy use, which can have environment impacts. Heating and ventilation are important factors in managing site conditions.

A case study has been performed on Finnish construction sites involving observation of the heating methods, weather guards, drying and other circumstances at the sites. The purchased energy and electricity consumption were measured and analysed at two building sites. The energy use in the measured construction sites varied from 18 to 54 kWh/m^3. Site heating for concrete strengthening and structure drying were the highest energy consumers.

This paper reviews drying and heating practices and some recent development in moisture safety issues in Finland. In the end of the paper, related to topic of reducing energy related to moisture management, this paper also discusses, how more energy efficient heating and drying planning methods could be developed for construction sites.

Keywords: construction site, drying, energy, heating, moisture,

1. Introduction

Finland is a Nordic country in the temperate/boreal climate region. The weather conditions significantly vary between seasons in the Nordic countries. For example, the average wintertime duration is 163 days in southern part of Finland. The century-long average for wintertime snowfall is 175 mm in Helsinki and 228 mm in Sodankylä, whereas the rainfall values are 191 mm in Helsinki and 67 mm in Sodankylä. (Irannezhad et al. 2015).

During construction, there are various temperature and relative humidity requirements for the concrete drying time in cold conditions. Unnecessary wetting of concrete and other elements should be avoided because, among other things, it can require additional drying. The energy, hiring, working, transportation and energy distribution system costs must be considered when choosing a drying method. The speed of drying depends on the internal and external humidity, temperature, amount of ventilation and drying materials as well as the related chemical reactions. The larger the temperature and humidity difference between the internal and external climate, the more effectively the ventilation can accelerate the drying processes. The ventilation facilitates drying in the building site most of the year, but ventilation is not as helpful in the summer and early autumn periods, when the outside humidity is high. In summer and autumn, dehumidification equipment is often utilized at Finnish construction sites to speed up the drying processes.

Heating is necessary for enabling construction work during the winter and spring for both technical reasons and productive working conditions. Heating is one of the biggest energy consumers at construction sites during the cold winter climate. Unnecessary energy consumption is both economically and environmentally unsuitable. One aim of energy efficiency management at construction sites is to keep heat inside the envelope while maintaining adequate ventilation. There is remarkable energy and emission savings potential at construction sites. The energy use for construction site moisture management has been inadequately studied to date. In Finland, the energy used for constructing and producing construction materials is estimated as approximately 8% of the total energy use. This energy use accounts for an approximately 4% share of the building material manufacturing; 3% is allocated to ground transportation, and 1% is allocated to building site operations. (Vainio 2012.) According to Teriö & Honkanen (2013) the energy use in Finnish new building construction sites varies approximately from 18 to 54 kWh/m^3.

The purpose of this paper is to introduce the scope of moisture management at construction sites in cold climate. Moisture management is crucial to achieving good construction quality in the Nordic countries. Heating and ventilation can be used to manage the site conditions. Also, the aim of the paper is to determine i) how much energy is used at construction sites in Finland and what energy sources are utilized ii) what kind of measures have been taken to improve moisture safety in Finnish construction, iii) how moisture and heating management could be further developed also towards more energy efficient directions. These issues are important to consider when the goal is to produce high-quality construction sites environmentally efficiently.

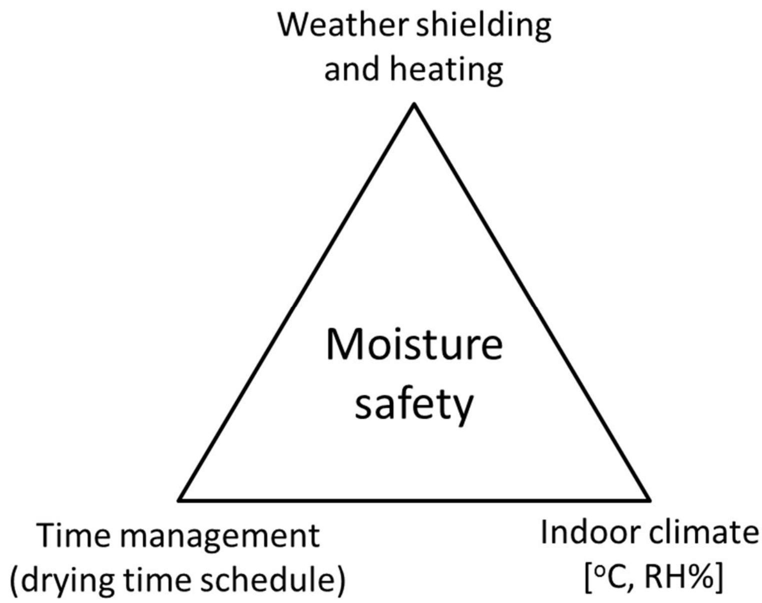

Figure1. The moisture safety needs an integration of weather shielding, heating, good indoor climate and enough time to dry moisture. The moisture of the concrete is a key issue. It takes time and heating to dry process water away from concrete before coating it. Relationships between heating, indoor climate and drying time are dealt with in this paper.

2. Drying and heating at Finnish construction sites

A case study has been performed on two Finnish construction sites by observing the drying and heating methods, weather guards, and indoor climate circumstances at various sites. The construction sites were from southern part of Finland, where most new buildings are In addition, the energy consumption at six sites was analysed based on accounting information. currently being built. Energy use was measured at two construction sites. At these sites, the energy for electricity, fuel, gas and district heating were measured and the heating, drying and site office energy use were evaluated. At one site, a crane's electricity use was measured. In addition, the energy consumption at six sites was analysed based on accounting information. During the study, interviews and workshops were performed to collect data and improve the knowledge and knowhow of construction personnel. Ground work machines are also considerable energy consumers in construction sites, but these were restricted from the present study.

Both case buildings were six-floor high, multi-storey apartment houses. The area of the first site (case A) was 6467 square meters and building volume was 20900 cubic meters. It had 99 apartments. In addition, there was a parking hall (1600 m^3). In the other case (case B), the area of the site was 3797 m^2 and volume was 14161 m^3. There were 51 apartments and there was a parking hall (2300 m^3). The construction time was 20 months in case A and 17 months in case B.

According to the case study interviews, liquefied gas heating was used at the frame phase for both building sites. The liquefied petroleum gas heaters were light and small relative to the heating power. The gas heaters can be situated only in rooms where the ventilation level is sufficiently high. Usually, the power of the gas heaters in the building site is 25-150 kW. The gas heating itself produces a considerable amount of water vapour, which increases the need for drying.

Oil heaters are used to heat wide spaces, such as industrial halls, office premises and storage spaces. Usually, oil heating is used at a frame phase when the heating power is forceful. Oil heating produces carbon dioxide and water vapour, but the water by-product level is lower than for gas heating. Also, oil heater containers can be placed outside the envelope. Then, carbon dioxide and water vapour can be directly ventilated outside.

Different methods of electric heating include heater fans, heating carpet, infrared heaters and electric heating cables for concrete. Electric heating is easy to use, and it is especially important for heating small areas. The heating cables for concrete can be used for the footing units, pillars, beams and element joints. The heating cable is an energy-efficient method for strengthening and pouring concrete structures compared to heating wider spaces, but additional work is needed to install the cables in the concrete. The accessibility of the electric network is often too small for electric heating to be applied for all uses. According to interviews, the expertise regarding cable heating is decreasing.

General district heating systems are utilized if they are available. District heating fans are often placed at the late phase of the framework or before beginning indoor work. The intensity of district heating is not always sufficient for heating the entire building. Also, energy prices vary, and district heating is often the cheapest method of energy in Finland; therefore, it is used as early as possible.

Over 2/3 of the energy is used to heat and illuminate buildings and barracks. Drying equipment is also a relevant topic. Cranes and electric tools use notably little energy. The total energy consumption in two Finnish case studies is described in the Table 1. District heating consumes approximately 55% of the energy, heating by gas 14%, lighting and other equipment 21%, drying 6%, site office heating and rest room electricity 3% and cranes 1%.

Table 1. Energy consumption at two building site cases, energy sources and distribution. (Teriö & Honkanen 2013)

	Case A	Case B	
Total energy consumption	1087	742	MWh
Energy consumption per volume	52	52	kWh/m^3
Total heating energy (direct)	35.9	39.5	kWh/m^3
-District heating	28.6	21.8	kWh/m^3
-Heating oil		5.7	kWh/m^3
-Gas	7.3	12	kWh/m^3
Total electricity	16.1	12.5	kWh/m^3
-Lighting, embedded-wire heating, crane (1%), gas evaporator, other equipment	11.6	Not measured	kWh/m^3
-Drying machines	3.1	Not used	kWh/m^3
-Site office and rest rooms	1.6	Not measured	kWh/m^3

Table 2. Typical climate circumstances in the case study area.

Weather statistics			
Month	Average temperature	Average RH %	Rain [mm]
I	-6.7	89	45
II	-7	87	44
III	-2.8	82	41
IV	3	71	36
V	9.5	62	31
VI	14.4	65	33
VII	16.5	69	35
VIII	14.6	76	38
IX	9.4	82	41
X	4.7	87	44
XI	-1	90	45
XII	-4.6	91	46

In a framework phase, liquefied petroleum gas was typically used for heating, but oil and district heating were also used. An indoor phase mostly used district heating. In case B, oil heating was used in the parking hall site of the indoor phase. Approximately 40%-50% of the total energy use was used during the frame work and 50%-60% during the indoor phase.

Approximately 70% of the electric energy is used for lighting, fans, drying equipment and electric tools. In the first case, the indoor phase used 63 MWh of electric energy, which corresponds to 22 kWh/m^2/year. The second case used 141.5 MWh of electric energy, which corresponds to 29 kWh/m^2/year.

The total energy use at a site office was 7680 kWh/year. The site offices are placed side-by-side and one on top of the other. Approximately half of the energy was used for space heating and the other half for office equipment. In the summer, most of the energy was used for the equipment because heating was not needed. The electricity use of barracks is approximately 30% of the total electric energy use in case studies.

3. Measures taken for improving moisture safety of building processes in Finland

Moisture damages, and mold and health problems related to them, are serious and expensive problems in Finnish building sector (Audit Committee of Parliament of Finland, 2012). In the year 2013 the Parliament of Finland required the government to take measures for mold and moisture problems in the building sector, including instructions of construction processes and guidance issues (Parliament of Finland, 2013). Thereafter there have been several projects for developing new methods and best practices, for example with the funding of Finland's Ministry of the Environment and the Confederation of Finnish Construction Industries RT, some web pages have been drawn up which presents instructions from the separate points of view (see www.hometalkoot.fi and www.kosteudenhallinta.fi)

In addition to giving instructions, there has been also some legality development. Ministry of Social Affairs and Health (2003) had given an Instruction for housing healthy in 2003 (in Finnish: Asumisterveysohje). However, instruction level regulation was not seen as enough anymore, and in 2015 a new Act was given by Ministry of Social Affairs and Health, which has more legal force than voluntary type instructions. In this Act there are several commands related to what kind of circumstances have to be in houses. This Act also sets competence requirements for qualified external experts in the case of moisture and mold damage and indoor air problems.

Moisture management practices have been also developed by the building inspection authorities. Building inspection authorities in Oulu have developed so called DryChain10 (In Finnish: Kuivaketju10) procedure, which strive to prevent the moisture problems by recognizing the most typical risks (Mäkikyrö 2015). The procedure has three basic ideas: 1) measures will be focused on ten most significant moisture risks, that cause moisture problems in the buildings , 2) chosen risks are prevented systematically in all construction phases (purchasing, design, construction period, commissioning and maintenance), and 3) results are measured, verified, documented and the further tasks will be appointed. According to developers of DryChain10 the most common moisture problems in Finland are:

1. Moisture from the building's surroundings damages the foundation and the base floor structures.
2. Rain water penetrates into the exterior walls.
3. Water penetrates through leaks in the roof structures and gets all the way to insulation and interior boarding.
4. Moist concrete structures are coated too early in the drying process which causes deterioration of the covering materials.
5. Moisture migrates through the air barrier layer's leakages into exterior wall and roof structures and then condensates into water.
6. Incorrectly designed and/or adjusted ventilation doesn't remove moisture from the building but forces it to migrate into structures.
7. Leakages in the piping cause massive water damages.
8. Badly executed sanitary and bathroom spaces damage the surrounding structures when moisture gets through the surfaces.
9. Materials and structures getting wet damages the building.
10. Neglected maintenance and care cause the building to slowly but surely deteriorate. (www.kuivaketju10.fi.)

The ten most significant risks are prevented by 20/80 –principle. By concentrating on 20 % of the issues causing problems and getting most of them under control, is striven to achieve about 80 % of the problems in the end.

4. Proposal for developing planning drying and heating management in construction sites

There are several project management tools for planning schedules by working performance, but nevertheless, drying times can be difficult to integrate into schedule planning. Conversations with foremen in case projects sparked the idea of developing a new calculation model that could facilitate planning for heating and drying.

The scheduling of drying process of concrete is especially is sometimes especially challenging to forecast, because drying process of concrete include many chemical processes, because there are so many things that can affect the drying process both in conditions and materials utilized, and because the process itself is so complex.

However, a simple Excel based model was developed for the drying management purposes in such situations when other issues than the air's humidity are not limiting factors in drying process. With the model the user can tentatively determine how to plan heating and drying conditions as well as the schedule for drying at a construction site. In addition to using the model, the measurements of the concrete moisture remain essential before surfaces are covered.

Inputs to the model include the building features, such the project size [Vm^3] and heating time schedule. Also, the target circumstances of the indoor climate, such as the temperature and relative humidity, need to be defined. The energy price could also be entered into the model [cnt/kWh].

The model proposes the water level (seven litres per building volume), but the user can change the value. The monthly statistics for the climate (the temperature, humidity, and rain) are entered into the model for several locations. The user can also change the climate values. The ventilation factor [1/h] varies substantially during the seasons. The level is low in the winter and high in the summer. When testing the model, these levels were calibrated to the seasons so that the total energy use nearly matches true consumption. In real life, it is unnecessary to know the ventilation factor. However, the current temperature and relative humidity of the site's indoor climate are essential. If the values are insufficient, the ventilation should be increased or decreased. An adequate temperature is approximately 21 degrees and adequate relative humidity is 50% or lower.

The model calculates the time required to transfer the moisture outside. In practice, the time is usually decided earlier so that the user can arrange for proper ventilation (assess the ventilation factor), achieve more efficient drying methods and observe the site circumstances. In the very early stage of the project, it is possible to define the drying time. Then, the user can decide the appropriate drying schedule and methods.

Table 3. The model calculates indicative information for the project manager, such as the time schedule for dehumidification, approximate maximum heating capacity (kW) for planning equipment and total heating energy for cost planning.

Outputs													
Months	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Total
Ventilation factor (1/h)	0,5	0,5	0,6	0,8	1,2	1,2	1,2	1,2	1,3	0,9	0,7	0,6	
Heating capacity, Ventilation (kW):	48	48	49	50	48	27	19	26	52	51	53	53	
Heating capacity, Envelope conduction (kW):	23	23	20	15	9	5	4	5	10	13	18	21	
Envelope and ventilation, total (kW):	70	71	69	64	57	33	22	32	61	64	71	74	
Envelope and ventilation energy consumption (MWh)	0	48	51	46	42	24	16	24	44	48	0	0	343
Heating of framework phase (MWh)	50	0	0	0	0	0	0	0	0	0	10	30	90
Solar energy (MWh)		1	2	4	5	5	5	4	3	1	0		29
Total MWh													404
Total €													44430
Approximate maximum heating capacity (kW)	187	190	187	184	173	84	35	57	154	170	192	199	

There are numerous challenges when planning drying, such as with the rain per construction volume, the moisture level, weather, building shape, conduction through wet isolation materials, and more. Anyhow the total moisture is approximately 5-10 litres/building volume.

Optimization of heating and drying is a complicated issue. There is an obvious need for simple tools to plan shielding, heating, ventilation and drying. In discussions at sites, many site managers become aware of the preconditioning circumstances for improving the quality and time management and cost of drying.

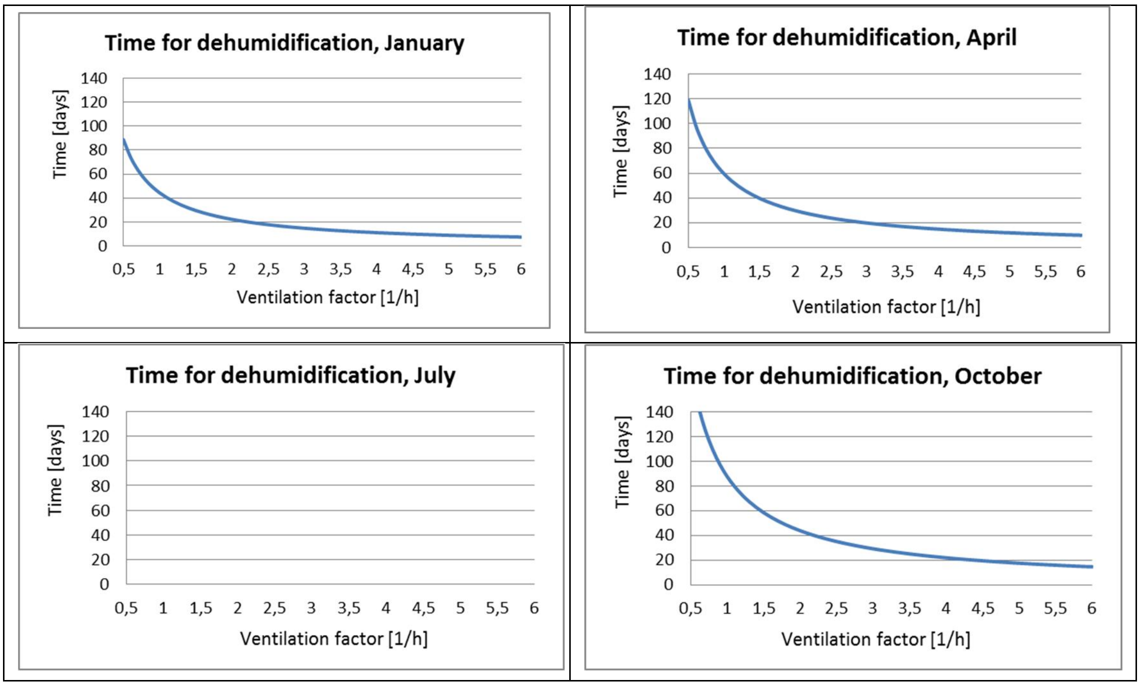

Figure 3.The drying by ventilation is effective in winter and early spring, In July, it can be impossible to dry concrete just by ventilation. At cold season the ventilation factors between 1-3 are usually suitable and energy efficient.

5. Discussion

The attitude of foremen is crucial towards achieving moisture safety and energy savings. Knowledge and awareness of moisture behaviour and energy issues are important contributors to energy saving. For example, before starting heating, weather shielding should be adequate. Unfortunately, in practice, there is often insufficient shielding.

When the results of energy use measures of construction site was presented at supervisor training, there was substantial confusion about the amount of energy costs related to heating. Many supervisors were surprised about the extent of heating costs.

There is a substantial need for energy and moisture management training at construction sites. Some sites handle these issues very well, but too many sites either misspend energy or leave concrete wet for too long. When using heating in the coldest seasons, it is important to cover the window and door openings and seal other locations that are not airtight.

There are many areas for further studies. Simple methods for planning site heating and structural drying should be constructed. For example, the heating, drying and schedule optimization are important research areas. Quantitative research on concrete drying in different relative humidity and temperature conditions would be useful. Also, the economics related to the topics presented here should be evaluated in more detail.

6. Conclusions

Different measures have been taken in Finland for improving moisture safety of living spaces and construction processes. Improving moisture safety is issue where there are several stakeholders, like legislators, authorities, developers, designers, constructors and users. Several kind of check lists, like in DryChain10, can help in focusing on the most important risk factors, and so intervene especially in the case of most typical moisture risks in the building sites.

Site heating is a significant consumer of energy in cold climates. Heating is needed for concrete hydration and drying and workable working conditions. When the aim is to save energy in the construction sites, heat should be kept inside the envelope while still allowing for adequate ventilation. To boost ventilation, dehumidifiers and fans should be used in certain conditions, especially in the summer and autumn. Unnecessary additional drying should be minimized by sealing interiors from the rain and snow.

The primary energy consumption is related to strengthening the concrete structures and drying them. Energy saving and rapid drying can be conflicting goals, and heating and drying are difficult to plan. There is an obvious need for site education and guidelines. Dehumidifiers and fans should be used in certain conditions, especially in the summer and autumn. Unnecessary drying should be minimized by sealing interiors from the rain and snow.

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Volume II

Environmental Opportunities and challenges

Constructing commitment and acknowledging human experiences

Edited by
Matthijs Prins, Hans Wamelink, Bob Giddings, Kihong Ku and Manon Feenstra

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WBC16 Proceedings : Volume II

Environmental Opportunities and challenges

Constructing Commitment and Acknowledging Human Experiences

Tampere University of Technology. Department of Civil Engineering
Tampere 2016

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Preface

The main theme of WBC16 is the cogent message that the built environment is an important enabler for the well-being of its citizens, the success of its companies and the competitiveness and coherence of the whole society. Special attention is given to the development of the built environment in different countries and continents, and the interplay of various stakeholders and experts at all scales of activities.

This is the second volume of five for the proceedings of the *2016 CIB World Building Congress "Intelligent Built Environment for Life*" (WBC16) held May 30 – June 3 2016 in Tampere Finland. This volume contains contributions, which were submitted to the themes 'Environmental Opportunities and Challenges; Regarding Nature and Outdoor Conditions' and 'Constructing commitment and acknowledging human experiences', and thus it is divided into two main parts. The first part (sections one and two) contains 16 papers, which were allocated to the theme 'Regarding nature and outdoor conditions'. The second part (sections three to six) contains 46 papers, which were allocated to the theme 'Constructing commitment and acknowledging human experiences'. In total, there are 156 authors from throughout the world.

Environmental Opportunities and Challenges; Regarding Nature and Outdoor Conditions

This theme considers issues such as the interaction of the built and natural environment, sustainability indicators, environmental aspects, resilience, roles and responsibilities, and international cooperation. The assessment of sustainability issues, from life cycle impacts, to service life predictions and carbon emission measurements, appear as a distinctive collection of papers and are therefore grouped in section *1* under the heading **'***Sustainability Assessment'*. Papers about the effects of the natural environment and climate change on buildings, workers conditions, resilience and facades, are grouped in *section 2* under the heading *'Nature and Outdoor Conditions'.*

Constructing commitment and acknowledging human experiences

The second part of this volume presents papers related to leadership, end users, decision making, human resource management, communication and behavioural studies. A significant proportion of the papers submitted to this theme investigate health and safety issues; with specific topics like national regulations, post-accident disputes, permits, SME safety policies and even workaholics on site. These are grouped in *section 3* under the title **'***Health and Safety'*. Knowledge management, organisational characteristics, skills development, and communication are also vital issues, and these papers are grouped in *section 4*, titled **'***Organisations, Knowledge and Communication***'**. Papers exploring subjects such as contract management, project management, procurement and tendering, project organisation, project performance and productivity constitute *section 5 'Projects, Procurement and Performance'*. A genre of papers about human experiences attracted contributions focused on learning behaviour, clients and stakeholders' experiences, as well as user satisfaction. Papers addressing these issues are grouped in *section 6* with the title *'Users, Clients and Stakeholder Engagement'*.

Acknowledgements

The editors of the second volume of the WBC16 proceedings would like to express their sincere thanks to all authors who contributed to this volume with their valuable work. We are grateful to all the reviewers from the scientific committee who assisted authors to improve their papers to the level of publishable quality. Last but not least we would like to compliment the members of the Congress Programme Committee and the Local Organising Committee for their efforts over the

past years, which have resulted in the inspiring CIB World Building Congress 2016, of which this volume is one of the deliverables for future reference.

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Part I: Environmental Opportunities and Challenges

1. Sustainability Assessment
2. Nature and Outdoor Conditions

Co-production of energy use and carbon emission reductions in building environmental assessment

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Abstract

Building Environmental Assessment (BEA) has been increasingly utilized in low carbon building design as a structured approach to evaluating alternative design solutions. Energy use and relevant carbon emission are two most important aspects of BEA schemes. However, almost all BEA schemes only allow credits to energy use and carbon emission reductions to certain levels, which are far below the net zero standards promoted in many countries as a government climate change policy. Any interaction between energy use and carbon reductions is largely unknown. The aim of this paper is thus to explore the co-production between energy use and carbon emission reductions in order to support the delivery of buildings towards net zero energy and net zero carbon in tandem. This paper first examines the weights of the energy use and carbon emission related criteria in selected typical BEA schemes. The paper then drawing on the case of Hong Kong traces the evolution of such weights in BEA during the period 1996-2015 since BEA was first introduced in Hong Kong. The scenario of zero carbon was used to forecast the trend of the weights' evolution using the industry life cycle theory combined with linear, polynomial and ladder functions. The results show that the use of ladder function can best describe the possible trend of the weights of energy use and carbon emission reductions criteria in BEA, while linear and polynomial functions are more applicable if emerging low-carbon technologies are popularly adopted. The findings suggest that the co-production existing between energy use and carbon emission reductions can accelerate the transition of buildings towards net zero energy and zero carbon.

Keywords: Decision criteria weight, carbon emission, energy use, building environmental assessment, zero carbon.

1. Introduction

Buildings together account for over a third of greenhouse gas (GHG) emissions and energy consumption in the world, and therefore are a key sector where to achieve energy consumption and carbon emission reductions (Zhang, Pan and Kumaraswamy, 2014). There have been concerns about how to improve building practices to eliminate or minimise their detrimental effects on the environment (Cole, 1999; Holmes and Hudson, 2000; Ding, 2008). Since the 1990s, the concepts of sustainable design and high performance building, as well as their increasing industrial applications, have been furthering with the cognisance of the impact of buildings on the environment (Todd, Crawley, Geissler and Lindsey, 2001; Haapio and Viitaniemi, 2008). Significant changes were witnessed to mitigate the side impact of the building sector, such as the application of renewable energy and the usage of recycled materials. More recently, low-carbon building (LCB) and zero-carbon building (ZCB) have emerged as innovative and important approaches to reducing carbon emissions and energy consumption of buildings, and have attracted essential policy attention in many countries and regions (Pan and Ning, 2015). For example, in the United Kingdom (UK), the government has set ambitious targets to achieve “zero carbon” for new homes from 2016 and for non-domestic new buildings from 2019 (DCLG, 2007; HM Treasury, 2008). Similarly, in the United States (USA) and the European Union (EU) member countries, carbon reduction agenda of new buildings has been prompted as part of their building energy policies with clear goals (EU, 2010; Crawley, Pless and Torcellini, 2009; Panagiotidou and Fuller, 2013).

With the rising interest and demand from policy decision makers for achieving buildings’ energy savings and carbon emission reductions, there is also an increasing need for comprehensive and structured building environmental assessment (BEA) (Forsberg and Malmborg, 2004). The first attempt to establish comprehensive means of simultaneously assessing a broad range of environmental considerations in buildings was the Building Research Establishment Environmental Assessment Method (BREEAM) established in the UK in 1990 (Crawley and Aho, 1999; Grace, 2000; Haapio and Viitaniemi, 2008). Since then many different BEA schemes have been launched and adapted around the world, *e.g.* PromisE in Finland, Leadership in Energy and Environmental Design (LEED) in the US, Comprehensive Assessment System for Built Environment Efficiency (CASBEE) in Japan and Building Environmental Assessment Method (BEAM) in Hong Kong. These BEA schemes cover different phases of a building’s life cycle and take different environmental issues into account, assessing different building components and whole buildings in global, national and even local contexts (Haapio and Viitaniemi, 2008).

There have been previous studies of reviewing various BEA schemes (Crawley and Aho, 1999; Reijnders L and van Roekel A, 1999; Forsberg and Malmborg, 2004; Aotake et.al, 2005; Finnveden and Moberg, 2005; Haapio and Viitaniemi, 2008; Ding, 2008), comparing the assessed criteria in different BEA schemes (Jonsson, 2000; Todd, Crawley, Geissler and Lindsey, 2001) and exploring the application of BEA in the building sector (Lowe, Kortman and Howard, 2000; Gibberd, 2005). However, little research has focused on the weighting systems or credits of the detailed criteria and indicators. Furthermore, almost all BEA schemes only allow credits to the reductions of energy use and carbon emission to certain levels that are far below the net zero standards promoted in many countries as a government climate change policy. Any interaction between energy use and carbon reductions is largely unknown. The aim of this paper is thus to explore the co-production between energy use and carbon reductions in BEA in order to support the delivery of buildings towards net zero energy and net zero carbon in tandem. The results of this exploration should inform decision making in building energy and carbon policy and practices and help accelerate the take-up of the LCB and ZCB approaches.

2. Methodology

The research was carried out through the combination of a comparative analysis of the weights or credits of identified energy use and carbon emission criteria in selected BEA schemes, and a detailed examination of the co-production of energy use and carbon emission reductions in Hong Kong during the period 1995-2015 since the first BEA was introduced in Hong Kong. The overall research design is illustrated in Figure 1.

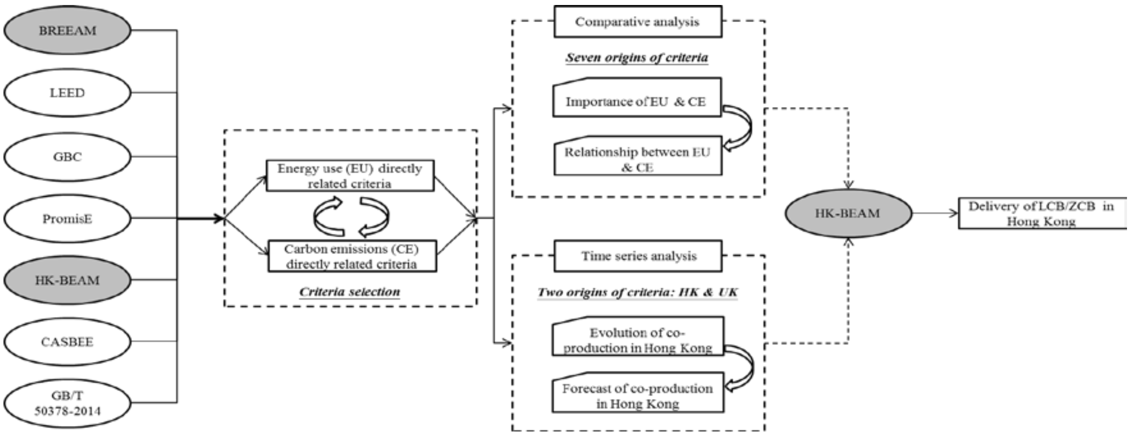

Figure 1: Detailed research methodology

There exist many different BEA schemes that share many similarities and also contain differences (Haapio and Viitaniemi, 2008). In order to achieve focused and effective comparison, only typical BEA schemes were selected to be included in the analysis reported in this paper. The in-depth examination of the co-production of energy use and carbon emission reductions was carried out with the case in Hong Kong for the period from 1996 (when the first BEA was introduced in Hong Kong) to 2015 when the results are being reported. The practices of building towards zero carbon in the UK are regarded as leading in the world, and thus are used as a benchmark for the analysis of the case in Hong Kong. The industry life cycle theory (Klepper, 1997) and mathematical methods were adopted to analyse the trend of the weights of energy use and carbon emission reductions in BEA in Hong Kong. The scenario of zero carbon was engaged for forecasting the trend.

2.1 Selection of BEA schemes

Seven typical BEA schemes were selected for analysis (*Table 1)*. The selection took into account the factors of evaluation objects, climate, culture of building and living, the development of building industry and the moderate uniform of new buildings (Haapio and Viitaniemi, 2008), and was particularly based on the following considerations. First, all the schemes included in the analysis have been published and widely adopted (*e.g.* Grace, 2000; Hansen, 2005). Second, only those for new constructions were considered due to the focus of the study on design decision making for sustainable buildings. Third, considered in favour were those BEA schemes developed in Europe and North America, where the BEA schemes are comparatively more established and widely used, and in Hong Kong, Japan and Mainland China which share similar climatic and/or building conditions.

As a result, the seven selected BEA schemes include BREEAM, LEED, Green Building Challenge (GBC) and PromisE which were developed and adopted popularly in North America and Europe, and HKBEAM/BEAM Plus, CASBEE and Assessment Standard for Green Building which were developed in Hong Kong, Mainland China and Japan, respectively.

Table 1: Building environmental assessment schemes selected

Name	***Issue year (Latest version)***	***Country/ Region***	***Primary level assessment criteria***
BREEAM[1]	*2014*	*UK*	*Management; Health and wellbeing; Energy; Transport; Water; Materials; Waste; Land use and ecology; Pollution; Innovation.*
LEED[2]	*2014*	*USA*	*Location and transportation; Sustainable sites; Water efficiency; Energy and atmosphere; Material and resource; Indoor environmental quality.*
GBC	*2012 (known as SBTool 2012)*	*Canada*	*Site regeneration and development, urban design and infrastructure; Energy and resource consumption; Environmental loadings; Indoor environmental quality; Service quality; Social, cultural and perceptual aspects; Cost and economic aspects.*
PromisE[3]	*2006*	*Finland*	*Health of users; Consumption of natural resources; Environmental loadings; Environmental risks.*
HK-BEAM/BEAM Plus	*2012*	*Hong Kong*	*Site aspects; Materials aspects; Energy use; Waste use; Indoor environmental quality; Innovations and additions.*
CASBEE	*2014*	*Japan*	*Indoor Environment; Quality of service; Outdoor environment (On-site); Energy; Resources and materials; Off-site environment.*
Assessment standard for	*2014*	*Mainland China*	*Land saving and outdoor environment; Energy saving and energy utilization; Water saving and water*

green building (GB/T 50378-2014)			*resources utilization; Material saving and material resource utilization; Indoor environment quality; Construction management; Operation management; Promotion and innovation.*

Note 1: BREEAM UK New Construction for non-domestic buildings.

Note 2:LEED v4 for Building Design and Construction: New Construction.

Note 3: PromisE for new office buildings.

2.2 Identification of energy and carbon criteria

Each typical BEA scheme contains various assessment criteria, at different levels of the criteria hierarchy, to achieve the comprehensive and detailed evaluation of buildings and constructions. Relevant energy use and carbon emission criteria as specified in the selected BEAM schemes were selected. Those criteria are primarily at the first level of the criteria hierarchy. Nevertheless, relevant criteria at the secondary level are also considered for the special cases where there exists overlap between energy use directly related criteria and carbon emission directly related ones. The identified criteria are summarized in *Table 2*.

Table 2: Building environmental assessment targeted criteria

Name	***Targeted criteria***
BREEAM	*For energy use:* ➢ *Energy;* *For carbon emission:* ➢ *Energy-Reduction of energy use and carbon emissions;* ➢ *Energy-Low carbon design.*
LEED	*For energy use:* ➢ *Energy and atmosphere (EA);* *For carbon emission:* ➢ *Energy and atmosphere (EA)-Green power and carbon offsets.*
GBC[4]	*For energy use:* ➢ *Energy and resource consumption;* *For carbon emission:* *Environmental loadings-* ➢ *C1.1 GHG emissions from energy embodied in original construction materials;* ➢ *C1.2 GHG emissions from energy embodied in construction materials used for maintenance or replacement(s);* ➢ *C1.3 GHG emissions from primary energy used for all purposes in facility operations;* ➢ *C1.4 GHG emissions from primary energy used for project-related transport.*

PromisE	*For energy use:* ➢ *Consumption of natural resources-Energy consumption;* *For carbon emission:* ➢ *Environmental loadings-Emissions into air.*
HK-BEAM/BEAM Plus	*For energy use:* ➢ *Energy use (EU);* *For carbon emission:* ➢ *EU-EU 1Reduction of CO_2 emissions.*
CASBEE	*For energy use:* ➢ *Energy;* *For carbon emission:* ➢ *Off-site environment-consideration of global warming.*
GB/T 50378-2014	*For energy use:* ➢ *Energy saving and energy utilization;* *For carbon emission:* ➢ *Promotion and innovation-bonus item (no weights).*

Note 4: Cause the active criteria and their weights are adjustable in SBTool, this paper uses the example focusing on Energy and Emission issues in design phase of SBTool 2012 User Guide-Part B.

3. Comparative analysis using typical BEA schemes

3.1 Overview of weights of energy use and carbon emissions

(1) USA-LEED: LEED does not specify weights of each criterion, but allocates available credits to each indicator. The weights of energy use (EU) and carbon emission (CE) related criteria can be calculated:

$$\begin{aligned} &EU \quad weights = (Available \quad credits \quad of \quad EU / Total \quad available \quad credits) \times 100\% \\ &CE \quad weights = (Available \quad credits \quad of \quad CE / Total \quad available \quad credits) \times 100\% \end{aligned} \tag{1}$$

(2) Canada-GBC (SBTool): In the latest version of GBC framework, SBTool 2012, the criteria and weights are both adjustable by users. In order to simplify this study, all the criteria and their weights used in this study are all derived from the example of SBTool applications focused on energy and emission issues in SBTool 2012 User Guide-Part B (2012).

(3) UK-BREEAM: In the latest version of BREEAM (UK) New Construction for non-domestic buildings (2014), the weights of primary level criteria, section weighting, have been given, but the weights of secondary level criteria have not been given. Having the available credits of each criterion and considering the overlaps existed between EU and CE criteria, we can get:

$$CE \quad weights = \frac{Available \quad credits \quad of \quad CE}{Total \quad available \quad credits \quad of \quad EU} \times EU \quad weights \tag{2}$$

(4) Finland-PromisE: PromisE (2006) provides the weighted value, available weights, of indicators. Therefore, equation (1) can also be used to calculate the weights in this scheme.

(5) Hong Kong-BEAM (BEAM Plus): Hong Kong BEAM and BEAM Plus are similar to BREEAM in the UK. The weights of EU criteria are given without weights of CE criteria, and can also be calculated using equation (2).

(6) Japan-CASBEE: CASBEE divides the criteria into two equal parts: environmental quality of building (Q) and environmental load reduction of building (LR). The weights of EU criteria are given, and CE related criteria can be calculated using:

$$CE \quad weights = (1/3 \times \Pr imary \quad Level \quad weights)/2 \tag{3}$$

(7) Mainland China- GB/T 50378-2014: The weights of the EU related criteria have been provided in this scheme, but not of the CE related criteria.

3.2 Comparative analysis

According to the identified criteria in *Table 2* and their corresponding weights embedded in the typical BEA schemes, the statistic results are summarized in *Table 3* and *Figure 2*.

Table 3: Weights of energy use and carbon emissions directly related criteria

Countries/Regions / ***Criteria***	***North America***		***Europe***		***Asia***		
	USA[5]	*Canada*	*UK[5]*	*Finland*	*Hong Kong[5]*	*Japan*	*Mainland China*
Energy use	*26.40%*	*27.61%*	*15.00%*	*13.5%*	*35.00%*	*20.00%*	*28.00%*
Carbon emission	*1.60%*	*45.82%*	*7.26%*	*17.5%*	*12.50%*	*10.00%*	*0*

Note 5: Overlaps existed in EU and CE related criteria.

(1) Importance of energy use & carbon emission

The comparative analysis reveals that all of the countries affiliated with the BEA schemes studied are concerned with the EU criteria, whose weights are all above 10%. The weight of the EU criteria in BEA is the highest in Hong Kong (35%), followed by in Mainland China (28%), Canada (27.61%), USA (26.4%) and Japan (20%), albeit being much lower in the UK (15%) and Finland (13.5%). These results indicate that energy saving has become an international consensus, with increasing recognition of the importance of the EU criteria in BEA schemes.

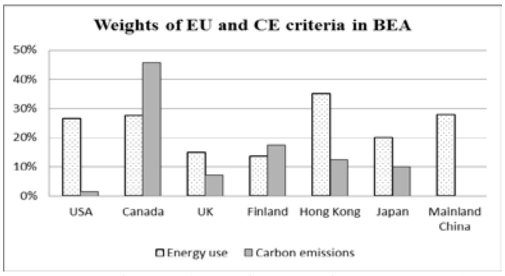

Figure 2: Comparison of weights of identified EU and CE related criteria

The weights of the CE criteria in the BEA schemes vary from each other to a greater extent than that of the EU criteria. Canada takes the lead in specifying the weight of the CE criteria being 45.82%, far higher than other countries and regions, including Finland (17.5%), Hong Kong (12.5%), Japan (10%) and UK (7.26%). It is worth noting that such weights in the USA and Mainland China are extremely low or none, being 1.60% and 0%, respectively. Considering the criteria in LEED and GB/T 50378-2014, this result suggests that the USA and Mainland China are still focusing on energy use rather than carbon emission reductions. However, similar with the UK, the USA and China incorporate the importance of carbon emissions reductions into that of EU criteria, leading to the relatively low weights of CE criteria. These results reveal very imbalanced recognition of the weighting level of carbon emission reductions among the BEA schemes in different countries and regions, which is mainly attributed to the scope of CE and EU criteria in different BEA schemes.

(2) Relationship between energy use and carbon emission

The interrelationship is obviously existed between EU and CE criteria in BEA schemes from the UK, the USA, Mainland China and Hong Kong. In these four countries and regions, CE criteria always act as sub-divisions of EU criteria which usually have higher weights than CE criteria, revealing that the reductions of energy use can be achieved through the reductions of carbon emissions. However, unlike the BEA schemes where the weights of EU criteria are higher than CE criteria, GBC and PromisE have the relatively lower importance of EU criteria, which is mainly attributed to the relatively independence of EU and CE criteria in these BEA schemes.

4. Evolution of co-production of energy use and carbon emission reductions in BEA in Hong Kong

In Hong Kong, EU criteria and CE criteria in BEA schemes are interrelated as mentioned before. As a pioneer in the delivery of low-carbon/zero-carbon buildings in subtropical climate, it has developed its own BEA schemes, HK-BEAM/HK-BEAM Plus. The first version of HK-BEAM (for new offices) was launched in Hong Kong in 1996, and the latest version of HK-BEAM (Plus) in 2012. During the past two decades, HK-BEAM and HK-BEAM Plus have been prompting the development of sustainable buildings, low-carbon buildings and zero-carbon buildings in Hong Kong. The importance of energy saving and carbon reduction has been revealed to the public and the government (*Table 4 and Figure 3*). Meanwhile, the Hong Kong government has set ambitious carbon reduction targets (Environment Bureau, 2010) and issued comprehensive building energy codes and regulations (BEC) in Hong Kong (EMSD, 2012). BEC in Hong Kong have evolved during the past nearly two decades since their introduction, towards more stringent requirements on energy efficiency and further carbon reduction (Figure 4). The promotion of energy saving in Hong Kong actually drives more people to pursue carbon emission reduction in tandem.

Table 4: Weights of energy use and carbon emissions directly related criteria in Hong Kong

Criteria* \ *Issue year	***1996***	***1999***	***2004***	***2010***	***2012***
Energy use	*27.12%*	*23.75%*	*29.63%*	*35.00%*	*35.00%*
Carbon emission	*0*	*0*	*0*	*12.5%*	*12.50%*

5. Towards net zero carbon building in Hong Kong

According to the trend shown in figure 3, from 1999 to 2012, the increasing concern with energy use has been promoting the attention paid to carbon emissions. The future development of the weights of EU and CE related criteria in Hong Kong BEAM can correspondingly divided into three scenarios.

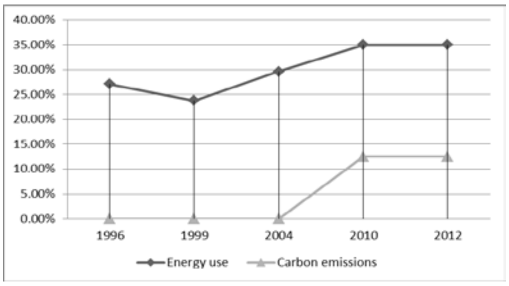

Figure 3: Weights of energy use and carbon emissions directly related criteria in Hong Kong

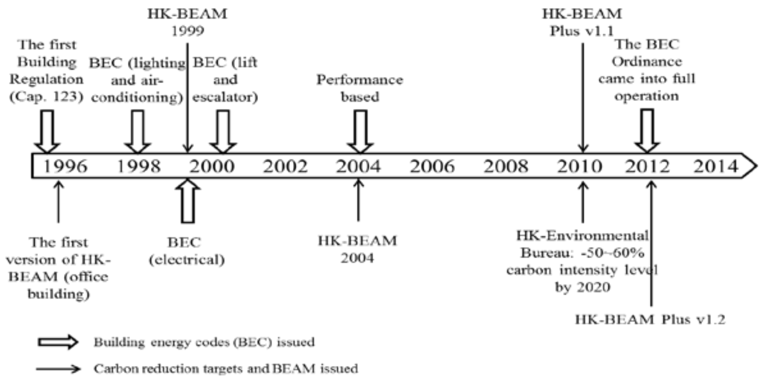

Figure 4: Timelines of BEAM and carbon reduction agenda issued in Hong Kong

Scenario (1) Short-term (polynomial function): After the stable period with static weights of EU and CE criteria, Hong Kong will pay more attention to the carbon emission reductions. Some new low-carbon technologies, such as renewable energy and solar panel, will arise and the industry is gradually adapt to these changes. Eventually the weights of EU criteria, especially the CE criteria, will increase gradually at the smooth speed, preparing for the following rapid development in the second scenario. Hong Kong currently is also moving into this scenario.

Scenario (2) Medium-term (linear function): After scenario 1, more and more new low-carbon technologies will be proposed, popularly adopted and eventually forge a path for the industrial revolution towards zero carbon buildings. The weights of EU and CE criteria thus trend to increase linearly without any adjustment period, indicating that EU and CE criteria are rapidly improving their importance and attracting the public attention.

Scenario (3) Long-term (ladder function): After a long time of development of energy saving and carbon reductions technologies and relevant ordinances, the construction industry needs much time to digest these new technologies and prepare for the possible increase next time. The weight will also increase in this scenario as in scenarios (1) and (2), but the scenario (3) has adjustment period where the weight keeps stable and unchanged, indicating the attention and efforts paid to EU and CE criteria are enough to accelerate the delivery of ZCBs in Hong Kong.

These three scenarios together comprise the comprehensive “Zero-carbon industry life cycle” as shown in figure 5.

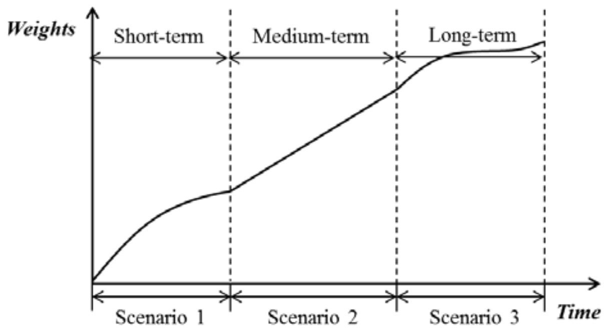

Figure 5: Zero-carbon industry life cycle

6. Conclusions and future research

This paper has explored the co-production between energy use and carbon emission reductions in order to support the delivery of buildings towards sustainability and zero carbon in tandem. The research was conducted through a comparative analysis of the weights of energy use and carbon emission related criteria in seven typical BEA schemes and case study of the evolution of such weights and BEA development in Hong Kong. Based on the time series analysis method and industry life cycle theory, the co-production of energy use and carbon emission reductions in Hong Kong and three scenarios of “Zero carbon industry life cycle” have been identified. These three scenarios are named short term, medium term and long term, based on the use of the polynomial, linear and ladder functions for forecasting. These scenarios together contribute a new perspective of exploring the future of sustainable development of buildings towards zero carbon in Hong Kong. Future research should examine the evolution of the weights of EU and CE related criteria in other BEA schemes. Quantitative examination of multiple cases should validate the co-production functions in a wider context.

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An ecomimetic case study: Building retrofit inspired from the ecosystem of leaf-cutting ants

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Abstract

Ecomimetics is a branch of biomimetics that focuses on the transfer of functions and processes from ecosystems to architectural systems. One goal of this emerging field is to optimize resource use in buildings for climate change adaptation and mitigation. The design method presented here is an iterative and transdisciplinary approach that guides architects, engineers and designers through an ecomimetic exercise. This paper adopts a case study approach to test the performance of the ecomimetic method. Thermoregulatory functions of leaf-cutting ants' thatched nests were studied as a case for inspiring resource use optimization in an existing building in Montreal, Canada. This case study reveals the opportunities for building design innovation, as well as some modifications and improvements to the ecomimetic method.

Keywords: biomimetics, biomimicry, ecomimetics, ecological design, sustainable design

1. Introduction

During the past few decades the fields of engineering and design have seen increased efforts to innovate with nature-inspired solutions (Lepora, Verschure, & Prescott, 2013). Researchers and professionals refer to the process of learning and modeling from nature as biomimetics, biomimicry or bionics (Benyus, 1997; Gruber, 2011), which are used interchangeably in this paper. Despite recent advances and growing interest in the field, biomimetic projects in architecture lack a systematic approach to the design process, and most of the successful examples are a result of haphazard collaborations between biologists and designers. Mimicking biological systems can be done in multiple ways: designers can opt to transfer properties from a single organism or a part of an organism; they can learn from the behavior of a group of organisms; or they can mimic the multiple interactions and processes occurring in an ecosystem (Pedersen Zari, 2007; Garcia-Holguera, et al., 2015b). Most researchers agree that there are two main approaches to biomimetic design: a top-down and a bottom-up (Ayre, 2004; Gamage & Hyde, 2012; Gruber, 2011; Pedersen Zari, 2007; Speck & Speck, 2008). The former starts with a design problem and then looks for a solution in the biological realm, whereas the latter identifies a biological strategy first and then finds the field, process, or product where its properties could be transferred. The research presented here follows a biomimetic top-down approach aiming at transferring properties of an ecosystem into a building system. Ecosystems are complex systems integrating biotic and abiotic components that present multiple interactions and feedback relationships amongst each other. Ecosystems show nonlinear behavior, and in most cases rely solely on sun heat and light as their primary source of energy. Ecosystems are resilient in part because of the redundancy of their components, functions and processes. The property of resilience allows ecosystems to more easily adapt to new or changing conditions, while evolving into new ecological organizations. Like ecosystems, buildings are also complex systems and they as well integrate biotic (e.g. users, plants) and abiotic components (e.g. construction materials). Both buildings and ecosystems are governed by thermodynamics: both are dissipative systems that need constant inflow of high quality energy (i.e. exergy) in order to maintain their structures (Allen, 2001; Fernandez-Galiano, 1991; Kibert, Sendzimir, & Guy, 2000). These commonalities are at the core of the research presented here because they allow abstracting characteristics and properties of ecosystems and transferring them into building systems. The purpose of such endeavor is to address climate change adaptation and mitigation through the optimization of resource use in buildings.

Garcia-Holguera et al. developed a systematic approach to biomimetic design for architects, engineers and designers, referred to as the ecomimetic design method (2015b). The purpose of this paper is to test the usefulness and applicability of the ecomimetic design method, and to identify possible improvements for it as well as to highlight potential challenges and obstacles that designers might encounter. To do so, this paper develops a case study that implements such ecomimetic design method as a step-by-step process for mimicking the thermoregulatory properties and functions found in leaf-cutting ants' nests into a building system.

2. Methods

The ecomimetic design method makes part of a PhD research work, and it is open to improvements and modifications resulting from its implementation in several case studies. The ecomimetic design method uses a top-down approach in that it starts with a design problem and addresses it by following

a process of design steps that can be repeated in multiple exercises. Such a design approach is more familiar to engineers and architects than a bottom-up approach. The ecomimetic design method currently consists of six design stages: 1) Architectural design goals; 2) Ecological solution searching; 3) Abstraction and representation of ecological systems; 4) Correlation of architectural and ecosystem components; 5) Transference of ecosystem's principles to an architectural system; 6) Modeling and benchmarking. Each stage will be described in parallel to their implementation in the results section. For a detailed explanation of the ecomimetic method refer to Garcia-Holguera et al., 2015b.
For the purpose of this case study, the ecomimetic design method was applied to an existing building of our selection: Thomson House, a heritage building located in Montreal, Canada. Thomson House was selected due to the fact that audit reports were easily accessible and because of its considerable thermoregulation issues. The following section describes each stage of the ecomimetic design method applied to our selected building.

3. Results

3.1 Stage 1: Architectural design goals

The first stage of the ecomimetic design method consists of identifying one or several design objectives. These must be expressed in thermodynamic language and address resource issues as well as specific contextual environmental concerns of the building (Garcia-Holguera et al. 2015b). Thompson House was built in 1935 and shows deficiencies in energy performance. A recent audit report evaluated roof and wall insulation as well as thermal resistance of windows and found them to be significantly below the required ratings of the New Buildings Code (*Règlement sur l'économie de l'énergie dans les nouveaux bâtiments)* (MMA and BP, 2013). Due to its location in Montreal, Canada, temperature regulation of the building must confront extreme changes in seasonal temperatures as well as significant snowfall. Montreal has a humid continental climate with a low annual average of daily temperatures of 5.3°C. Over an average year, daily minimum temperatures range between -16.5°C and 14°C while daily maximum temperatures range between -6.5°C and 25.7°C. The average yearly precipitation is of 1067.7 mm of which about 228.8 cm is snowfall (Climate, 2015). Thompson House offers study lounges, offices, conference rooms, a restaurant, and a bar and consumes an average of 1 428 434 MJ per year (MMA and BP, 2013). If combining all its sources of energy (i.e. electricity, natural gas and steam), energy is used mainly by the cooking equipment (34%) and for space heating (31%) (MMA and BP, 2013). In consideration of all of the above, the architectural design goal for the building system of Thompson House is to identify one or more strategies inspired by ecological systems that can help reduce the energy use in the building. The next step consists of searching for an ecosystem whose function addresses this design goal.

3.2 Stage 2: Ecological solution searching

The second stage of the ecomimetic design method provides guidance on how to search for the ecosystem to be mimicked. The publicly available and online database AskNature was used for this exercise as suggested by the ecomimetic method (Garcia-Holguera et al., 2015b). The AskNature database catalogs numerous "nature's solutions to human design challenges" through a search function which require an input that refers to an organism's function (e.g. prevent turbulence, process information, break down etc.) (AskNature, n.d.). Different searching approaches on the database provided several results whose strategies are related to the desired goals defined in stage 1.

The nests of South American leaf-cutting ants (*Acromyrmex heyeri*) were selected as the ecosystem to mimic due to their appealing thermoregulatory functions. In accordance to stage 2, we gathered information about this ecosystem in order to acquire a deeper understanding of its thermoregulatory functions. Studies by Bollazzi and Roces describe the performance of the leaf-cutting ant ecosystem (2008; 2010a, b, c). These ant species live in temperate regions of South America and build mound shaped, single-chambered thatched nests on the soil surface that achieve more stable temperatures than those of the environment. Like other leaf-cutting ant species, they cultivate a fungus inside the nest chamber, which constitutes the sole food for their larvae. The fungus' optimal growth requires temperatures between 25-30°C and a high relative humidity. To enable such growth, the ant colony maintains a proper nest climate through various building properties and behaviors. First, according to the authors, it is the thermal properties of the thatch, which largely manage the temperature surpluses inside the nest (Bollazzi and Roces, 2010c). The thatch material consists mainly of plant materials and soil particles providing it with a lower thermal diffusivity than the surrounding soil. These thermal properties of the thatch have been proven to prevent nest overheating by the incoming solar radiation during the day and avoid losses of the accumulated heat into the cold air during the night. Second, temperature surpluses inside the nest are also gained from metabolic heat inputs from ants' work and organic material decay inside the nest. Third, the fungus' high heat capacity also helps in storing heat in the nest. Moreover, a dynamic behavioral process of modifying the thatched nest architecture controls for temperature and humidity inside the nest: the ants open and close nest apertures and add or remove thatch thickness (Bollazi and Roces, 2010a, b, c).

Although the geographical locations of the *Acromyrmex heyeri*'s ecosystem and of Thomson House are not related, the strategies learned from the ecological system can be adapted to the specific climate conditions of Montreal because this exercise relies on the abstraction of functions and processes. The depth and extent of available quantitative information about the thermoregulatory processes of this ecosystem were a major advantage that made us choose this ecosystem over others. Another reason to select this ecological system is that the leaf-cutting ant mounds have more similarities with human constructions than other ecosystem's structures, and a more straightforward approach was preferable considering this is the first case study putting the ecomimetic design method in practice. With an ecosystem selected and information on its functioning gathered, thatched nests' thermoregulatory functions can be abstracted and represented in the following stage.

3.3 Stage 3: Abstraction and representation of ecological systems

Stage 3 consists of understanding the ecosystem's organization and behavior through time. Throughout this design stage, the ecosystem's components, structure and interactions as well as intervening parameters are identified, abstracted and represented with graphic tools used for environmental modeling, engineering and system thinking theories (Garcia Holguera et al, 2012; 2015a; 2015b). The appeal of using these tools lies in their regard for transdisciplinary understanding (Garcia Holguera et al, 2012; 2015b).

The first tool is an Energy System Diagram (ESD), which graphically represents the flows of energy and materials as well as the structural organization of our chosen ecosystem. American ecologist Howard T. Odum developed ESD. ESD's value for visualizing a system's components, organization and interactions has been recognized in several disciplines (Garcia Holguera et al 2012, Odum, 1994, 2007). Figure 1 illustrates the ESD of an *Acromyrmex heyeri* thatched nest. It is worth noting that developing such ESD was an iterative process of which many versions could have resulted.

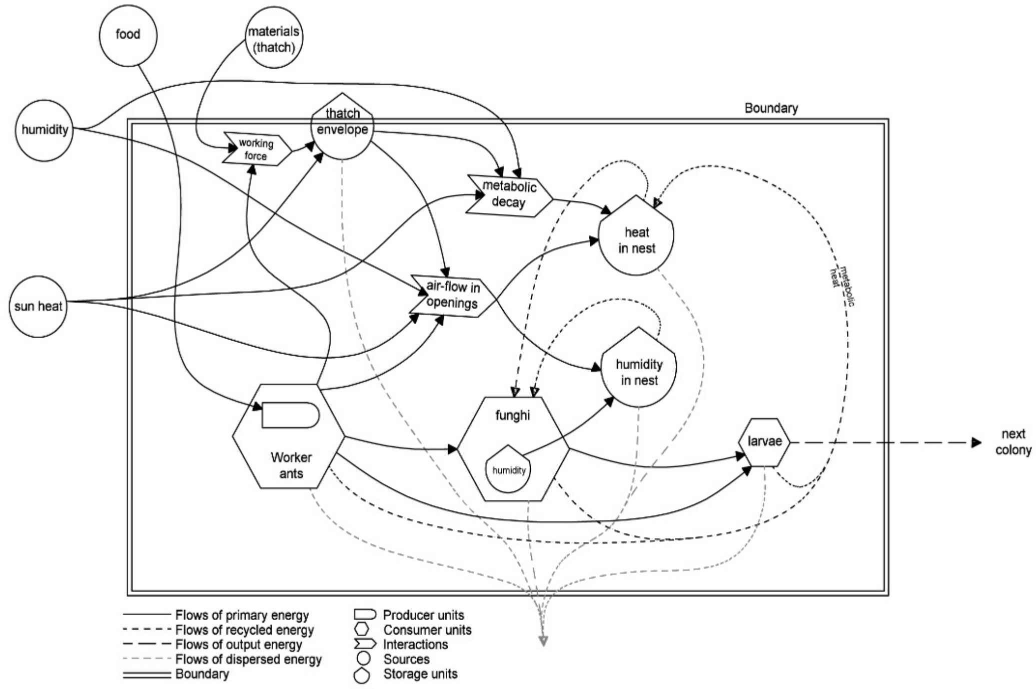

Figure 1: Energy System Diagram of a leaf cutting ant thatched nest

The second tool suggested in stage 3 of the ecomimetic method is STELLA, a software used particularly for environmental modeling. STELLA is a computer simulation tool that helps understanding the dynamic behavior of complex systems and has been proven useful for representing the behavior of both architectural building systems as well as environmental systems (Ford, 2010; Garcia-Holguera et al, 2015a). Figure 2 illustrates the conceptual model built on STELLA of an *Acromyrmex heyeri* colony thatched nest. Each parameter of the model was assigned a quantitative value that defined the initial conditions of the model. Such values were based on a series of informed assumptions and thermodynamic values found on the literature about leaf-cutting ants' nests (a detailed description of such assumptions can be provided by the authors upon request). Simulations of the model were conducted to ensure the modeled and theoretical ecosystem's performance exhibits its real behavior as empirically tested by Bollazzi and Roces (2010 a,b,c). Figure 3 represents the modeled behavior of the ecosystem over time for our final simulation.

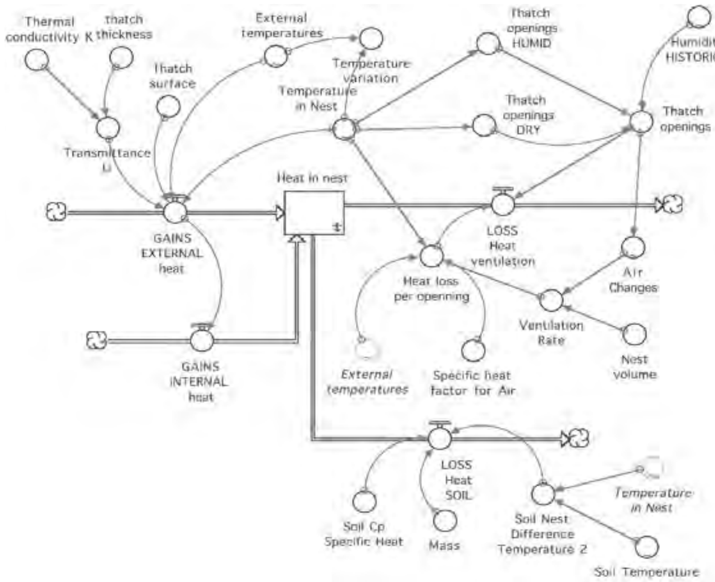

Figure 2: Conceptual model of a leaf cutting ant thatched nest developed with STELLA

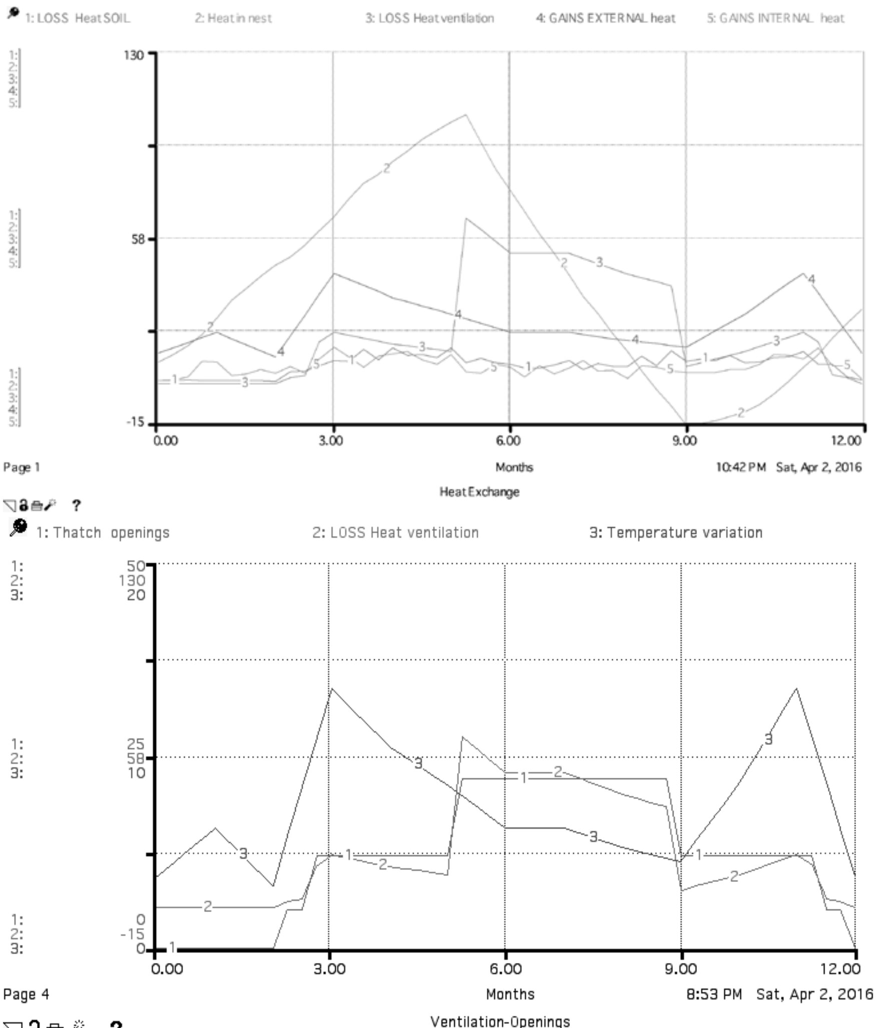

Figure 3: a) Heat exchange of the thatched nest over time; b) Ventilation interactions in the thatched nest over time. For the x axis on both graphs, month 0 and 12 refer to December.

From Figure 3a, we can observe that the heat in the nest has a cyclical variation over a year and that such variation seems to be affected primarily by the heat loss through ventilation. The rapid increase in heat loss by ventilation around May seems to be particularly correlated with a rapid drop of the heat in nest (Fig. 3a: decrease after month 5 in x-axis). This contrasts with the other heat inflows and outflows (i.e. external heat gains, internal heat gains and heat losses through the soil) whose relationship with the variation of nests heat is not as clear. This observation is important as it suggests that the ventilation plays a major role in the thermoregulatory behavior of the thatched nest ecosystem and therefore is a function we could focus on pursuing further in the ecomimetic exercise. With this focus in mind, understanding the influences that contribute to the variation of the heat losses through ventilation becomes of special interest. Figure 3b helps us address such inquiry. It is from this second graph that we can observe that the heat loss through ventilation is closely correlated to the number of thatch openings. Therefore, from this exercise and in consideration of all of our model's assumptions, we are able to suggest that the function of the openings in the thatch are central to the admirable thermoregulation performed in *Acromyrmex heyeri* nests and that such function is therefore a source of inspiration for potential application in human building systems.

These abstractions, representations and simulations have allowed us to recognize the components and their relative contribution intervening in the ecosystem's thermoregulation. In other words, this stage has provided us a thorough understanding of the ecosystem to mimic. We have recognized the components affecting the system and their relationships as well as the feedback loops that support the dynamic thermoregulatory behavior of thatched nests. With this understanding, correlations between the ecosystem and the building can be drawn in the following step.

3.4 Stage 4: Correlation between ecological systems and architectural systems

The goal of stage 4 is to find one or several correlations between the function performed by a component of the ecological system and the function performed by another component in the architectural system. To reach this goal, the ecomimetic method suggests classifying such functions in the form of a table using H.T. Odum's functional typologies of ESD as seen in Figure 1(i.e. source, storage, producer, consumer) (for a detailed description of the symbols of functional categories, refer to Garcia Holguera et al., 2012; 2015b). Table 1 shows the components of the ecosystem associated with corresponding components in the building. The column listing components of the leaf-cutting ant thatched nest was derived from the ecosystem's ESD of stage 1 (Figure 1). For the column of Thompson House, current components were gathered from the Audit Report's description of the building, and the ecomimetic retrofit hypothetical components were listed out of a creative brainstorming process stemming from our understanding of the ecosystem (MMA and BP, 2013).

Table 1. Correlation between components in ants thatched nests and components of both current and hypothetically retrofitted Thompson House

Symbol	Leaf-cutting Ants Thatched Nest	Thompson House	
		Current	Ecomimetic Retrofit
Source	Thatch material, food, external air humidity, solar radiation	Construction materials, steam, electricity, natural gas, external air humity, solar radiation, municial water, food	Thatched-like envelope materials
Storage	Thatched envelope, heat in nest, humidity in nest, water content in fungus	Building envelope, heat in building, humidity in building	Thatched-like envelope, humidity retention unit/fungus-like component (i.e contained strucutre with high water content for high heat capacity) (e.g. greenhouse, solarium)
Interaction	Metabolic decay (i.e. microorganisms decomposing nests materials), Air flow through openings	Air-flow ventilation	Air-flow ventilation induced by thatched-like openenings
Consumer	Ant workers, Fungus, Larvae	Plugload equipment (e.g. fan/pump), lighting system, heating system, hot water system, hydraulic system, users (e.g. from adminstration, kitchen, and students)	Programmed ant-like behaviour openings, cooling system, improved control equipment

3.5 Stage 5: Transference of ecosystem's principles to an architectural system

In this stage, the architectural system is modeled and its dynamic behavior simulated so that it mimics the abstracted performance of the selected ecosystem. The goal of this stage is to obtain a set of design guidelines for retrofitting the selected building. The design guidelines may be implemented if the technology exists, however if the technology is not yet available, the design guidelines will constitute a new lead for their research and development. In accordance to this stage of the ecomimetic design method, first, an ESD of Thompson House was developed in order to represent the hypothetical structure and component's organization of the retrofitted building (Figure 4). The ESD of Thompson House is a simplification of the potential architectural system that integrates the various thermoregulatory strategies observed in the thatched nest ecosystem and identified as important in stage 3. The ESD of Thompson House allowed us to gather a broad understanding of the energy flows in the proposed building system.

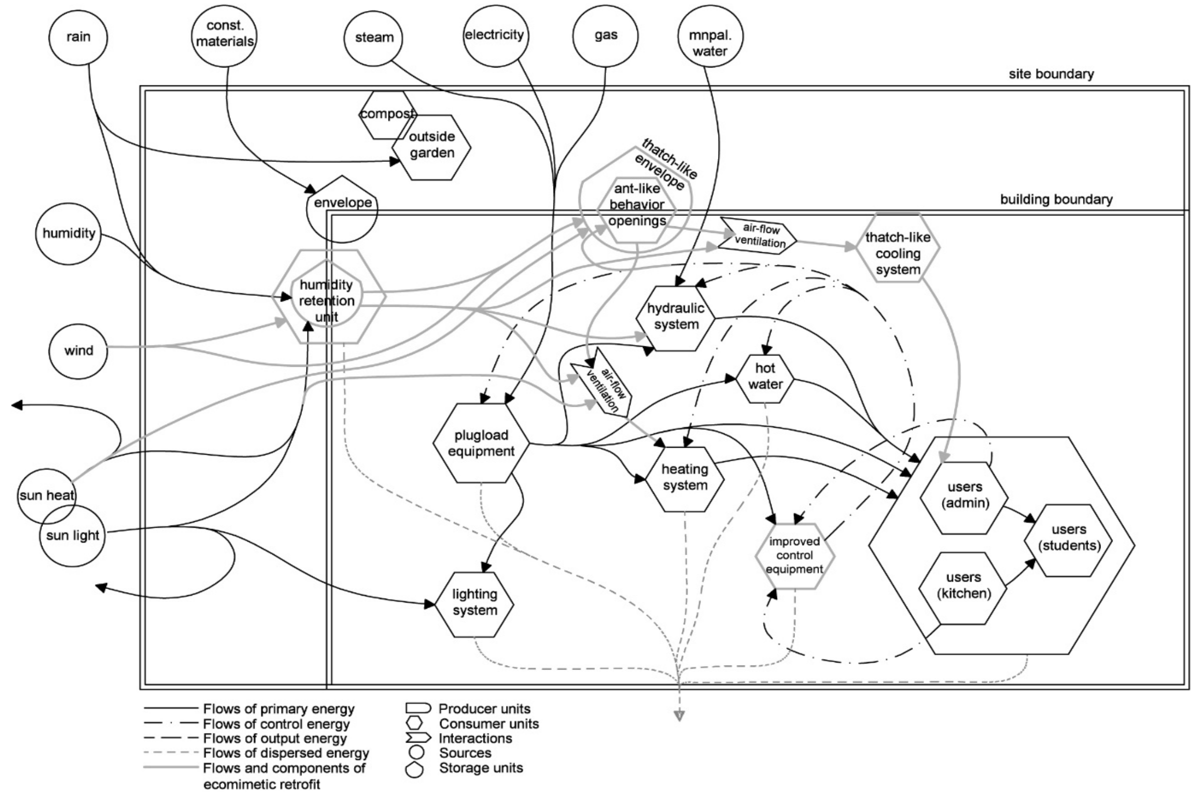

Figure 4: Energy Systems Diagram of a Thompson House hypothetical architectural system based on the leaf-cutting ant thatched nest ESD.

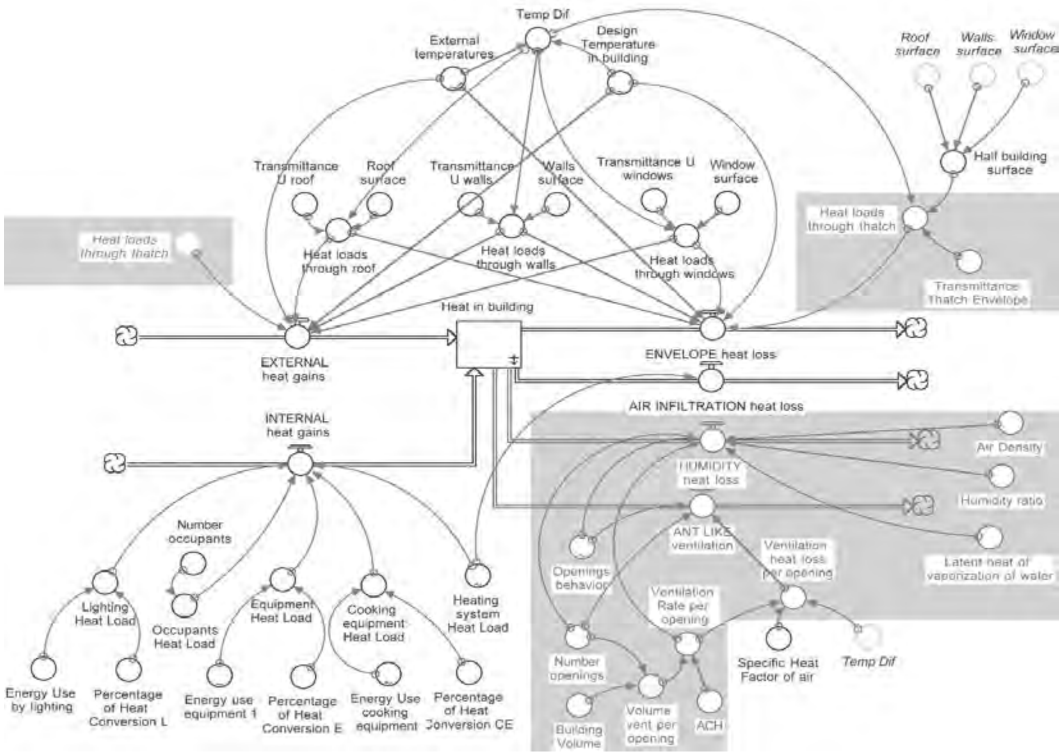

Figure 5: Conceptual model of Thompson House hypothesized architectural system developed with STELLA software. The elements over the grey rectangles represent the new variables for the ecomimetic retrofit (Appendix 2 for a detailed description of assumptions can be provided by the authors)

Then, a dynamic model of the hypothesized Thompson House was conceived in STELLA after multiple iterations (Figure 5). The model integrates different components and their interactions in order to reproduce in the building system the dynamic behavior observed in the selected ecosystem. The STELLA conceptual model presented in Figure 5 shows in black some existing components in the Thompson House building, and also incorporates other proposed components (components with grey rectangles underneath) to mimic a thatched nest. Simulations of the dynamic interactions among these components can be seen in Figure 6.

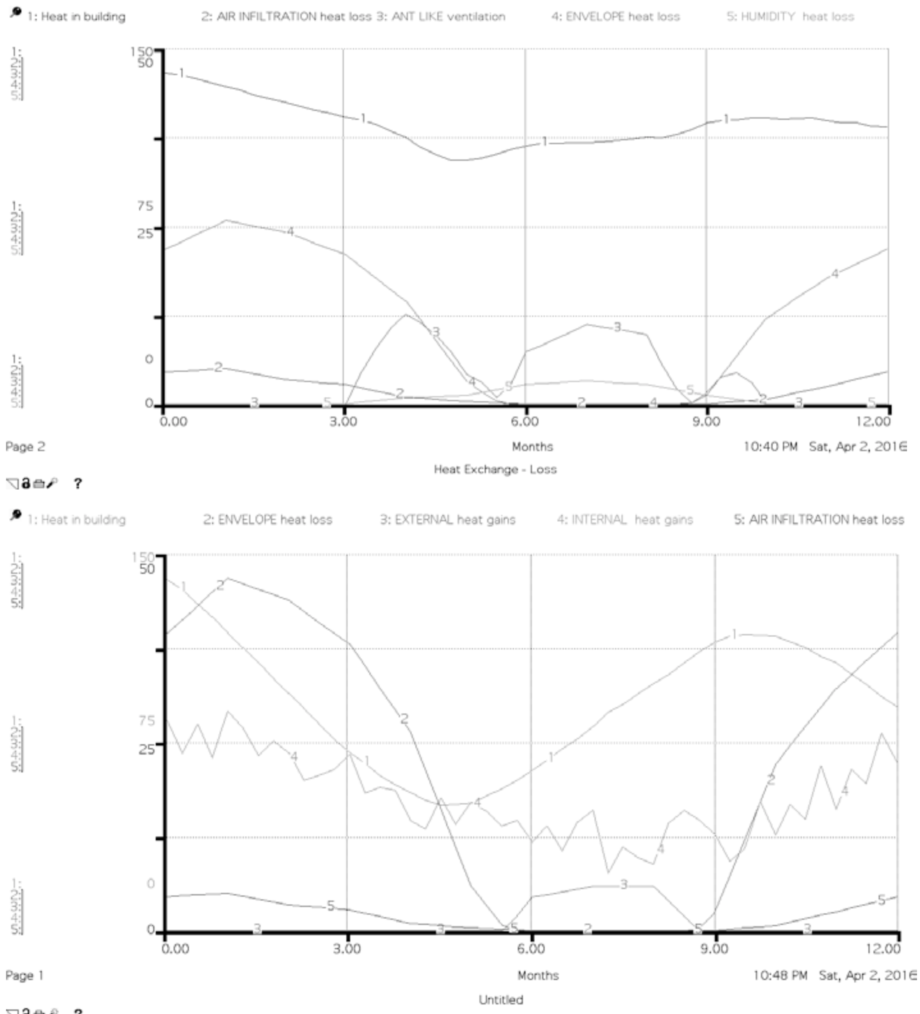

Figure 6: Dynamic behavior of Thomson House with the ecomimetic strategies incorporated: a) Representation of flows of heat losses in Thompson House. b) Detail of the heat losses through the envelope including the 'thatch like' envelope. For the x-axis on both graphs, month 0 and 12 refer to December.

The ecomimetic model of Thomson House reduces the heat losses during the winter months thanks to the thermal properties of the new envelope and reduces the heat gains during the summer season by implementing a ventilation strategy that mimics leaf-cutting ants' behavior of opening and closing thatch apertures. The amounts of 'Envelope heat loss' in the ecomimetic model of the Thomson House (Fig. 6a) are substantially reduced when compared with the 'envelope heat loss' in the model of the existing Thomson House (Fig. 7).

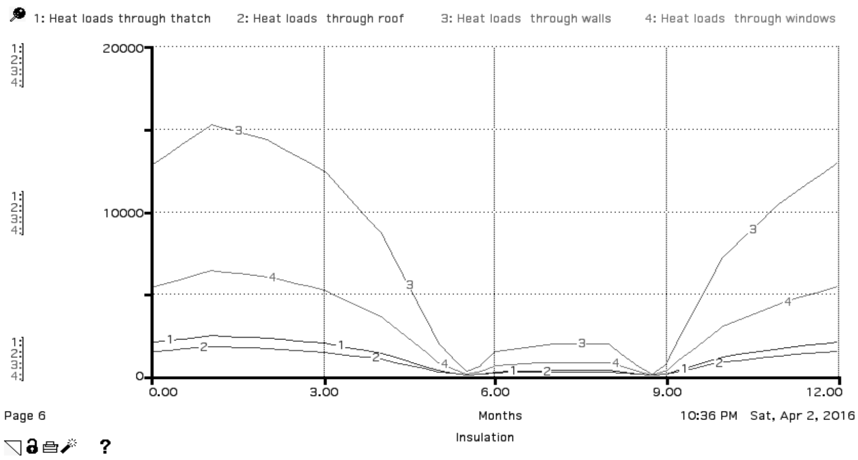

Figure 7: Current annual heat exchange in Tomson House based on data from (MMA & BP, 2013). For the x-axis month 0 and 12 refer to December

A more detailed analysis of the building envelope in Figure 6b shows that the 'thatched-like' envelope displays a substantial reduction in heat losses compared with the existing components of the envelope (walls, roof and windows). The results obtained with the STELLA dynamic model, as shown in Figure 6, are relevant for estimating the expected behavior and usefulness of the proposed ecomimetic strategies.

The set of design guidelines resulting from this stage consist of retrofitting Thompson House with an envelope that has thermal properties similar to those observed on the thatched nest and small apertures whose opening and closing behavior function similarly to those in the thatched nest. This 'thatched-like envelope' would cover the south and southwest facades of the original building because of their higher exposition to sun radiation (the thermal properties of the envelop, for the purpose of this exercise, would be similar to those present in aerogels). In addition part of the thatch envelope's surface will be able to open and close small apertures controlled through artificial intelligence and coded by the administrators of the building. Analogous to the apertures on thatched nests, these openings will react to changes of temperature and humidity in the internal and external environment. Another design guideline drawn from this exercise is to add a 'humidity retention unit' in the building whose main function would be to help regulate the humidity and temperature levels. This component, like the 'thatch-like envelope', may be realized in a variety of ways. One of them could be a vertical garden under the new envelope, which could additionally have the function of supplying food to the kitchen in Thompson House and improving indoor air quality.

Before the set of guidelines are implemented in the architectural project, the ecomimetic design method suggests a modeling and benchmarking exercise as the last stage, Stage 6. In Stage 6, first an architectural model integrating the ecomimetic strategies identified in Stage 5 is built. This model needs to provide enough information to run a performance evaluation of the design. If the evaluation shows that the energy use was optimized then the ecomimetic strategies might be implemented in the construction documents. If the evaluation shows no optimization of resources use, then an iterative process must be undertaken at some stage of the ecomimetic method. Such stage allows comparing the results with building performance standards. Stage 6 is currently under development by the authors so its results will not be covered in this paper.

4. Discussion

We tested the usefulness and performance of the ecomimetic method stages 1-5 under the hypothetical scenario of designing a retrofitted Thompson House. The ecomimetic inspirations were the thermoregulatory properties and processes leaf-cutter ants' thatched nest. The purpose of this discussion is to comment on the challenges and obstacles we encountered using the ecomimetic method, to give recommendations for future users of the method, as well as to identify possible improvements of the method itself.

On stage 1, the main challenge encountered was determining the scope of the design objectives. For our hypothetical scenario, targeting a broad design objective was appropriate enough, but for other cases a better-defined and more specific objective may be needed. We recommend users of the method to, if possible, start with rather open objectives and maintain flexibility in redefining their objective iteratively as they go through other stages.

For stage 2, an important obstacle we encountered was the limited extent of ecosystem options in the AskNature database from which to choose to continue the exercise. The ecomimetic method suggests that the element from nature to be inspired from ought to be an ecosystem. However, the AskNature database does not offer a filter for ecosystems, but rather for options such as: strategies, products, people etc. Therefore, the database results had to be trimmed down by the authors to those that were ecosystems. For example, typing on the search bar "how does nature regulate temperature" yielded 161 results of which only less than 10 were ecosystems (e.g. south american grass cutting ant colonies, mallee fowl nests, hot spring grass & fungus, Honey bees hive vibrations, wood ants nest). Similarly, exploring the database by nature's function for 'resource efficiency' yielded 93 results of which very few were ecosystems (e.g. transvaal savanna, tropical rainforests, dehesa ecosystem, riparian habitat). In addition to the limited ecosystem options offered by AskNature, the selection of the ecosystem was largely restricted by the availability of scientific research about the ecosystem that included thermodynamic quantitative values. A detailed and ideally quantitative thermodynamic understanding of the ecosystem is required for stage 3 and so the lack of such available information seems to largely constrain the application on the ecomimetic method. We recommend users of the method to conduct stage 2 without solely the help of the AskNature database. The ecomimetic method could benefit from refining search approaches beyond the suggested searching tools included in Garcia-Holguera et al. (2015). Another important concern that arose from this step was the appropriateness of our selected ecosystem in being able to inspire a building under very different contextual conditions, particularly climatic considerations. To what extent are *Acromyrmex heyeri* thermoregulatory strategies context dependent and non-transferable into other contexts, such as the context of extreme weather of Montreal? Without the ability to answer this inquiry, here we adopted an attitude of predisposition and openness to learn from the leaf-cutting ants' strategies. However this important consideration ought not to be ignored by users of the method.

As for stage 3, developing the ESD of the ecosystem was a useful tool for clarifying a common understanding of the ecosystem's components, structure and interactions. This leads us to suggest that the value of developing an ESD lies largely in being an exercise for users of the method (e.g. designers, ecologists, architects, etc.) to engage in a common interpretation of the ecosystem. Challenges may arise when categorizing the components of the ecosystem according to Odum's symbols or when identifying feedback loops. It remains pertinent to develop ESDs in an iterative and

collective manner and acknowledge that different versions might arise. The validation of the ESD consists in a consensual process among the users of the ecomimetic method.
Developing the STELLA model that performs the desired behavior was the most challenging undertaking of the method both for the ecosystem and the building system on stages 3 and 5. Obstacles were encountered particularly in finding quantitative values for the multiple parameters. STELLA requires all parameters in the system to have quantitative values assigned. Homogenizing units of the multiple values is also imperative for coherent simulations. The lack of available information is a barrier that users of the ecomimetic method will likely encounter at this stage. Assumptions were brought in and the model design was largely an iterative process. The validity of our assumptions ought to be taken with caution. Modeling ecosystems and theoretical buildings require a bundle of estimations, some less refined than others. We recommend users of the method keep a clear record of the following: the assumptions made on the model, the justifications for their relaxation, and the sources from which parameter values were taken from.
Whereas the modeling process requires substantial creativity, the creation of table 1 (Stage 4) was a creative process as well. This is the case particularly for the ecomimetic retrofit column, in which for some desired functions performed in the ecosystem, there were no known associated architectural components. This obstacle calls for up-to-date knowledge on recent innovations and provides clues for innovation opportunities through the development of non-existing components. As for the known components suggested in the ecomimetic retrofit, different ideas might create equally valuable sets of functional components.

5. Conclusions

The ecomimetic method as developed by Garcia-Holguera et al. (2015b) was tested throughout this research. The method has proven to be a useful step by step process for learning from an exemplary ecosystem: leaf-cutting ants thatched nests, and theoretically transfer relevant processes and functions to potentially optimize resource use in a building: Thompson House in Montreal, Canada. The method has facilitated the understanding of our selected ecosystem's structure, organization, components interactions and behavior thanks to the use of abstraction and representation tools. The exercise permitted us to identify openings in the thatch and their consequent ventilation to be a relevant thermoregulatory function in *Acromyrmex heyeri* colonies. We have suggested strategies to implement such ventilation-based approach in our building system alongside other potential additional components that could perform other thermoregulatory strategies in a similar way than in the thatched nests. It has been observed that the design process was enriched by the multidisciplinary collaboration of the researchers involved in this project. Different backgrounds and points of view have facilitated a better understanding of the ecological and building systems.
In the future, the ecomimetic design method will be implemented in at least two more case studies. The second case study will learn from freshwater marshes for optimization of water use in buildings as well as other resource use issues. Further development of this research should address the professional environment and the educational aspects of future users of the design method. First, the method could be tested with the collaboration of architectural and engineering firms throughout the design of a real building to be built. The implementation and construction of the ecomimetic strategies obtained in the design process would represent the most relevant validation of the method and would highlight additional challenges. Second, the method could be integrated in architectural and engineering design courses to better understand the pedagogical obstacles that undergraduate and

graduate students might encounter when developing innovative and multidisciplinary projects. This educational goal would also facilitate the future implementation of the method in the architectural and engineering practices.

In addition, the ecomimetic design method could be used for developing new technologies in collaboration with other researchers. Some strategies identified in the design process are incipient and need further development with the involvement of biologists, ecologists, architects and engineers. Overall the ecomimetic method is a useful tool for innovative design that can help architects and designers optimize resource use in buildings.

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A BIM-based Embodied Energy Calculation Prototype for Life Cycle Energy Analysis of Buildings

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Abstract

Buildings consume approximately 40% of global energy each year in their operation alone. In order to reduce a building's total energy use effectively, a life cycle energy accounting is critical that accounts for both the embodied and operating energy. Embodied energy is consumed in the processes of building material production, transportation, construction, maintenance, renovation and final demolition. Operating energy is consumed in operating the buildings in the processes of air-conditioning, heating, lighting, and powering building equipment. For a comprehensive reduction in a building's total life cycle energy usage, optimizing both the embodied and operating energy is recommended. Computing operating energy is more straightforward than embodied energy due to a lack of a complete and representative embodied energy database. Additionally, while operating energy computation capability has been added to Building Information Modelling (BIM) authoring tools, embodied energy calculation remains isolated. There are commercial software available to estimate embodied energy, however, they are based on secondary data. For an industry-wide application of embodied energy analysis, it is crucial to integrate embodied energy calculation capabilities into a BIM authoring tool.

Among major embodied energy accounting methods are process-based, input-output-based and hybrid methods. The process-based method is product specific but provides incomplete calculation, whereas the input-output-based method is complete but lacks specificity. The hybrid method is a combination of the process and input-output-based methods. According to literature, there is no perfect method currently available to compute embodied energy in a complete manner. In this paper, an improved embodied energy calculation method is proposed and used to compute complete and representative embodied energy of commonly used building materials. A framework to integrate embodied energy data into a BIM authoring tool such as Autodesk Revit Architecture is also proposed. The results of embodied energy computation are validated by comparing them to empirical data.

Keywords: Embodied energy, building materials, life cycle energy analysis, embodied carbon, Building Information Modelling

1. Introduction

The building sector consumes approximately 40% of global energy mostly in building operations (BEDB, 2012). Because most of this energy usage is fossil fuel-based, it contributes to approximately 40% of the global carbon emission annually (BEDB, 2012). A growing consensus in literature agrees on an urgent need to optimize building energy consumption by identifying energy saving opportunities and developing tools to simulate energy performance (Bassett et al., 2013). Additionally, studies (Hernandez and Kenny, 2010; Snow and Prasad, 2011; Dixit and Yan, 2012) emphasized meeting the optimized energy demand through onsite or offsite renewable energy sources so that dependence on fossil fuels can be reduced. Although a great number of studies focused on energy optimization, most of them did not include all life cycle energy components (Paleari et al., 2013). The research community must analyze a building as a system of energy input and output in order to effectively optimize its life cycle energy consumption (NSTC, 2008; Karimpour et al., 2014). This lack of a system's approach hinders efforts to reduce building energy consumption comprehensively (Sturgis and Roberts, 2010). Before we optimize the energy use of a building, there should be a systemic net-energy accounting tool in place covering the entire life cycle of a building (Sturgis and Roberts, 2010; Dixit, 2015).

According to Dixit et al. (2012), the total energy consumed by a building over its service life includes the energy of its construction, maintenance, operations, and final demolition. The sum of all energy consumed in constructing the building is termed initial embodied energy (IEE). IEE includes the energy embodied in construction materials, related onsite and offsite transportation, construction and administration processes (including labor), and other required services such as consultancy, banking, marketing, etc. (Crawford, 2004). When occupied, the building is maintained and renovated using building materials and related processes. The total energy used in these activities is called recurrent embodied energy (REE) (Vukotic et al., 2010; Dixit et al., 2015). During this stage, operating energy (OE) is also consumed in building operations (lighting, HVAC, hot water, power etc.). At the end of its service life, the building is deconstructed and its waste is sorted and hauled for reuse, recycling, or disposal. This end-of-life phase energy usage is termed demolition energy (DE) (Vukotic et al., 2010). The total energy consumed by the building is a sum of IEE, REE, OE, and DE (Dixit, 2015). In order to reduce energy use of a building effectively, one must account for all of these energy components and compute the net-energy requirement of the building (NSTC, 2008; Bassett et al., 2013).

While computing operating energy is straightforward, embodied energy calculation is not (Ristimaki et al., 2013). It is due to a lack of location-specific, accurate, and complete embodied energy data of construction materials (Dixit, 2015). Most existing databases are questionable due to their geographic, technological, and temporal non-representativeness (Khasreen et al., 2009; Dixit et al., 2010). Studies identified an urgent need to establish an embodied energy database for commonly used construction materials (Karimpour et al., 2014; Dixit, 2015). This paper provides a framework of an Application Programming Interface (API) for embodied energy calculation integrated into a building information modelling (BIM) authoring tool.

An improved embodied energy calculation method was used to compute embodied energy values for construction materials. The improved method proposed by Dixit et al. (2015) and Dixit (2015) is referred, which provides material-specific and complete embodied energy values for materials manufactured in the United States.

2. Literature Review

2.1 Embodied Energy and Net-zero Buildings

Buildings consumed over two fifth of the annual energy in 2009 in the United States resulting in approximately 40% of the total carbon emission (USDOE, 2012). Most of this energy consumption originated from a buildings' operation. If the energy embodied in construction is also incorporated, the share of construction industry in the total national energy consumption would reach 48% (Baum, 2007). Literature agrees on applying a systemic approach to reducing energy consumption of the building sector in order to reduce its carbon footprint effectively (Fischer, 2010; Sturgis and Roberts, 2010). One of the approaches suggested in the literature is the concept of net-zero energy building. A net-zero energy building supplies its optimized energy requirements through onsite or offsite renewable energy sources in order to be net-zero in its fossil fuel-based energy usage (Hernandez and Kenny, 2010; Marszal et al., 2011; Dixit, 2015). In order to optimize energy needs substantially, a life cycle-based energy accounting of buildings which focuses on both the embodied and operating energy is important (NSTC, 2008). Optimizing operating energy of a building may affect its embodied energy. For instance, installing better insulation in a building envelope to minimize heat transfer may increase its embodied energy because most insulation materials contain higher embodied energy (Sturgis and Roberts, 2010; Waldron et al. 2013). Similarly, optimizing embodied energy may increase operating energy usage. Calculating operating energy is more standardized and simpler than embodied energy due to the unavailability of complete and reliable embodied energy data (Langston, 2006; Dixit et al., 2013).

2.2 Embodied Energy Calculation: Methods and Issues

Among widely known methods to compute embodied energy are process-based and input-output-based (IO) methods (Crawford, 2004). There are also hybrid methods that combine the process and IO-based methods (Dixit, 2015). The process-based methods involve gathering energy use data from material manufacturers, construction sites, vendors to calculate the total energy embodied in construction materials and processes (Acquaye, 2010). Although some energy use data is easy to collect, some is not due to data confidentiality or unavailability. Therefore, process-based embodied energy calculations are considered reliable but incomplete (Crawford, 2004; Acquaye, 2010). In addition, when process-based embodied energy values of construction materials are used to compute the embodied energy of a building, some processes related to services such as consultancy, inspection, administration, etc. may remain excluded (Ding, 2007).

In an IO-based method, the flow of money from energy sectors to an industry sector manufacturing the material under study is utilized to compute embodied energy (Treloar, 1998). The national IO accounts that include IO tables publish monetary flows annually (Horowitz and Planting, 2009). The IO tables can be used to calculate the direct and indirect input requirements of an industry sector from energy providing sectors. The direct requirements indicate the total energy directly required to produce one $ output of an industry sector. The direct requirements also result in industry-wide indirect requirements. The sum of direct and indirect requirements is termed total requirements of a sector, which indicate its total energy usage (in $) per unit of its monetary output (in $) (Crawford, 2004). The total energy requirements are then converted from monetary units ($/$ output) to energy units (British thermal unit (Btu)/$ output) using energy prices (Crawford, 2004). However, if the energy prices are inaccurate, they may cause serious errors to embodied energy values (Acquaye, 2010). The IO-based embodied energy values, therefore, are complete but may be unreliable due to the uncertainties of energy prices. Because an IO-based method involves calculating the embodied energy of an industry sector with an aggregated output, all products manufactured by the sector have the same embodied energy values, which may not be accurate (Dixit, 2015). According to Treloar (1998), IO-based methods may also count energy inputs more than once resulting in an overestimation of embodied energy.

A hybrid method is either process-based or IO-based (Acquaye, 2010). In a process-based hybrid method, the framework remains process-based and IO data are used to make up for unavailable data (Bassett et al., 2013). Because the main framework is process-based, the process-based hybrid method still carries the limitations of a process-based method (Acquaye, 2010). For instance, using a bill of quantities and embodied energy of construction materials, the embodied energy of a building can be calculated. However, other onsite and offsite processes such as construction, fabrication, administration, transportation, and services are not completely covered (Crawford, 2004). Similarly, when the embodied energy of complex materials such as reinforced concrete is calculated using a process-based hybrid method, the embodied energy of cement, gravel, and steel is multiplied to their respective volumes. This, however, excludes the energy consumed in mixing, placing, and curing the reinforced concrete components (Crawford, 2004).

In an IO-based hybrid method, process data is inserted into an IO framework to make it more reliable (Dixit et al., 2015). For instance, when energy usage is inserted in energy units into an IO model, the embodied energy calculation can avoid the use of unreliable energy prices (Carter et al., 1981). However, the conversion of embodied energy from the unit of Btu/$ to Btu/lb still needs material prices, which may not be reliable (Dixit et al., 2015). In addition, due to the main framework being IO-based, the embodied energy intensity is for the entire industry sector rather than one specific material (Treloar, 1998). Furthermore, this method excludes the energy embodied in labor and capital inputs because IO tables do not cover these inputs (Treloar, 1998). Other issues such as the counting of energy inputs multiple times also remain unresolved (Treloar, 1998). In spite of some limitations, an IO-based method is considered relatively the most complete method (Treloar, 1998; Crawford, 2004; Acquaye, 2010; Dixit et al., 2014).

3. Research Goal and Methods

In this paper, the current version of the IO-based hybrid method is improved to enhance its completeness, reliability, and specificity. The energy embodied in commonly used construction materials is calculated using the improved method. A framework of a BIM prototype is developed to demonstrate embodied energy and BIM integration. First, using the Benchmark Input-Output Accounts published by the United States Bureau of Economic Analysis (USBEA), an IO model is developed using the raw Make and Use tables. The process of creating an IO model can be referenced from Horowitz and Planting (2009). Note that the calculated embodied energy values include all energy and non-energy inputs used in the manufacturing of study materials. These values do not include related transportation or energy embodied in construction. The following improvements were done to the IO-model:

Process/Actual Energy Data Integration: Actual energy use data was collected for each industry sector and integrated into an IO model developed using 2002 United States Benchmark Input Output Accounts using the approach suggested by Carter et al. (1981). This approach does not rely on energy prices, which may be under-estimated or over-estimated. A detailed explanation can be found in Dixit et al. (2015).

Primary Energy Factor (PEF) Calculation and Integration: Treloar (1998) revealed that an IO model may involve counting energy inputs multiple times and suggested using PEFs for each energy providing sector of the IO model. In this paper, all energy and material inputs to energy sectors were removed and PEFs for the energy sectors were calculated and used instead. Dixit et al. (2014) provides a detailed explanation of the PEF calculation.

Calculating and Integrating the Energy of Labor and Capital Inputs: The energy embodied in human labor and capital inputs was quantified and integrated into the IO model to fill any system boundary exclusions related to human labor and capital investment. A more detailed explanation of the calculation can be referred from Dixit et al. (2015).

Sectorial Disaggregation: To compute the embodied energy of a specific material, the aggregated output of an industry sector must be decomposed as suggested by Joshi (1998). In this study, some of the industry sectors that originally had an aggregated output were disaggregated using their input and output data.

The calculated values of embodied energy of commonly used construction materials were comparatively evaluated with the published values. Because embodied energy values of all materials were not available in the referred studies, average values were calculated and used. The referred studies include Chen et al. (2001), Scheuer et al. (2003), Alcorn (2003), and ICE (2011). Note that the referred studies come from different time and may not represent the calculated values temporally. Therefore, a correlation analysis was preferred for comparative evaluation of the results. For comparing the results with published values, a scatter chart (coefficient of determination) was used. A coefficient of determination (r^2) greater than 0.81 and less than 0.81 but more than 0.64 is assumed to show a very strong and strong positive correlation, respectively (Taylor, 1990; Chan, 2003). To demonstrate the integration of embodied energy and a BIM authoring tool (Autodesk Revit Architecture), two approaches were discussed.

4. Results and Discussion

The calculated values of embodied energy of construction materials under study are listed in Table 1. The embodied energy values calculated using the improved IOH model were in MBtu/$ of industry output. Using the appropriate material prices, these values were converted into the unit of MBtu per unit length, area, or volume. The units of embodied energy values are mentioned in the first column of Table 1. Note that the energy embodied in study materials was quantified with a break up of energy sources used in their manufacturing process. Such a calculation is important to accurately determine the carbon dioxide emissions resulting from energy consumption.

Table 1: Calculated values of embodied energy of study materials

		Embodied Energy in kBtu						
Study Material	*Unit*	*Oil & Gas*	*Coal*	*Electricity*	*Natural Gas*	*Petroleum*	*Human & Capital Energy*	*Total Energy*
Carpet (3/8" Thk.), Level Loop	*ft2*	*0.4*	*0.9*	*8.2*	*5.2*	*6.5*	*1.3*	*22.5*
Wood Lumber	*ft3*	*1.5*	*0.8*	*30.6*	*10.9*	*53.3*	*10.6*	*107.8*
Hardwood Plywood & Veneer	*ft3*	*6.6*	*3.8*	*130.2*	*57.9*	*155.1*	*42.4*	*396.0*
Softwood Plywood & Veneer	*ft3*	*0.9*	*1.1*	*58.7*	*24.1*	*46.9*	*12.6*	*144.3*
Paints & Coatings	*gal*	*6.0*	*9.7*	*51.8*	*47.0*	*90.9*	*11.7*	*217.0*
Adhesives	*gal*	*5.8*	*10.7*	*59.9*	*49.5*	*90.7*	*13.7*	*230.3*
Plastic Pipes & Fittings	*ft*	*3.6*	*2.3*	*25.5*	*22.1*	*51.9*	*4.2*	*109.7*
Polystyrene Insulation	*ft2*	*4.7*	*5.6*	*44.2*	*44.7*	*73.6*	*9.0*	*181.7*
Bricks (2 1/4"X3 5/8"X7 5/8")	*No.*	*0.0*	*0.2*	*1.8*	*4.8*	*1.5*	*0.4*	*8.7*
Clay Wall & Floor Tiles (1/4" Thk.)	*ft2*	*0.2*	*0.7*	*11.0*	*14.2*	*6.0*	*3.0*	*35.2*
Vitrified Clay Sewer Pipes (6" Dia.)	*ft*	*0.5*	*2.8*	*23.5*	*67.4*	*24.7*	*9.9*	*128.9*
Glass (1/4" Thk.)	*ft2*	*0.1*	*0.4*	*9.7*	*19.2*	*3.8*	*1.1*	*34.3*
Cement	*ft3*	*0.6*	*111.2*	*81.7*	*17.5*	*70.7*	*8.5*	*290.3*
Concrete	*ft3*	*0.4*	*18.4*	*21.2*	*12.8*	*28.8*	*5.8*	*87.4*
Gypsum Board (1/2" Thk.)	*ft2*	*0.0*	*2.8*	*2.4*	*3.3*	*3.0*	*0.3*	*11.7*
Lime	*ft3*	*0.2*	*20.8*	*14.9*	*23.7*	*24.0*	*3.5*	*87.1*
Stone	*kg*	*0.0*	*0.1*	*1.1*	*0.5*	*1.0*	*0.5*	*3.2*
Mineral Wool Insulation	*ft2*	*0.1*	*1.0*	*9.8*	*9.0*	*3.9*	*1.4*	*25.2*
Virgin Steel	*kg*	*0.1*	*20.5*	*29.0*	*19.1*	*6.1*	*2.1*	*76.9*
Primary Aluminum	*kg*	*4.7*	*0.5*	*130.7*	*13.5*	*29.0*	*2.2*	*180.7*
Copper	*kg*	*0.1*	*3.6*	*29.0*	*15.3*	*6.4*	*2.4*	*56.8*

Figure 1 compares the embodied energy intensities (kBtu/$ industry output) of the industry sector manufacturing the study materials. Apparently, the energy intensity of aluminium was the highest (126 kBtu/$), particularly for electricity usage (91 kBtu/$), which is in agreement with the literature opinion. The second most energy intensive material was lime (112 kBtu/$).

Materials with mostly heating dominated manufacturing processes such as glass (31 kBtu/$), lime (31 kBtu/$), and brick (23 kBtu/$) demonstrated higher natural gas consumption per $ of industry output. Similarly, materials such as cement (36 kBtu/$), lime (27 kBtu/$), and steel (16 kBtu/$) involve a production process that showed a higher coal consumption. The production processes of materials such as paints, adhesives, and plastics consume a significant amount of petroleum products as raw material (feed stock), which was evident in their higher petroleum intensity. The most labor and capital intensive material was lime that consumed 4 kBtu of labor and capital energy per $ of its output. Note that the embodied energy per unit of mass or volume for each of the study material would be quite different than energy intensities due to different product prizes.

The embodied energy results (Table 1) were compared with comparable studies. Figure 2 presents a scatter chart illustrating the correlation of the calculated and published values. A coefficient of determination (r^2) of 0.72 indicates a high positive correlation. It means that the calculated values may be different than the published values but the pattern of change across the study materials is in agreement. A difference in the magnitude of calculated and published embodied energy values is expected due to a wider system boundary covered by the IOH model used in this study.

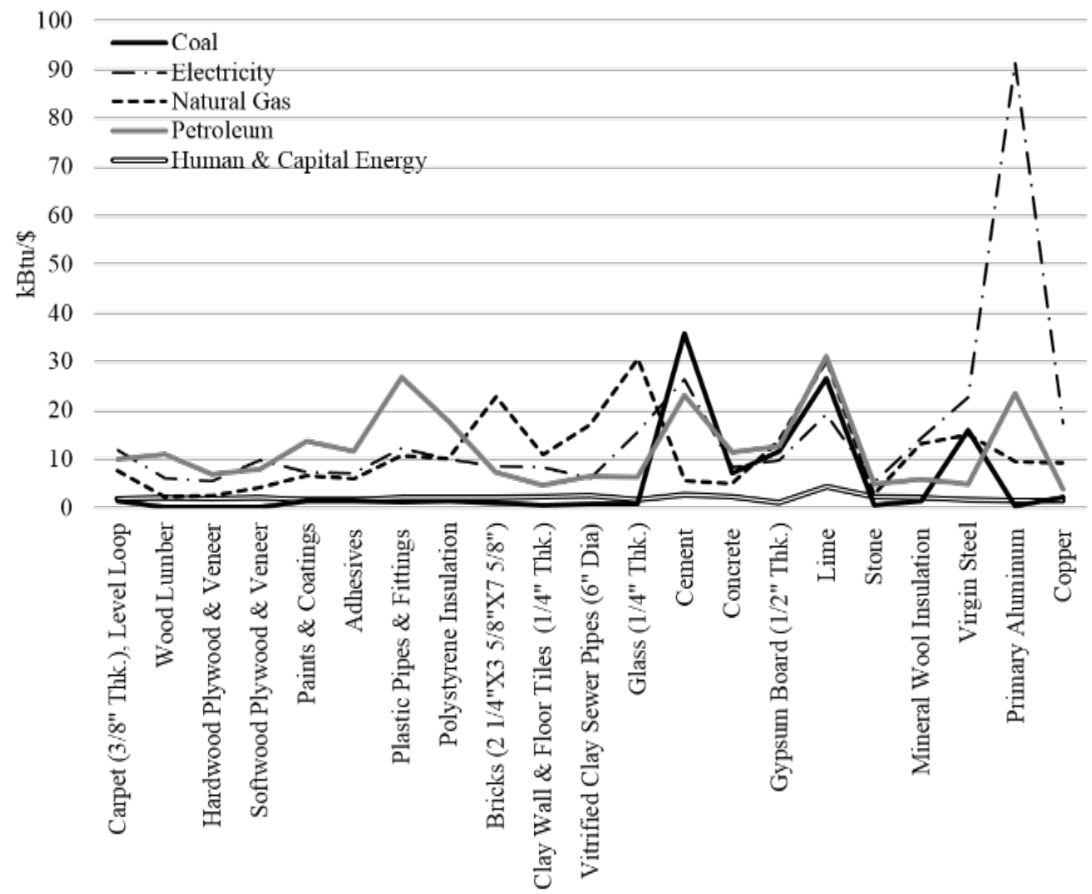

Figure 1: Embodied energy intensities of industry sectors producing study materials

4.1 A BIM-Embodied Energy API Framework

The IOH-based values calculated in this study can be integrated into a BIM authoring tool such as Autodesk Revit Architecture. There are two approaches to BIM-embodied energy integration. In the first approach, embodied energy of construction materials can be manually inserted into Autodesk Revit Architecture using a shared parameter. A shared parameter can be shared across projects within the same organization. As an example, a shared embodied energy and embodied carbon parameter was created in Autodesk Revit Architecture to integrate embodied energy and carbon emission values. The shared parameter then can be converted into a project parameter attached to the Materials category in a Revit project. Using custom parameter option, the values of embodied energy and carbon can be inserted into the Revit material library. Figure 3 shows a generic Revit project with concrete columns, beams, and slabs. The schedule on the left provides the embodied energy schedule of structural columns. Using the same process the total embodied energy of the entire project can be calculated. In the second approach, an Application Programming Interface (API) is developed to access the shared parameter of embodied energy associated with each material in Revit Material Library. Figure 4 demonstrates a framework for a BIM-embodied energy API. An API gets a required parameter (e.g. embodied energy) from a Revit project and finds the right value from a spreadsheet. It also sets the new value to that parameter and returns it to the Revit project. The API is developed using the C-sharp programming language. The spreadsheet includes embodied energy and carbon dioxide emission values for commonly used construction materials.

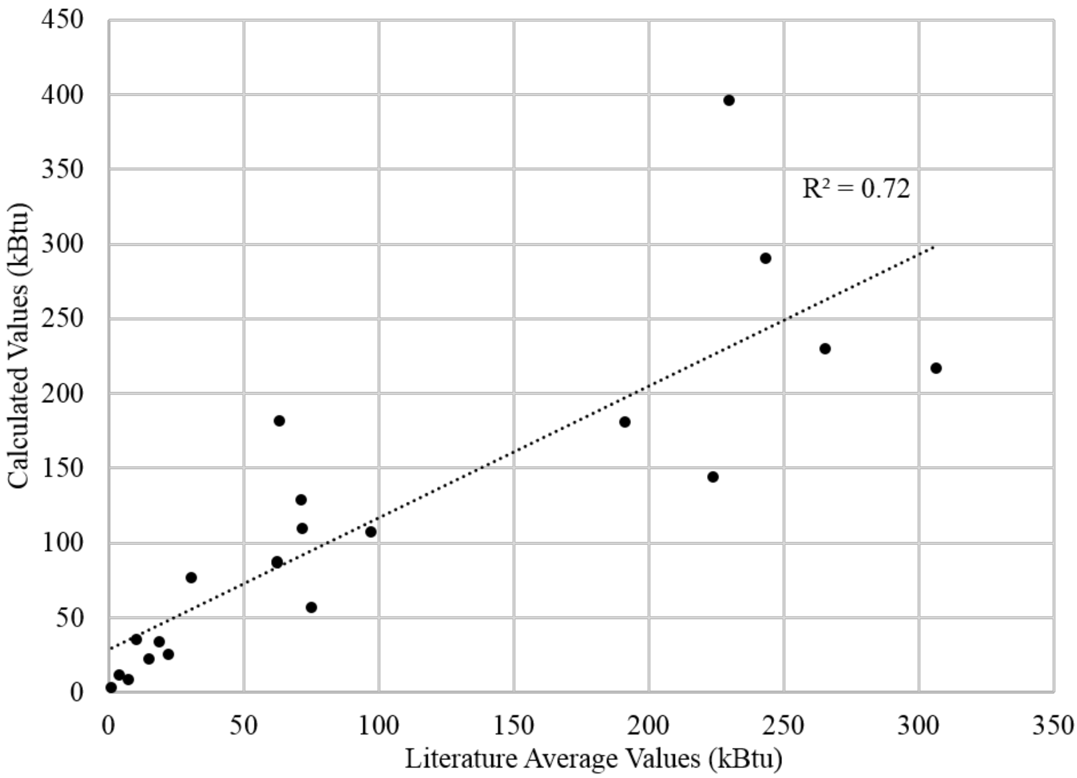

Figure 2: Correlation of the calculated and published embodied energy values

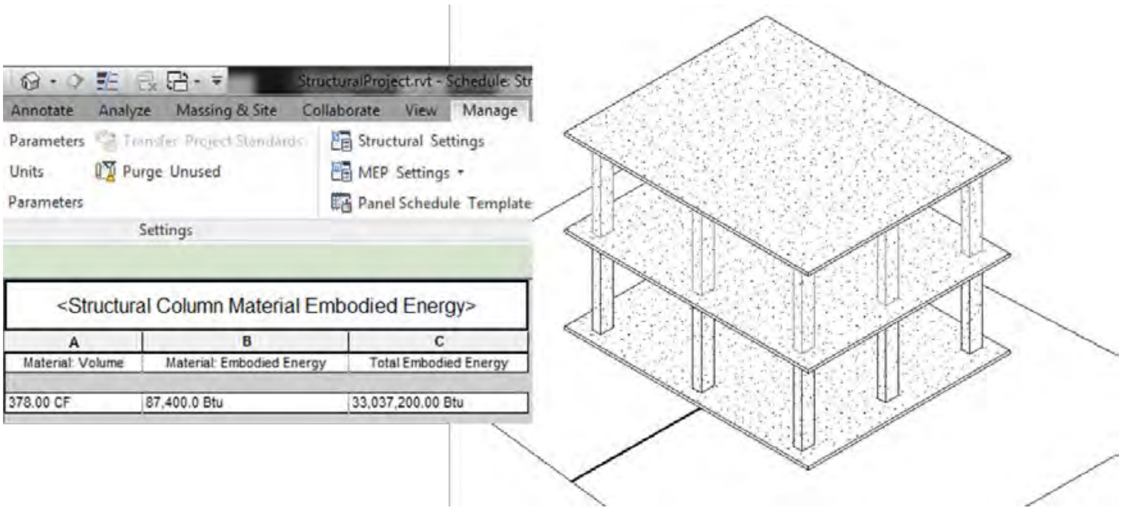

Figure 3: An example of shared parameter being used to pass along embodied energy values

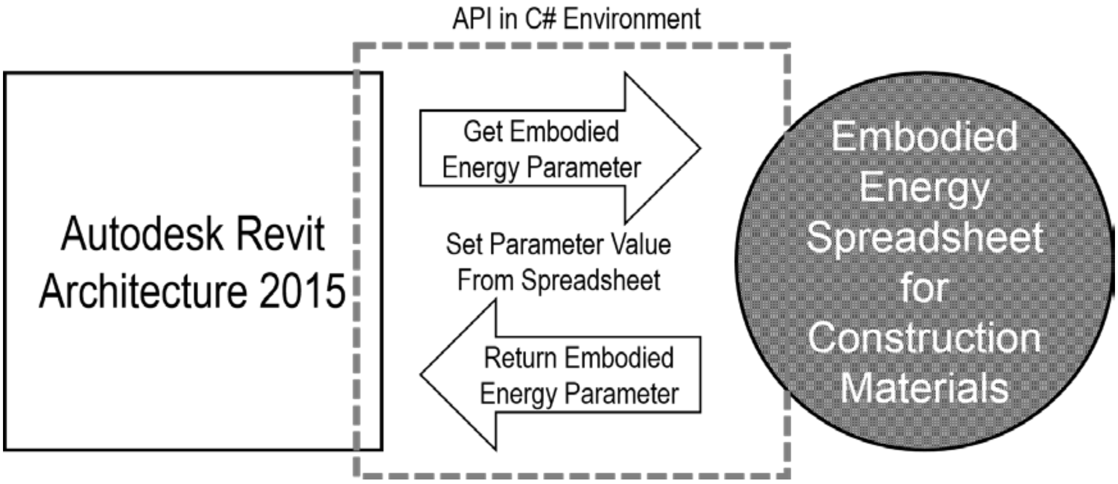

Figure 4: A schematic illustration of API development process

5. Conclusions

This study demonstrates an embodied energy calculation using an improved IOH method to provide more complete and accurate material-specific embodied energy values. Because the fuel or energy source-specific embodied energy is calculated, the calculated energy values can be translated into carbon dioxide emissions more accurately than using an average embodied energy value aggregated for all energy sources. Although the calculated values differed significantly from published values in their magnitude, they were in agreement with the published values when compared using the correlation analysis. Note that system boundary differences across this study and other referred studies would cause embodied energy values to vary. A framework for integrating embodied energy and carbon dioxide values into a BIM authoring tool is also proposed and discussed. One of the key challenges to creating and evaluating a net-zero/carbon neutral building design is the lack of a single integrated tool to assess the life cycle energy and carbon impacts. The author of this study in collaboration with other researchers have already developed two Revit APIs for computing operating energy use and renewable energy generation (see Dixit and Yan, 2012 and Yan et al., 2013). The future research goal is to integrate embodied energy analysis into a BIM-integrated operating and renewable energy assessment tool. Such a tool is expected to simplify the time and resource consuming net-energy analysis process, which currently involves creating separate models and switching back and forth among renewable energy, operating energy, and embodied energy tools.

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An Input-Output-based Hybrid Recurrent Embodied Energy Calculation Model for Commercial Facilities

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Abstract

Built facilities consume a significant amount of energy during their service life contributing considerably to carbon emission. In the United States, buildings alone consume 40% of annual energy causing at least 39% of total annual carbon emission. The total energy consumed by built facilities includes operating and embodied energy. The amount of energy used in the processes of air-conditioning, heating, hot water supply, lighting, and operating building equipment is called operating energy. The embodied energy is used in constructing, maintaining, and deconstructing the facility. A significant portion of the embodied energy comes from construction processes and building materials used during a facility's maintenance and replacement processes. This portion of embodied energy is called recurrent embodied energy. Because the field of facility management involves decisions regarding a facility's operational, maintenance, and replacement performance; it can help reduce both the embodied and operating energy and consequently the life cycle carbon footprint of the facility.

One of the commonly used embodied energy calculation methods is the input-output-based hybrid method, which provides embodied energy intensities per unit of an industry sector's output (in $). The embodied energy intensities of an industry sector representing maintenance and replacement activities can be integrated into a life cycle cost model to compute the recurrent embodied energy of a facility's maintenance and replacement phases. In this paper, a model is proposed to calculate the recurrent embodied energy of a commercial facility. The model is developed based on the United States input-output accounts. The calculated embodied energy values are used to compute carbon emission due to maintenance and replacement activities. The results are discussed and compared with the published studies from literature. Finally, a discussion on the involvement of facility managers during the facility design and construction phases is presented.

Keywords: Embodied energy, recurrent embodied energy, facility management, life cycle energy, life cycle cost model

1. Introduction

Built facilities, in the United States, consume nearly 40% of nation's energy in their operation alone adding nearly 39% of the annual carbon emission (Dixit et al., 2013). If the energy consumed in building construction is added, this percentage may reach 48% of the total national energy supply (Baum, 2007). For a comprehensive and effective reduction in this vast energy and carbon footprint of built facilities, the energy consumed in both the facility construction and its operation and maintenance must be optimized (Bassett et al., 2013). So far, studies have had a unidirectional focus on either the energy of construction or operation (Dixit et al., 2013). However, a need to address total life cycle energy has been strongly emphasized in the relevant literature (Fischer, 2010). A built facility consumes two types of energy over its service life: (1) embodied and (2) operating energy. The embodied energy is consumed in constructing a facility directly through construction, transportation, and related processes. It is also consumed indirectly through the use of construction materials and equipment. Each material or equipment installed in a building consumes energy when it is manufactured and delivered to a construction site. This energy is called its embodied energy (Treloar et al., 2001). The total energy directly and indirectly consumed in a facility's construction is called its initial embodied energy (IEE) (Cole and Kernan, 1996; Dixit et al., 2015). Once constructed and occupied, the facility is operated consuming operating energy. When occupied, the facility is maintained, repaired, and its components are replaced. These processes of maintenance, repair, and replacement consume construction materials and require related processes. The sum of total energy consumed directly and indirectly in these maintenance and replacement processes is called recurrent embodied energy (REE) (Cole and Kernan, 1996; Langston and Langston, 2007).

Unlike IEE, REE is consumed annually and depends largely on a facility's service life (Dixit et al., 2014a and 2014b). This means that the longer the service life of a facility the higher it's REE. In a study of commercial facilities, Dixit et al (2014a) found a very strong and positive correlation between the total REE and the total life cycle embodied energy (LCEE). This strong and positive correlation suggests a strong influence of REE over LCEE. Literature has also indicated that the amount of REE embodied in a facility can constitute a significant portion of the total life cycle embodied energy. For instance, in a study of secondary schools in Australia, Ding (2007) found that the total REE over a 60-year service life can be equal to approximately 72% of the school buildings' total LCEE. Similarly, Cole (1996) determined that for a service life of 25, 50, and 100 years, the REE of these components was 1.3, 3.2, and 7.3 times their IEE, respectively. A strong influence of REE on a facility's LCEE also suggests its importance in optimizing the life cycle carbon footprint of the facility. Dixit et al. (2014a) concluded that by selecting low-embodied energy, durable, and long-service life materials, a facility's total REE can be optimized. Because a majority of maintenance and replacement decisions are made by facility managers, their role in reducing the energy and carbon footprint of facilities could be very important. According to Dixit et al (2014a) and (2015), the field of facility management can influence approximately 10% of the United States' annual carbon emission through REE.

Calculating a facility's operating energy is more straightforward than its LCEE due to a lack of a standard calculation method (Ristimaki et al., 2013; Dixit et al., 2015). Among widely-used embodied energy calculation methods are: (1) process-based method, (2) input-output (IO)-based method, and (3) hybrid methods (Dixit et al., 2012; Ristimaki et al., 2013). Each of these methods cover different extents of system boundaries. A system boundary defines the embodied energy inputs covered by a calculation method (Dixit et al., 2013). Most of the existing versions of the calculation methods do not provide complete, accurate, or reliable embodied energy calculation (Acquaye, 2010). For instance, a process-based method is accurate but is considered incomplete, whereas an IO-based method is unreliable but is regarded as complete. Hybrid methods combine the benefits of the two methods (Crawford, 2004). One of the hybrid methods is the IO-based hybrid (IOH) method, which utilizes the national input-output data (Acquaye, 2010). The output of this method is in the units of energy usage/$ output of an industry sector (e.g. MJ/$). Although an IOH method is considered to provide most complete results, it also requires improvements as suggested by the literature (Acquaye, 2010; Dixit et al., 2015).

In this paper, an IOH model is developed and improved for the United States' industry sectors to compute the IOH intensity of an industry sector involved in the maintenance and replacement activities of non-residential facilities. Using life cycle cost data and IOH intensity, the REE of 88 healthcare facilities is quantified and evaluated.

2. Literature Review

2.1 Embodied Energy Model for Built Facilities

The total Life cycle embodied energy (LCEE) of a facility constitutes its initial (IEE), recurrent (REE), and demolition embodied energy (DE). As shown in Figure 1, the IEE covers the energy embodied in construction materials and processes used in the initial construction of a facility. IEE also includes the energy embodied in various equipment installed in the facility and other processes such as transportation, administration, and consultancy services. After the facility is built, occupied, and used, the activities of maintenance and replacement consume energy and also nonenergy inputs such as building materials, assemblies, and equipment. Also, if any part of the facility is refurbished or a system is retrofitted, energy and non-energy inputs are consumed. Sum of the energy spent directly and indirectly in the use phase maintenance and replacement activities is termed REE (Cole and Kernan, 1996). Because the maintenance and replacement works occur periodically, the amount of REE depends primarily on the facility's service life. It also depends on its materials, assemblies, and systems. For instance, materials or systems with lower embodied energy and replacement ratio (long service life) would result in lower REE. REE also depends on the maintenance requirements of products used in the facility (Winistorfer et al., 2005; Dixit et al., 2014b). Similar to the construction phase, the maintenance and replacement activities require resources such as building materials, labor, and equipment (Dixit et al., 2014a). The processes of construction (e.g. repair), transportation, and management are also needed at this stage. The sum of energy directly and indirectly required to demolish the facility and haul its materials for recycling, reuse, or disposal is called its DE (Cole and Kernan, 1996).

2.2 Embodied Energy Calculation: Major Issues

A process-based calculation, a bottom up approach, utilizes the process-based embodied energy data of construction materials and construction and other related processes (Crawford, 2004; Dixit et al., 2015). An embodied energy database of construction materials with robust data quality, therefore, becomes extremely important in a process-based analysis. Most process-based data comes from material manufacturers and, therefore, considered reliable. However, due to unavailability or confidentiality not all data can be sourced. Apparently, most process-based data may be regarded as incomplete (Ding, 2004; Crawford, 2004). Unlike process-based analysis, an IO-based analysis is a top down approach in which the embodied energy of an entire industry sector is quantified (Crawford, 2004; Dixit et al., 2015). The basic assumption in an IO-based approach is that all of the products manufactured by the industry sector have the same embodied energy intensity per monetary unit of their output. Because all monetary transactions by an industry sector can be traced and translated into energy flows using energy tariffs, IO-based data are considered complete (Dixit et al., 2015). However, due to aggregated output of the industry sector, the results are not specific to a product (Crawford, 2004). Additionally, the unreliability of energy tariffs induces a potential for under estimation or over estimation of embodied energy (Acquaye, 2010). Other issues such as homogeneity and proportionality assumptions also contribute to the unreliability of IO-based results (Crawford, 2004; Dixit et al., 2015). Because none of the two methods is perfect, a hybrid method combines the two methods to improve the quality of embodied energy calculation. Two types of hybrid methods are available: (1) process-based hybrid and (2) IO-based hybrid (IOH). In a process-based hybrid approach, the void of unavailable data is filled by integrating IO data, whereas process-based data are incorporated into an IO model to improve the reliability of calculation in an IOH method (Crawford, 2004).

Although both the hybrid approaches can be further improved, enhancing the reliability and specificity of an IOH method is more straightforward. Studies such as Treloar (1998), and Crawford (2004) improved the current form of the IOH method. In spite of these advances, studies (Crawford, 2004; Acquaye, 2010) suggested further improvements to its system boundary completeness, accuracy, and specificity. A potential incompleteness arises from the energy embodied in labor and capital investment, which may not be included in IO accounts (Dixit, 2015). Additionally, to make the IOH results more material-specific, an industry sector can be decomposed into two sectors using the sector's input and output data (Dixit et al., 2015). Furthermore, if the actual energy usage of all industry sectors of IO accounts can be determined, it can be integrated into the IO model to circumvent the use of unreliable energy tariffs. Treloar (1998), Acquaye (2012), and Dixit et al. (2014 and 2015) also discussed the potential of counting energy inputs multiple times in an IOH method, and suggested using primary energy factors (PEFs) to address this issue.

2.3 Recurrent Embodied Energy

The REE of a facility is consumed primarily in two types of activities: maintenance and replacement. A facility's systems and components may not possess the same service life as the facility, and may require one or multiple replacements over its service life (Winistorfer et al., 2005). These replacements involve material use and construction processes, which contributes to the total REE of the facility (Ding, 2007). In the case of facility maintenance, two types of maintenance activities are common: scheduled and unscheduled. Over 50 years of service life, a facility's REE could be equal its IEE (Cole, 1996). In a study of secondary school facilities in Australia, Ding (2007) found that the REE, over a 60-year service life, was 72% of the school facilities' total LCEE. Building components such as envelope, finishes, and services, which may not contain higher initial embodied energy, require a significant amount of REE (3.2 times the initial embodied energy in a 50-year service life) (Cole, 1996). Likewise, Cole (1996) determined that for a service life of 25, 50, and 100 years, the REE of these components was 1.3, 3.2, and 7.3 times their IEE, respectively. Treloar et al. (2000) and Adalberth (1997) also calculated REE as 45% (50-year service life) and 32% (30-year service life) of IEE, respectively. Pullen (2000) calculated an annual REE of 1% of the total IEE of a facility. This % value agrees with the values calculated by Adalberth (1997b) and Treloar et al. (2000).

2.4 Facility Management and REE

The management of facilities involve decisions regarding maintenance and replacement, which can affect their energy and carbon footprint significantly (Elmualim et al., 2010; Dixit et al., 2014b). The maintenance, repair, and replacement activities consume significant REE directly in construction, transportation, and administration processes and indirectly through the use of construction materials and equipment (Brown and pit, 2001; Dixit et al., 2014b). With an effective maintenance and replacement program, the amount of REE can be significantly optimized by selecting low-embodied energy, locally available, and durable materials or products with a longer service life. Materials with high reuse and recycling potential would also contribute to REE savings (Dixit et al., 2014a). Additionally, facility managers are involved in the operation of building systems such as air-conditioning, heating, lighting, etc., which consume a majority of a facility's total operating energy. With an effective facility management strategy, this operating energy usage can be considerably optimized (Brown and pit, 2001; Elmualim et al., 2010). In a study focused on commercial facilities, Dixit et al. (2014) concluded that approximately 90% of a facility's total life cycle embodied and operating energy can be influenced by facility management decisions.

3. Research Goal and Methods

The main goal of this paper is to develop an improved IOH model for computing the REE of commercial facilities in the United States. The calculated values of REE were quantified with a break up of different energy sources used in the United States. Using the fuel-specific carbon emission factors, the carbon embodied in commercial facilities was calculated. For comparative evaluation, the results were compared with those published in relevant literature.

The process of IOH model development was completed in four steps. First, an input-output (IO) model was developed using the detailed Benchmark Input-Output Accounts published by the United States. The model comprised of a direct requirement and a total requirement matrix of commodities manufactured and used in the United States. Next, to create an IOH model, actual energy consumption by each industry sector (process data) of the IO model was collected, refined, and integrated into the model. Integrating process data of energy use avoided the use of unreliable energy tariffs to translate energy flows from monetary to physical units and enhanced the reliability of the model. In the third step, the energy embodied in labor and capital inputs was quantified and integrated into the model to improve its system boundary completeness. To address the issue of energy double counting, a set of Primary Energy Factors (PEFs) were calculated for five energy sources: (1) electricity, (2) natural gas, (3) petroleum; (4) coal, and (5) crude oil and natural gas. Finally, using the PEFs, the embodied energy intensity of the industry sector involved in maintenance, repair, and replacement activities (NAICS 230201, Nonresidential Maintenance and Repair) was computed. A more detailed explanation of the IOH model and PEF calculation can be found in Dixit et al (2015) and Dixit et al (2014c), respectively. The embodied energy intensity resulted from the IOH model was in the units of MJ/$ output of the industry sector. By multiplying the maintenance and replacement costs and the embodied energy intensity, the total REE of facilities under study was calculated.

3.1 Case Study Facilities

This paper sourced total maintenance cost, current replacement value (CRV), and gross exterior floor area data of 88 healthcare facilities in North America from the Operations and Maintenance Benchmarks Survey for Healthcare Facilities (IFMA, 2009). Most of the facilities were acute care hospitals. Figure 1 illustrates a breakup of study facilities. Although survey included over 150 healthcare facilities, only 88 facilities available with all required data were used in the study. The age of the facilities were in the range of <5 years to >50 years. Because the survey did not provide replacement cost data on these facilities, standard replacement costs for hospital facilities published by the Whitestone Facility Maintenance and Repair Cost Reference was used (Whitestone Research, 2009). Using the three key life cycle data: maintenance cost, replacement cost, and CRV; this paper demonstrated the integration of embodied energy and life cycle cost model.

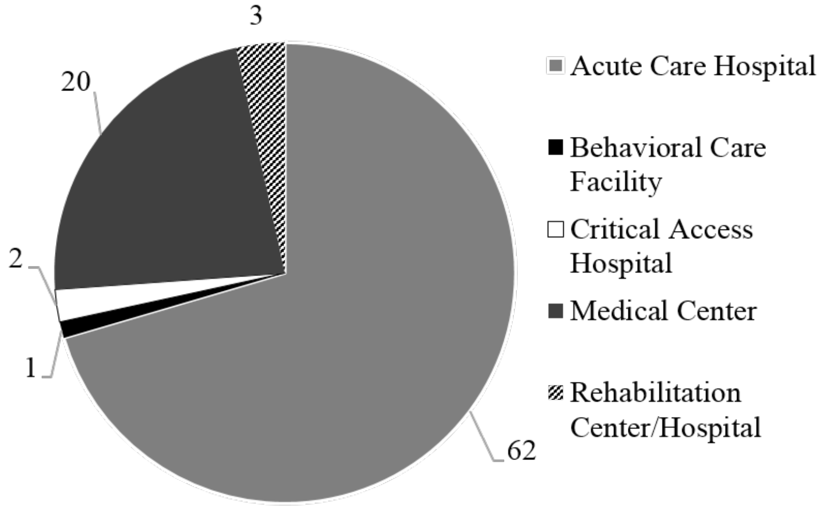

Figure 1: Types of healthcare facilities under study

4. Results

The total embodied energy intensity of the Nonresidential Maintenance and Repair sector was computed as 12.3 MJ/$ of the industry output. This value indicates that for each $ spent on maintenance, repair, or replacement activity, 12.3 MJ of total primary energy is consumed. Approximately 42% of this total energy (5.15 MJ/$) is directly consumed, whereas the remaining energy (7.15 MJ/$) is consumed indirectly through materials and related processes. Table 1 lists the embodied energy and embodied carbon intensities of the Nonresidential Maintenance and Repair sector for each energy source used by the industry sector.

Table 1: Calculated embodied energy and carbon intensity

Intensity of Industry Sector	*Energy Sources Used in the United States*					
	Coal	*Electricity*	*Natural Gas*	*Petroleum*	*Labor & Capital*	*Total*
Embodied Energy (MJ/$)	*0.48*	*2.85*	*1.66*	*5.64*	*1.67*	*12.30*
Embodied Carbon (kg/$)	*0.04*	*0.43*	*0.08*	*0.37*	*0.15*	*1.08*

Figure 2, on its secondary axis, illustrates the total annual REE calculated using the maintenance cost data sourced from the IFMA survey and the replacement cost referenced from the Whitestone Research. The primary axis shows the annual carbon dioxide emissions resulting from the REE consumption. The average annual REE per square meter of the floor area was approximately 1378 MJ resulting in around 11 kg/m^2 of average annual carbon emission. This is significant because when translated over a life cycle of 50 years, the total REE and carbon dioxide emission reaches 68.9 GJ and 560 kg per square meter of the gross exterior floor space, respectively.

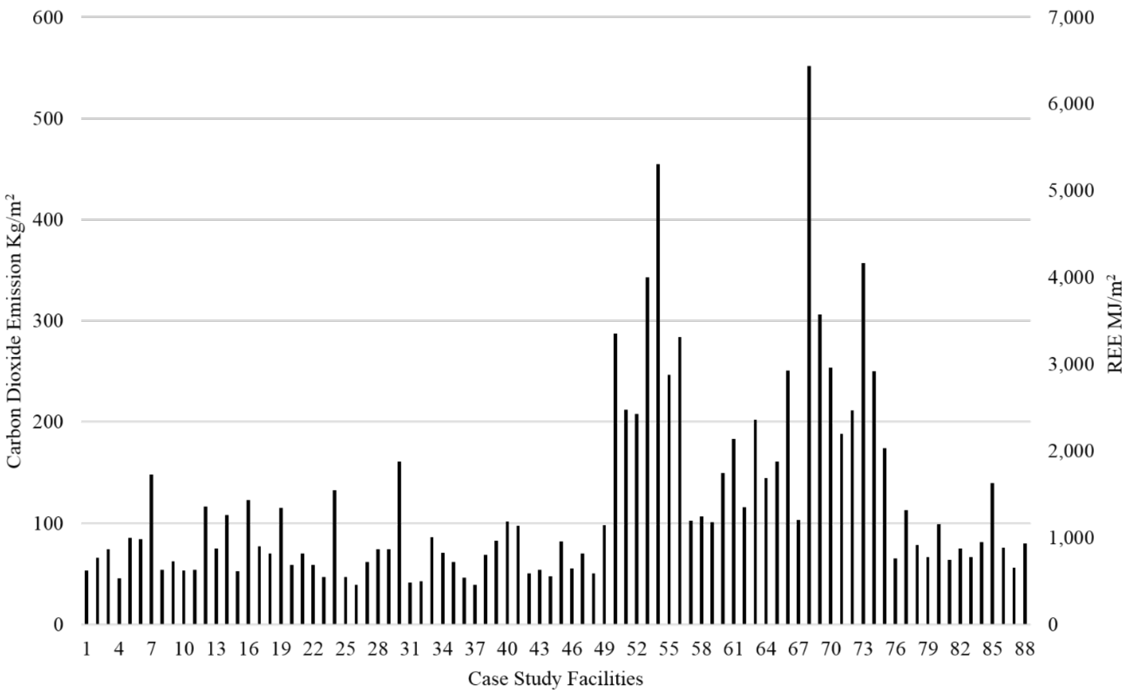

Figure 2: Total annual REE and carbon emission of case study facilities

When analysed by each REE component, the total REE of maintenance and replacement was computed as 950 MJ/m^2 and 428 MJ/m^2, respectively. Figure 3 shows the REE values associated with different maintenance and replacement components. The overall maintenance activities included the maintenance of building exterior, interior systems, roads and grounds, utility and central system, and process treatment and environmental systems. The total REE embodied in external maintenance activities was quantified as 21 MJ/m^2. All of the maintenance related to the facilities' envelope (roof, exterior walls, and ground slab) and exterior signage was included in the external maintenance. The interior system maintenance covered building interior elements (interior walls, doors, ceilings, partitions, finishes etc.), interior signage, and mechanical, plumbing, and electrical systems. The external and interior maintenance activities involved approximately 296 MJ/m^2 of REE.

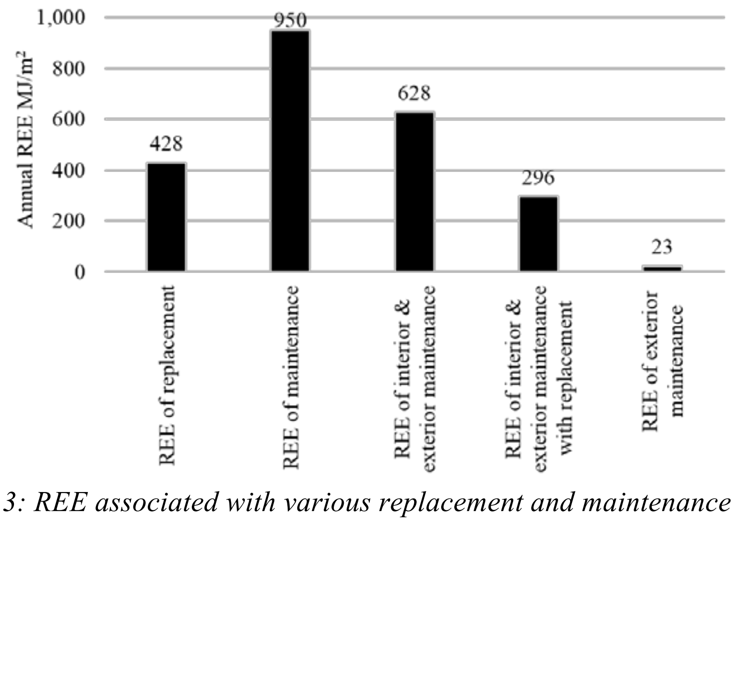

Figure 3: REE associated with various replacement and maintenance components

The calculated values of REE were also compared with those published in related literature. Note that the system boundary differences across these published studies would cause the calculated REE values to vary significantly. Table 2 compares the results of this study with the ones referred from various studies. Because most studies had multiple case studies, there results are displayed under the categories of minimum, maximum, and average. When total REE is compared, the differences with published values were large. One of the reasons for these large differences may be the varying system boundary definitions. Table 2 also provides a brief description of what is included in the referred studies. Some of the larger REE values calculated by Treloar et al. (2001), Suzuki and Oka (1998), Langston and Langston (2007), and Treloar (1993) were due to a wider system boundary covering a majority of building elements. In this study, almost all of the maintenance and replacement expenditure was covered, which may be the primary reason for larger REE values.

Table 2: Calculated embodied energy and carbon intensity

Studies	***Annual REE (MJ/m²)***			
	Min.	***Max.***	***Average***	***System Boundary Inclusions***
Treloar, 1993	*219*	*219*	*219*	*Envelope & interior components*
Cole & Kernan, 1996	*85*	*103*	*94*	*Envelope, interior, site, services components*
Jaques, 1996	*89*	*89*	*89*	*Only few envelope, interior, services components*
Suzuki & Oka, 1998	*224*	*224*	*224*	*Most envelope, interior, services components*
Eaton et al., 1998	*147*	*153*	*150*	*Structure & HVAC*
Pullen, 2000	*202*	*202*	*202*	*Few envelope, interior, services components*
Treloar et al., 2001	*435*	*435*	*435*	*All envelope, interior, site, services components*
Scheuer, 2003	*88*	*88*	*88*	*Most envelope, interior, services components*
Junnila et al., 2006	*85*	*166*	*125.5*	*Most envelope, interior components*
Page, 2006	*37*	*61*	*49*	*Repainting & replacing some envelope & HVAC components*
Ding, 2007	*49*	*216*	*132.5*	*Envelope, interior, site, services components*
Langston & Langston, 2007	*160*	*262*	*211*	*Most envelope, interior, site, services components*
John et al., 2009	*30*	*73*	*51.5*	*Envelope & interior components*
Fernandez, 2008	*33*	*122*	*77.5*	*Only building maintenance*
Average			*147*	
This study, total REE including maintenance & replacement	*445*	*6307*	*3376*	*All exterior, interior, site, utilities, & other building systems*
This study, total REE of maintenance	*18*	*5879*	*2948*	
This study, total REE of ext. & int. maintenance	*11*	*1148*	*580*	
This study, total REE of ext. maintenance	*0.06*	*167*	*83*	

5. Discussion

The calculated values of REE and resulting carbon dioxide emissions highlight the significance of facility management practices in controlling this extensive energy and environmental footprint of commercial facilities as also discussed by Dixit et al. (2014a). In the United States, the Building Energy Data Book (2014) reported 81.1 billion square feet of commercial floor space in 2010 that is projected to reach 103 billion square feet by the end of 2035. Using the REE and carbon dioxide values calculated in this study, this total commercial floor space represents approximately 10% of the total annual energy consumption in the nation in 2010. When translated into carbon dioxide emissions, the total annual REE results in over 16% of the total annual carbon dioxide emissions. Because facility managers are involved in decision-making regarding maintenance, replacement, and material and product selection, their decisions can greatly impact the total annual energy usage and carbon dioxide emissions of the nation. With the commercial floor space reaching 103 billion square feet in 2035, this impact would be enormous. As discussed by Dixit et al. (2014b), facility managers can help optimize this energy and carbon footprint by selecting durable, long-service life, locally available materials with low embodied energy and high reuse and recycling contents. Durability and long service life would decrease the number of replacement over a facility's service life. Sourcing materials or products from local vendors and suppliers can help reduce transportation distances considerably, which eventually optimizes total REE. Materials or products with low embodied energy and high reuse and recycling potential can assist in recovering initial as well as recurrent embodied energy.

6. Conclusions

The IOH model developed in this paper represents significant improvement to the completeness and accuracy of the current version of an IOH method. The calculation and integration of the energy embodied in labor and capital good filled some incompleteness inherent in an IO-based method. Furthermore, avoiding the use of energy prices enhanced the reliability of the model and its results. Most studies calculated embodied energy as a single energy value, which may be less accurate in determining the resulting carbon emission. In this paper, the values of REE were computed with a breakup of various energy sources, which provided a more accurate calculation of carbon dioxide emissions. The error originating from energy double-counting was also eliminated by apply the approach suggested by Treloar (1998). In spite of these improvements, there remains some potential for further advancement. For instance, the industry sector used in this study represents all nonresidential facilities, which may include other nonbuilding facilities. A sectoral disaggregation process can be applied to decompose the aggregated industry sector to compute facility-specific REE values.

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Artificial Intelligence-Based Models Applied to the Service Life Prediction of Adhered Ceramic Claddings

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Abstract

In Mediterranean countries, ceramic tiles are one of the most common materials for cladding, with a high diversity of dimensions, colours and textures, allowing the execution of decorative panels, which enrich the building stock. Ceramic tiles are also an extremely durable material. Lisbon presents, in old quarters of the city, several examples that witness this durability, showing buildings with more than a hundred years with their ceramic decorative panels intact. However, in recent years, due to changes in the construction methods and the development of new building materials (whose durability is unknown), ceramic coatings present increasing degradation levels, with a wide incidence of defects during their life cycle. Thus, it seems relevant to develop studies focusing the durability and service life of ceramic claddings. In this study, artificial intelligence-based models are applied to the service life prediction of adhered ceramic claddings. For this purpose, 195 ceramic claddings systems (directly adhered to substrate) are analysed, through visual inspections of façades in real service conditions. Artificial intelligence-based models are able to compute reality, emulating the ability of the human mind to learn in an environment of uncertainty and imprecision. These models try to measure real-life concepts using mathematical equations. In this study, two artificial intelligence-based models are applied: artificial neural networks (ANNs) and fuzzy systems. ANNs can be seen as emulations of biological neural systems, and are able to learn through patterns of behaviour, generalizing and adapting to new situations (predicting the behaviour of new case studies). Fuzzy systems combine numerical accuracy with transparency in the form of linguistic rules, describing the relationship between variables by if-then rules. Computationally, artificial intelligence-based models can be described as universal function approximators, achieving better results than classical linear regression models. The results obtained reveal that the proposed models are able to describe and predict the service life of ceramic claddings.

Keywords: Ceramic claddings; Artificial intelligence-based models; Service life prediction.

1. Introduction

Artificial intelligence-based models are able to compute reality resembling to "the remarkable ability of the human mind to reason and learn in an environment of uncertainty and imprecision" (Zadeh, 1992). According to Hernández-Orallo et al. (2016), this concept is based on the anthropocentric confidence that intelligence underlies most human behaviour. Artificial neural networks and fuzzy logic-based models are the most common artificial intelligence-based models, also called as soft computing methods or computational intelligence, with several applications in the construction sector. Jang et al. (1997) refer that neural networks can recognize patterns and are able to adapt themselves to deal with changing environments whereas fuzzy logic systems are able to apply human knowledge in mathematical inference and in decision-making processes. However, the application of these methodologies to service life prediction of building façades is relatively recent (Silva et al., 2013; Vieira et al., 2014). The main advantage of these models is related with their capability of solving problems without a previous knowledge of the specific model, as is the case for the traditional statistical approaches (Krarti, 2003). This study proposes the application of computational intelligence-based models to the service life prediction of adhered ceramic claddings. For this purpose, 195 ceramic claddings systems (directly adhered to substrate) are analysed, based on visual inspections, which evaluate the degradation condition of façades in real service conditions. In this study, two comutational models are applied: artificial neural networks and fuzzy logic-based models. Artificial neural networks act as an emulation of biological neurons and have the capability of reasoning based on a set of degradation patterns, learning with this patterns even when subjected to an environment of uncertainty and imprecision. On the other hand, fuzzy logic systems are able to apply human knowledge in mathematical inference and in decision-making processes. Although these models are very complex, they lead to consistent and reliable results that can be applied in the optimization of maintenance strategies, reducing the environmental and economic costs of these claddings during their life cycle.

2. Evaluation of the degradation condition of ceramic claddings

Mediterranean countries haves a long tradition in the application of ceramic tiles as decorative panels and as building claddings. Ceramic tiles are considered a noble and durable material, with a great diversity of sizes, colours and textures, thus having a significant aesthetic potential when applied as external cladding. Ceramic tiles are also an extremely durable material. Lisbon presents, in old quarters of the city, several examples that witness this durability, showing buildings more than a hundred years old with their ceramic decorative panels intact. In Portugal, ceramic claddings correspond to a small percentage of the façades claddings (present in 5.5% of the buildings built between 1946 and 2001) (Flores-Colen et al., 2008) and their use is often associated with fashion trends. For this reason, the sample analysed (195 case studies) presents a wide range of construction periods and typologies, which starts in the twentieth century until the present day. In the sample analysed, there is a clear peak of using this type of cladding (in the period 1920-1949), which can be explained by socio-economic reasons (Bordalo et al., 2011).

In recent years, due to changes in the construction methods and the development of new building materials (whose durability is unknown), ceramic claddings present increasing degradation levels, with a wide incidence of defects during their life cycle. Furthermore, various authors (Zhi and Wei; 1997; Guan et al., 1997) refer that the most common defects are the result of poor workmanship in tile placement, namely due to poor surface preparation, the presence of voids between the tile and the adhesive, caused by the application of a very thin adhesive layer either by not complying with the adhesive opening time, or due to an inadequate tile setting pressure. In this study, the most common defects detected in ceramic claddings are grouped into four categories (Silvestre and Brito, 2009; Bordalo et al., 2011): i) visual defects - e.g. defects of a strictly aesthetic nature, not compromising the loss of performance of the cladding; ii) cracking - considering three types: glazing cracking (normally caused by the ageing of the tiles); cracking with no predominant direction (usually of superficial nature and affecting large portions of the cladding surface); markedly orientated cracking (usually local, deep and wide); iii) deterioration of the joints - which can jeopardize the performance of the entire cladding, since joints absorb the claddings' deformation and for ensuring the water-tightness of the system; iv) adhesion failure and/or detachment of ceramic claddings - which is the most serious defect, with dire consequences to the built environment and in the safety of users and owners.

To evaluate the overall degradation of ceramic claddings a quantitative index, proposed by Gaspar and Brito (2008), is applied, which expresses the global performance of the façades according to their physical and visual condition, previously assessed by the field work inspections. This quantitative index, called severity of degradation, is obtained through the ratio between the extent of the degradation of the façade, weighted as a function of the degradation level and the severity of the defects, and a reference area, equivalent to the maximum theoretical extent of the degradation for the façade under analysis - equation 1.

$$S_w = \frac{\Sigma\left(A_n \times k_n \times k_{a,n}\right)}{A \times k} \qquad (1)$$

Where S_w is the weighted severity of degradation of the façade (%); A_n is the area of coating affected by an defect, in m^2; k_n is the defect's nth multiplying factor, as a function of its condition (between 0 and 4); $k_{a,n}$ is the weighting coefficient corresponding to the relative importance of each defect based on the cost of repair ($k_{a,n} \in R^+$); k is the weighting factor equal to the highest degradation level in the façade; A is the total area of the cladding, in m^2. Since distinct defects detected in claddings have different levels of severity. The coefficient $k_{a,n}$ takes into account the relative importance of each defect, concerning their repair cost. The cost of repair is calculated as the ratio between the sum of the costs of each operation within the required intervention and the cost of replacing the cladding.

3. Application of artificial intelligence-based models to the service life prediction of ceramic claddings

The use of "intelligent" models - as fuzzy logic systems or artificial neural networks - has been implemented in several knowledge areas, aiming to modelling complex phenomena. In this study, these two approaches are used in the service life prediction models of adhered ceramic claddings.

The durability and the service life of this type of claddings are estimated, according to their age and to the most relevant parameters that explain the loss of performance of this type of claddings. According to a sensitivity analysis performed in this study, the variables with higher influence in ceramic claddings' degradation process are distance from the sea and tiles size. Yiu et al. (2007) refer that external environmental conditions are one of the major causes of degradation of ceramic tiling systems. Claddings exposed to marine environments are subjected to harmful salts that promote the presence of defects such as exfoliations or spalling (Lubelli et al., 2004). Concerning the tiles' size, a study performed by Medeiros (2002) shows that one of the most unfavourable conditions for detachment of tiles stems from the use of ceramic tiles greater than or equal to 20 cm in any direction. Thus, in this study, the tiles' size was categorized according to the lateral sizes of the tile; if at least one size is greater than 20 cm, then the cladding belongs to category "L ≥ 20 cm", otherwise the cladding belongs to category "L < 20 cm".

3.1 Artificial neural networks

ANNs are usually seen as emulations of biological neural systems (Rezeki et al., 2006), being inspired by the basic mechanisms of the human brain functioning, gathering information through a learning process (Kazanasmaz et al., 2009). Typically, ANNs comprise hundreds of simple processing units interconnected through a complex communication network (Lippmann, 1987). ANNs can be "trained" to solve difficult problems, which the numerical solutions are not easily achieved by other more conventional approaches. In this study, a multilayer perceptron model (MLP) is applied, using a back-propagation algorithm in the training sample. The MLP is used to develop an expression to estimate the severity of degradation of ceramic tiling systems. In all runs the global set of patterns is divided into two groups: training (85% of the sample - 166 case studies) and cross-validation (15% - 29 case studies). The sample used for cross-validation is also used to test the networks. To apply this model it is necessary to codify the categorical variables; the variables distance from the sea and size of the tiles have only two possible arbitrary "values" according to the data collected during the field work, which are: i) distance of the building from the sea - less than 5 km, value 1; otherwise, value -1; ii) tiles' size - less than 20 cm for at least one of the sides of the tile, value -1; otherwise, value 1. A 3-4-1 architecture is adopted and the 3 entries are: age of ceramic claddings, distance from the sea and tiles' size, and the output is degradation severity. The degradation severity (S_w) is a function of these variables, as seen in equations (2) and (3). Coefficients h_0 to h_4 and c_{0i} a c_{8i} are presented in Table 1.

$$S_w = h_0 + \sum_{i=1}^{4} h_i H_i \quad \textbf{(2)}$$

$$H_i = \tanh\left(c_{0i} + \sum_{n=1}^{3} c_{ni} V_n\right) \quad \textbf{(3)}$$

Where V_1 represents the age of the ceramic cladding, V_2 distance from the sea and V_3 tiles' size.

Table 1: Coefficients of the proposed formula

i	h_i (-)	$c_{,0i}$ (-)	$c_{,1i}$ (-)	$c_{,2i}$ (-)	$c_{,3i}$ (-)
0	2.39E-01				
1	2.58E-02	3.02E-01	3.06E-03	-4.74E-01	3.74E-01
2	9.01E-02	-9.66E-01	2.86E-02	4.72E-01	-3.41E-01
3	1.61E-01	-5.20E+00	1.01E-01	1.62E-01	5.83E-01
4	-7.39E-02	4.15E-01	-7.53E-03	1.69E-01	-2.45E-01

3.2 Fuzzy logic systems

Conventional computational models tend to deal with reality in a binary form, restricting it to only two hypothesis, as “0 / 1”, “yes / no”, “true / false”. These models are therefore unable to deal with ambiguous variables (Mukaidono, 2001). However, the available knowledge about a given reality can be neither absolutely true nor absolutely false and can be sometimes inaccurate, imprecise, incomplete or even unrealistic (Klir and Yuan, 1995). In fact, as stated by Zadeh (1973), the human reasoning is not based on a traditional two value logic but uses instead fuzzy truths and fuzzy rules of inference. According to Rajasekaran et al. (2011), fuzzy logic is one of the modelling techniques most widely used in artificial intelligence and the models produced are based on four basic concepts: i) fuzzy sets; ii) linguistic variables; ii) possibility distributions; and iv) fuzzy IF–THEN rules. In this work, Takagi-Sugeno (TS) fuzzy models are used (Takagi and Sugeno, 1985), which consist of fuzzy rules where each rule describes a local input-output relationship. Furthermore, a fuzzy C-means (FCM) is applied as clustering algorithm.

Concerning the application of fuzzy systems to the 195 ceramic claddings studied, 85% (166 cases) of the sample are used in the model training and 15% (29 cases) as a test sample. The training and test samples are the same that were previously applied in the ANNs models, allowing a more precise comparison between the two proposed models. In the application of this model it is necessary to codify the categorical variables; in this case, the variables distance from the sea and size of the tiles have only two possible arbitrary “values”, which are: i) distance of the building from the sea - less than 5 km, value -1; otherwise, value 1; ii) tiles’ size - less than 20 cm for at least one of the sides of the tile, value 1; otherwise, value -1. The fuzzy rules describing the local input-output relation are presented in equations (5) and (6), with the three explanatory variables: age, size of the ceramic tiles and distance from the sea.

Rule 1: If u_1 is A_{11} and u_2 is A_{12} and u_3 is A_{13} and u_4 is A_{14} then:

$$y_1(k) = -2.59 \cdot 10^{-2} u_1 - 2.61 \cdot 10^{-2} u_2 + 6.34 \cdot 10^{-3} u_3 - 8.80 \cdot 10^{-2} \quad (5)$$

Rule 2: If u_1 is A_{21} and u_2 is A_{22} and u_3 is A_{23} and u_4 is A_{24} then:

$$y_2(k) = -8.05 \cdot 10^{-3} u_1 - 2.64 \cdot 10^{-3} u_2 + 2.43 \cdot 10^{-3} u_3 - 2.87 \cdot 10^{-3} \quad (6)$$

Where u_1 represents distance from the sea, u_2 size of the ceramic tiles and u_3 age of the buildings. The antecedent fuzzy sets are represented by A_{ij}, where i is the number of the rule and j represents the various variables analysed. In other words, the one-dimensional fuzzy sets A_{ij} are obtained from the multidimensional fuzzy sets defined point-wise in the i^{th} row of the partition matrix by projections onto the space of the input variables x_j.The model output, S_w (severity of degradation of ceramic claddings), is computed by aggregating the individual rules contribution - equation (7).

$$S_w = \frac{\sum_{i=1}^{C} \beta_i f_i(x)}{\sum_{i=1}^{C} \beta_i} \tag{7}$$

In Takagi-Sugeno fuzzy models the discriminant function $f_i(x)$ is defined as shown in equations (5) and (6). The number of rules C, the antecedent fuzzy sets A_{ij}, and the consequent parameters a_i and b_i are determined by means of fuzzy clustering in the product space of the input and output variables. β_i represents the degree of activation of the i^{th} rule.

Figure 1 shows the membership functions for each of the three input variables included in the fuzzy model applied to ceramic tiling systems. The analysis of the variables included in the model reveals that the clustering clearly divides the data between newer and older buildings. In the remaining variables, distance from the sea and size of the ceramic tiles, all the categories give the same contribution to the output of the rules number one and two.

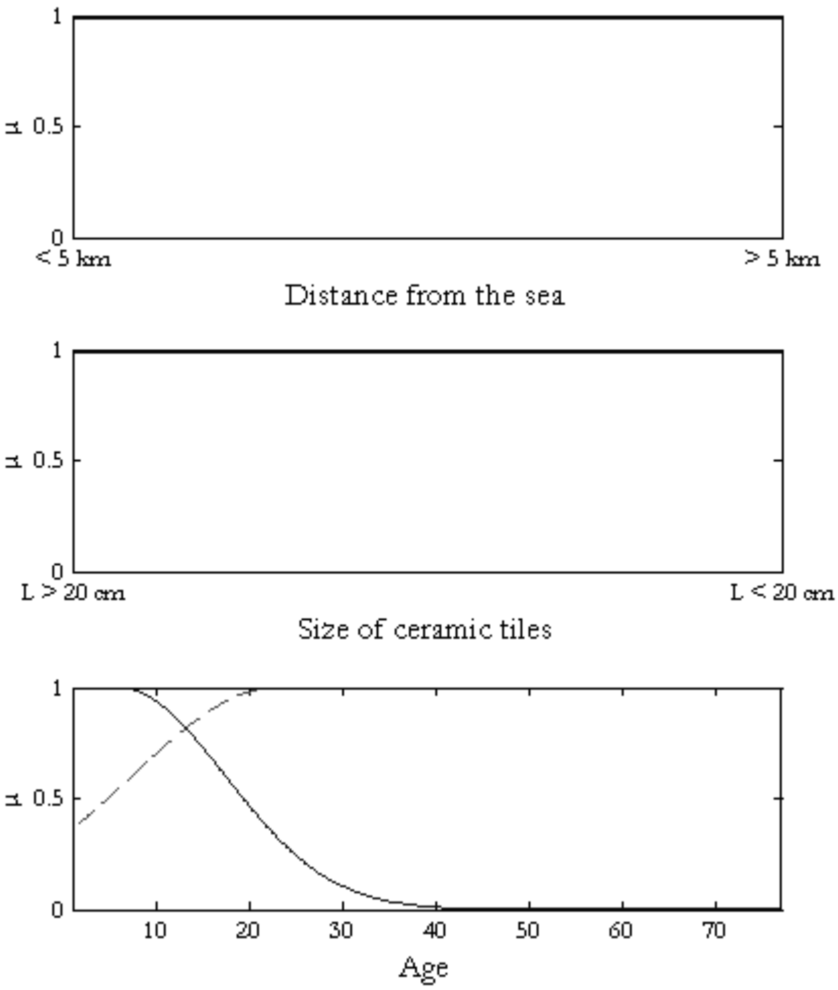

Figure 1: Membership functions for the fuzzy model proposed for ceramic tiling systems

4. Discussion

Table 2 presents some statistical indicators related to the accuracy of the proposed models. Both models present high accuracy levels with a Pearson correlation coefficient of 0.88 and 0.93 for ANNs and fuzzy logic models, respectively, which reveals a very strong correlation between the predicted and the observed values. Furthermore, the models have an MAPE (mean absolute percentage error, which is a statistical measure usually used for evaluating the performance of predictive models) lower than 10%, thus showing a potentially very good predictive capacity. Likewise, the percentage of patterns with APE (absolute percentage error) greater than x = 10%, x = 20%, and x = 30% is analysed, concluding that the errors of the models are relatively low, considering the complexity of the degradation phenomena of ceramic tiling systems.

Table 2: Statistical indicators used to evaluate the accuracy of the proposed models

Model	*r*	MAPE	APE > 10%	APE > 20%	APE > 30%
ANNs	0.93	5.2%	17.2%	0%	0%
Fuzzy systems	0.88	7.4%	31.0%	0%	0%

The proposed models lead to coherent and physical credible results. Figures 2 and 3 show the cumulative distribution function of the estimated service life values obtained by ANNs and fuzzy logic models, respectively.

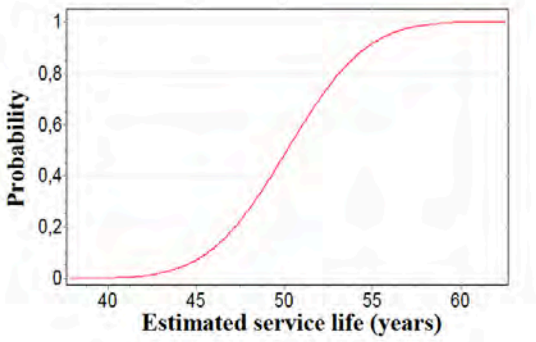

Figure 2: Cumulative distribution function of the estimated service life obtained by ANNs

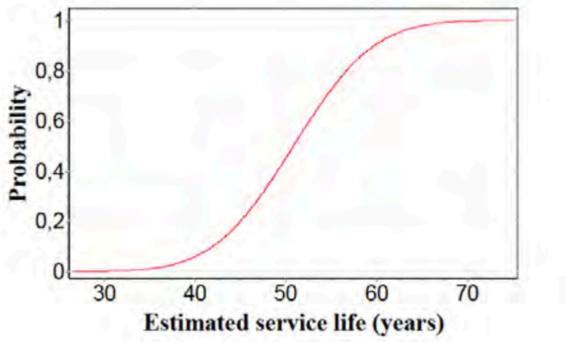

Figure 3: Cumulative distribution function of the estimated service life obtained by fuzzy model

From the application of the ANNs model an average estimated service life of 50.2 years is obtained, with a standard deviation of 3.52 years. From the analysis of the results presented in Figure 2, it is possible to conclude that an ESL of 44 years has a probability higher than 95% of being exceeded and an ESL of 56 years presents a probability higher than 5% of being exceeded. In this model, the estimated service life of ceramic claddings ranges between 39.8 and 53.5 years, with high prevalence of values between 50 and 55 years (86% of the sample). Using the Takagi-Sugeno fuzzy model, an average estimated service life of 50.8 years is obtained, with a standard deviation of 6.8 years. According to the results presented in Figure 3, an ESL of 39 years has a probability higher than 95% of being exceeded and an ESL of 62 years presents a probability higher than 5% of being exceeded. These results are in accordance with the values proposed in the literature; various authors (Tam et al., 1993; Galbusera et al., 2014) quantify the expected service life of external ceramic claddings as 50 years; the BMI (*Building Maintenance Information*) suggests an expected service life of 45 years for claddings using metallic elements for fixation (with a range of values between 25 and 55 years).

Figure 4 shows an analysis of the average estimated service life according to the variables included in the models applied to ceramic tiling systems. The results reveal that claddings located nearer the coast (< 5 km from the sea) are more prone to degradation, with lower estimated service lives (when the ceramic tiles have the same size). Smaller ceramic tiles (L < 20 cm) tend to deteriorate slower, having higher estimated service lives (for the same conditions concerning their proximity from the sea). The most favourable situation corresponds to a cladding located at more than 5 km from the sea and with smaller tiles (with an average ESL of 61 and 54 years according to fuzzy and ANNs models, respectively). The most harmful situation corresponds to façades in coastal areas with larger tiles (L ≥ 20 cm), with an average estimated service life of 45 and 40 years according to fuzzy and ANNs models, respectively. In intermediate situations, it is not possible to identify a clear degradation pattern, i.e. it is not clear which is the most influential variable, distance from the sea or tiles' size, in the degradation process of ceramic claddings. The results obtained by fuzzy model are usually more optimistic.

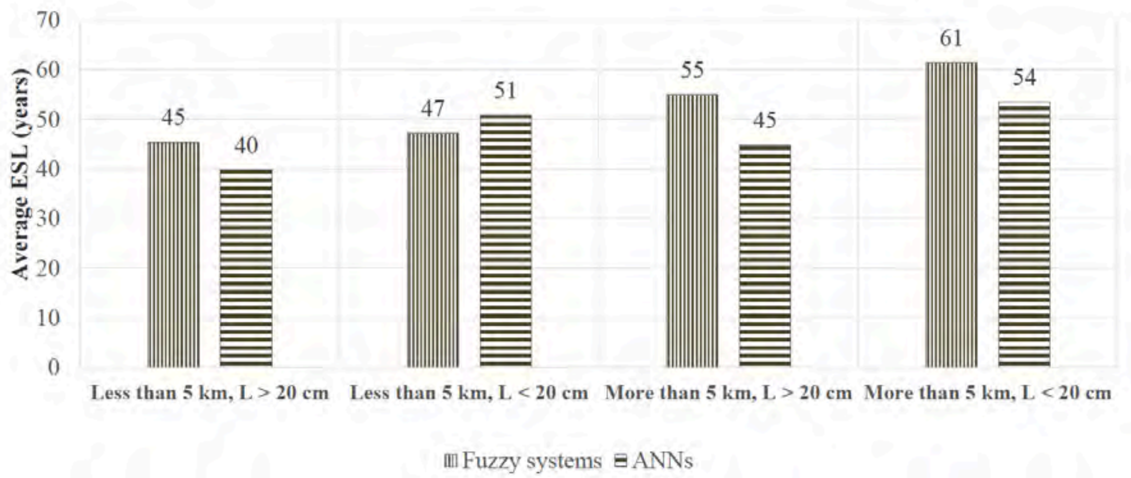

Figure 4: Analysis of the average estimated service life according to the variables included in the proposed models

Table 3 shows real examples (within the sample analysed) of the four possible combinations of the two variables included in the proposed models. As referred before, the results obtained by the ANNs and fuzzy logic models are close to field work data. These results are consistent and coherent with the empirical perception about the degradation phenomenon of ceramic tiling systems.

Table 3: Examples of the application of the proposed models to real case studies

Description of the case study		Observed values	Predicted values by ANNs	Predicted values by fuzzy logic model
	Ceramic cladding with 28 years, located at less than 5 km from the sea and with L < 20 cm.	**S_w = 7.7%** **ESL = 47.3 years**	S_w = 7.9% *ESL* = 50.8 years	S_w = 8.7% *ESL* = 47.4 years
	Ceramic cladding with 35 years, located at less than 5 km from the sea and with L ≥ 20 cm.	**S_w = 18.5%** **ESL = 36.6 years**	S_w = 13.8% *ESL* = 39.8 years	S_w = 18.3% *ESL* = 37.8 years
	Ceramic cladding with 34 years, located at more than 5 km from the sea and with L < 20 cm.	**S_w = 7.4%** **ESL = 55.7 years**	S_w = 6.4% *ESL* = 53.5 years	S_w = 7.5% *ESL* = 54.2 years
	Ceramic cladding with 42 years, located at more than 5 km from the sea and with L ≥ 20 cm.	**S_w = 15.8%** **ESL = 47.2 years**	S_w = 15.6% *ESL* = 44.8 years	S_w = 17.8% *ESL* = 45.6 years

5. Conclusions

In this study, the application of artificial intelligence-based models is analysed, namely artificial neural networks and fuzzy logic systems applied to the service life prediction of ceramic claddings. These methods seek to combine knowledge-based on human reasoning with mathematical inference, which may support decision-making processes, i.e. these approaches are able to learn from a set of behaviour patterns (in an uncertainty and imprecision environment), adapting to model and explain new cases and examples hitherto unknown to the model.

Artificial neural networks are able to acquire empirical knowledge from a set of learning data for a given problem. Therefore, these models is able to learn and generalize from experiences and examples (using for this a training sample), adapting to new situations. This is an extremely important capability because it allows solving complex problems whose analytical or numerical solutions are difficult to achieve by more conventional approaches. However, the models based on artificial neural networks are still regarded as “black box” models, since the model is defined using thousands of synaptic weights whose logic interpretation may be complex.

The fuzzy logic models are described in the literature as “grey box” models; the operation process is known, however, the results obtained depend on the sample used. Like the artificial neural networks, these models are able to learn and generalize based on experiments and examples. Furthermore, fuzzy logic models combine numerical precision with transparency in the form of linguistic rules. Fuzzy logic models can deal with the uncertainty associated with complex phenomena - such as degradation of construction elements - with higher precision and better performance than the classical linear models. In fact, fuzzy logic models are known to be able to effectively model inaccurate data, and even if the sample presents some outliers or influential points, these case studies do not contribute to bias the results. However, the complexity associated with such models can constrain their use in modelling the service life of ceramic claddings, since they can become difficult to understand by users who are not familiar with this type of mathematical approaches.

The proposed models react to data that are used in their definition (as any statistical or prediction model), being in principle more reliable and precise with the increase in the number of available data or by increasing the representativeness of the samples. Regardless of their benefits and limitations, artificial intelligence-based models are able to conveniently describe the degradation of ceramic claddings. In the case of artificial neural network models an estimated service life of 50 years is obtained and using the fuzzy logic systems an estimated service life of 51 years is obtained. These values seem realistic (in the same order of magnitude of the values present in the literature), with small deviations and errors. A high correlation between the observed values during the field work and the values predicted by the proposed models is also observed. Fuzzy logic models lead to the most optimistic results, but still reliable with regard to its physical sense. Finally, it should be noted that these models allow obtaining the estimated service life for each case study (within the test sample), making it possible to estimate the dispersion associated with the results obtained, as well as set histograms describing the behaviour of the data, that can be used to define probability distributions. This information is very useful in the definition of maintenance plans, giving information concerning the risk associated with the failure of ceramic claddings.

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Environmental Life Cycle Impacts of an Industrial Building in Finland

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Abstract

Buildings and construction activities account for a notable share of total energy consumption, greenhouse gas emissions, waste production and use of virgin materials over their life cycle in Finland and globally. Legislation and regulation concerning these issues is becoming stricter and the industry is also developing voluntary actions to tackle these problems. Life Cycle Assessment (LCA) is a tool that helps quantifying the environmental impacts over the whole building life cycle, without burden shifting.

The main objective of this research is to quantify the environmental impacts caused by an industrial building over its whole life cycle using process LCA. The results show, that the overall lifecycle greenhouse gas emissions - expressed in global warming potential - of the case study building reach 2.68E+07 kg CO_2 eq. 79 % of these are building operation related, and 21 % are embodied in construction materials. The results are in line with previous research assessing residential and office buildings.

LCA industry has developed multiple software tools that can be utilized to calculate environmental life cycle impacts of goods and services. The industrial case building material production impacts were calculated using three available LCA software tools, to find out whether the selection of the tool significantly affects the results. Even though the selected tools all use different database and have varying features and abilities, the results obtained are of the same magnitude for the whole building as well as the main building elements.

Keywords: Life Cycle Assessment (LCA), industrial building, environmental impacts, LCA tools

1. Introduction

1.1 Motivation for the Research

Sustainability related issues have gained more importance in the real estate and construction (REC) industry. In the European Union (EU) buildings account for 42 % of final energy consumption, 35 % of greenhouse gas (GHG) emissions, use of over 50 % of all extracted raw materials and 30 % of overall water consumption (European Commission, 2012). Legislation and regulation concerning these issues is becoming stricter and the industry is also developing voluntary actions to tackle these problems. The awareness of industry actors is rising when demand from clients and authorities for more sustainable solutions is becoming stronger (Malmqvist, et al., 2011).

Buildings are products with long service life over which they cause emissions and other waste flows into the environment (Junnila, 2004). Building life-cycle starts with extraction of raw materials and production of construction materials that are assembled together to form a building in the construction phase. After the building has been commissioned, the emissions extend over a long service-life, usually at least 50 years, over which substantive amount of energy is consumed in form of heat and electricity. Also other resources, like water and virgin materials required for building operation, maintenance and repairs are consumed continuously and waste is generated. The function of buildings might change several times requiring larger retrofits and hence even more resources. The end-of-life (EOL) phase continues to cause environmental impacts when the building is demolished and materials are processed and recycled, reused or disposed to landfills.

Environmental impacts, like GHG emissions that are contributing to climate change, are becoming more widely known and studied within the REC industry. Life Cycle Assessment (LCA) is a tool that enables quantification of environmental impacts generated during a product's life cycle from raw material extraction, production and use phase to end-of-life, like in a buildings' case, demolition (SFS-EN ISO 14040, 2006). One of the most important qualities of LCA is that so called burden shifts or trade-offs can be avoided when the whole product system is modelled and environmental impacts are assessed over the whole life cycle (Wolf, et al., 2012). Burden shifting means that improvements achieved in some part of a product system or at some stage of life cycle would bring about negative impacts in another part of the system or at another point in time.

When measured in gross floor area, industrial buildings cover approximately 11 % of the total Finnish building gross floor area making industrial buildings the second most important building type after residential buildings in Finland (Official Statistics of Finland, 2014). Several studies have been made where environmental life cycle impacts of buildings have been quantified and analysed. Most of these LCAs have been executed for residential buildings (Saari, 2001)(Blengini, 2009) (Ortiz-Rodriguez, et al., 2010) (Pasanen et al., 2011) (Passer et al., 2012) (Rossi, et al., 2012). There are also examples of studies analysing office buildings (Junnila, 2004) (Junnila, et al., 2006) (Wallhagen, et al., 2011) (Kofoworola & Gheewala, 2008) and public buildings (Chang, et al., 2012) (Scheuer, et al., 2003). Though environmental life cycle impacts of residential, office and public buildings have been studied rather widely, industrial buildings have so far not been addressed.

1.2 Scope of the Research and Used Methods and Materials

The main objective of this research is to quantify the environmental impacts caused by an industrial building over its whole life cycle. The results will be put in context of previous research to find out whether industrial buildings cause similar impacts as residential and office buildings. The material related embodied impacts are calculated using three different existing LCA software tools; SimaPro, 360Optimi and ILMARI. This is done in order to reveal possible difference in results and to find out why they might occur. This is important when new LCA tools are constantly being developed.

So to sum up, the aim of the study is to:

1. Quantify the environmental life cycle impacts of an industrial building in Finland;
2. See how the results settle in line with existing results obtained from studies assessing residential and office buildings;
3. Find out whether the impacts differ when calculated using different LCA software tools.

The empirical part of this research is a quantitative life cycle assessment of a case building. Cradle-to-grave process LCA is conducted for an industrial building using 360Optimi LCA software tool. The emissions caused by material manufacturing are also calculated using two other LCA tools: SimaPro and ILMARI. The obtained results are compared and reasons behind possible differences are analysed. All life-cycle stages from construction material production, building operation and maintenance to end-of-life are included in the case building LCA. Only the construction installation process on site is left outside the scope. The service life used in calculations is 60 years. The results are expressed in global warming potential (GWP) value in carbon equivalents.

Building elements that are included in the calculations include foundations, structural elements, building envelope, structural floors and ceilings, roof assemblies, structural wall assemblies, and interior non-bearing walls. Excluded items include all external site elements like paved areas, and site equipment, interior finishes as well as building service elements; plumbing, air conditioning, electrical, data transfer and mechanical elements and elevators. When assessing the operational life-cycle impacts, the studied building operations include space cooling and heating, service water heating, elevators, pumps and fans and other building services required to maintain desired indoor conditions. User related electricity, like lighting and receptacle equipment is also included.

2. Building Life Cycle Assessments

Typical building life cycle consists of the stages presented in figure 1 below (SFS-EN 15978, 2011). The product stage (modules A1 to A3) takes into consideration the cradle to gate processes for the construction material production from raw material extraction to the factory gate. The construction process stage (modules A4 to A5) covers the processes from the factory gate to the completion of the construction works, including all transportation, storage and installation. The use stage (modules B1 to B7) covers the building usage and operation from completion of construction works to the point of time when the building is demolished. This stage includes building services (heating, ventilation, air conditioning, cooling, lighting, water supply, etc.), maintenance and cleaning and other operations-related activities. The end of life stage (modules C1 to C4) covers building deconstruction and preliminary on-site sorting of materials, transport of materials to final disposal or recycling site and waste processing activities for reuse, recovery or recycling.

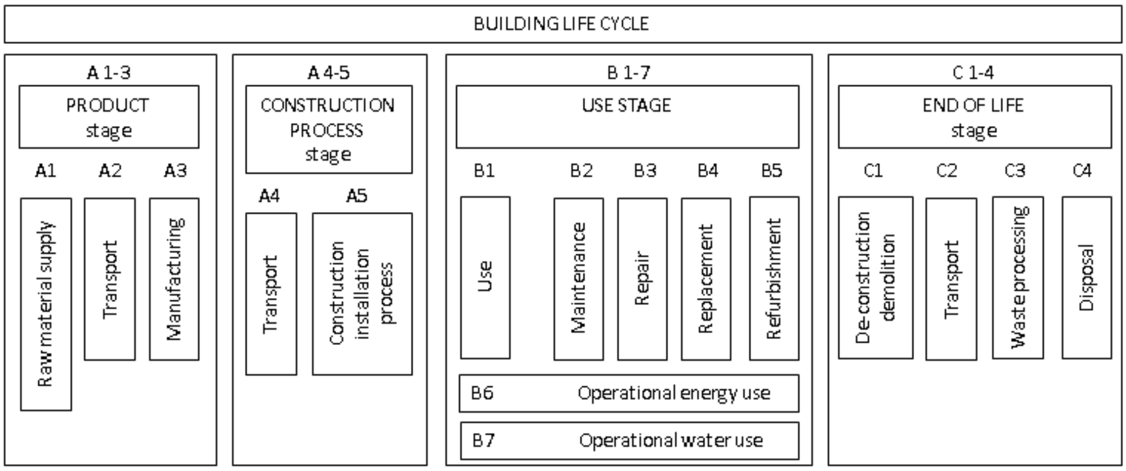

***Figure 1** Display of modular information for the different stages of building assessment (figure modified from SFS-EN 15978, 2011)*

As is often the case when studying buildings, process life cycle assessment is applied in this study. In process analysis, environmental impacts generated over a product life-cycle are assessed through flows of material, energy and emissions to and from the studied system (Pandey, et al., 2011). The system can be modelled to the required detail and specific products within the process can be studied. The inclusion and exclusion of processes is a subjective choice made by the person conducting the study which results in a problem with the system boundary definition (Suh, et al., 2004). The problem of system boundary selection and the incompleteness of LCA results (if all relevant processes are not included in the modelling of the studied system) is called truncation error (Lenzen, 2000). The influence of truncation error in overall LCA results can be as high as 50 %.

Total life-cycle environmental impacts of buildings consist of two types of emissions: embodied and operational (Ramesh, et al., 2010). Embodied emissions are caused by all processes of construction material production, transport, onsite construction activities and maintenance and renovation of the building while operational emissions take place in the use phase and are caused by energy consumption required to maintain the desired indoor environment through heating, cooling, lighting and other building services and appliance operation (Dixit, et al., 2012). After having assessed the LCA results of 73 case studies, Ramesh et al (2010) concluded that in average the operational energy accounts for 80-90 % and embodied energy for 10-20 %

of total building life cycle energy use and that the generated emissions are in line with energy consumption. Junnila (2004) studied three office buildings and stated that operation of the building causes 70-85 % of climate change impact over the building service life while embodied impacts account respectively for 25-30 %.

In this research, carbon equivalents are used to assess the negative environmental impacts caused over the life cycle of an industrial building. By the definition of ISO, greenhouse gases are "gaseous constituents of the atmosphere -- that absorb and emit radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth's surface, the atmosphere and clouds" (SFS-EN ISO 14064-1, 2006). The most known greenhouse gas is carbon dioxide (CO_2), but there are other gases like methane (CH_4) and nitrous oxide (N_2O). When talking about the GWP, the radiative forcing impact of one mass-based unit of these gases is compared to an equivalent unit of CO_2 over a given period of time.

3. Life Cycle Assessment of and Industrial Building

3.1 Presentation of the case building and used tools

The case building is a 12 547 gross square meter vehicle repair centre situated in Southern Finland. At the time of this research, the project was at its implementation design phase. The building consists of approximately 7200 m^2 of industrial space and 4300 m^2 of office space. The remaining area is either storage or technical space. The building frame is mainly executed as precast reinforced concrete element construction. Some characteristics of the case building industrial areas include high ceilings and long spans. There are no intermediate floors or walls in the industrial spaces and surfaces are left unfinished. On the other hand, the load bearing floor slabs are thicker than in regular office or residential buildings because they need to support large vehicles indoors. The building is connected to the local district heating network. Heat is distributed through radiators in office space and floor heating and air-circulation heating in industrial areas.

As one goal of this study is to find out whether the embodied impacts differ when calculated using different LCA software tools, three LCA software tools, that are capable of calculating the initial embodied impacts, were chosen: SimaPro, 360Optimi and ILMARI. SimaPro is widely known and one of the most used LCA tools (Pré, 2014). It is developed by Dutch Pré Consultants. 360Optimi is a fairly recent and building specific LCA tool developed by Finnish Bionova (Bionova, 2015). ILMARI carbon footprint calculation tool has been developed by the Technical Research Center of Finland (VTT) and Pöyry Finland Oy. It should be stated that within this research, the licence of 360Optimi used covers only LEED (Leadership in Energy and Environmental design) environmental certification system compliant LCA. So it is unclear whether other licences of the same software include more features.

In order for the results obtained from these different tools to be somewhat comparable, the LCA modelling was executed as similarly as possible with all the three tools. However, the tools are somewhat different by nature. SimaPro, for example, allows for a considerably more detailed analysis with option of developing own assemblies. SimaPro also features several options for life cycle impact assessment method, such as CML, EDIP, ReCiPe, TRACI, EPS and IMPACT. For this study, CML 2 (2000; v.2.05) is chosen, because it is also used within 360Optimi. ILMARI doesn't specify which methodology is used in calculations.

Within SimaPro, the Ecoinvent database is used. Ecoinvent includes data for most common construction products, like concrete and rebars. However in many cases when using SimaPro, construction materials are not ready in the database. The user has to know the material ingredients of construction materials, like insulation boards, which is not always evident. ILMARI and 360Optimi are building-specific LCA tools and include hence large material library of construction products. They both have information ready for whole structural elements, like hollow core slabs which are commonly used in Finnish construction projects. In SimaPro, the user has to "construct" these structural elements so information about their ingredients is required. The data in ILMARI is mainly collected from the Finnish Building Information Group's environmental declarations and secondly from public databases and most important Finnish manufacturers' EPDs (Häkkinen, 2011). 360Optimi contains emissions data from mainly Nordic and Central European construction material manufacturers.

3.2 LCA process

The bill of quantities used in the study was generated from the architectural and structural building information models using Solibri Model Checker and the structural types of the building. At the time of this research, the model was still incomplete, so some information was added to the materials list manually, such as the amount of steel reinforcement in prefabricated concrete elements. After the actual amounts of construction materials were determined, the amounts were submitted in all three LCA tools. Secondary data available in the built-in databases of the three used software tools was used in the inventory because actual material and product manufacturers were not known at the time of the LCA study. When possible, however, the data quality was estimated based on age of the data, geographical specificity, technology coverage and third party verifications.

As always in building life cycle assessments, set of assumption and simplifications were made during the study. As construction materials bill of quantity was compiled in volume, average densities were used in order to calculate the mass of different materials. Material densities were collected from literature and material manufacturer's technical product descriptions. Material losses that are expected to occur at the construction site were taken into consideration. The losses were estimated based on a study by Sirje Vares (2001). Transportation to the construction site was also estimated based on manufacturing plant location of biggest Finnish material manufacturers. Because the LCA was executed before the building construction began, actual distances could not be acquired. Transportation covers the distance from product or material manufacturing plants to the project site.

Operational impacts were calculated by hand using yearly electricity and district heat consumption values and average Finnish emission factors. Energy simulation of the case building was executed using IDA Indoor Climate and Energy software, IDA ICE. Yearly electricity and district heat consumption determined through energy simulation at design stage are assumed to stay equal during the 60 years which is of course not likely in reality. The emission factors used in this study are based on carbon neutral vision of Finnish Energy Industries. In the vision (2010), it is estimated that emissions caused by electricity production in Finland drop from 280 to 30 g CO_2 eq/kWh between 2010 and 2050 and respectively emissions from district heat production drop from 220 to 25 g CO_2 eq /kWh.

3.3 Results

In the actual research, six environmental impact indicators were studied but in this paper, only GHG emissions are presented. The case building total embodied GHG emissions expressed in carbon equivalents reach 5.51E+06 kg CO_2 eq. As the building gross floor area is 12 547 m^2, the normalized results are respectively 439 kg CO_2 eq/m^2. Embodied impacts consist of material production, transportation to the building site, maintenance and material replacements, and end-of-life stage including demolition and material processing. Embodied emissions in different life cycle stages are presented in table 1 below. Within the embodied impacts, material manufacturing causes almost 85 %; end of life little over 9 % and the rest (transportation and maintenance) together a little over 6 %. Global warming potential was chosen as reference indicator because so far it has been the most addressed environmental impact indicator within existing literature and previous research. Additionally, it is the only indicator that can be calculated using ILMARI software.

Table 1 *Embodied global warming potential of different life cycle stages of the case building*

Building life-cycle stage	Global Warming Potential	Share of total impacts
	kg CO2 eq	%
A1-A3	4,66E+06	84,60 %
A4	1,37E+05	2,49 %
B1-B3	5,20E-02	0,00 %
B4-B5	2,11E+05	3,83 %
C1	5,87E+04	1,07 %
C2	2,94E+04	0,53 %
C3-C4	4,12E+05	7,48 %
Total	**5,51E+06**	100

The building consumes annually about 2 210 MWh electricity and 990 MWh district heat energy. When multiplied with the average Finnish emissions factors, the total operational GHG emissions of the case building reach 2.13E+07 kg CO_2 eq over the 60-year study period. These values translate into normalized emissions of 1697 kg CO_2 eq /m^2 and 29.3 kg CO_2 eq/m^2,year.

When the operational emissions are added up with the embodied emissions discussed earlier and presented in table 1, the overall global warming potential of the studied building expressed in CO_2 equivalents reach 2.68E+07 kg CO_2 eq meaning 2136 kg CO_2 eq /m^2 and 35.6 kg CO_2 eq/m^2,year. As can be seen in figure 2, over the whole building life cycle, the operational energy use causes most emissions: 79 % of the overall emissions. Construction material production and the transportation of materials to the site together account for 18 %. The maintenance and material replacement and end-of-life phase both have a share of 1 % of the total emissions.

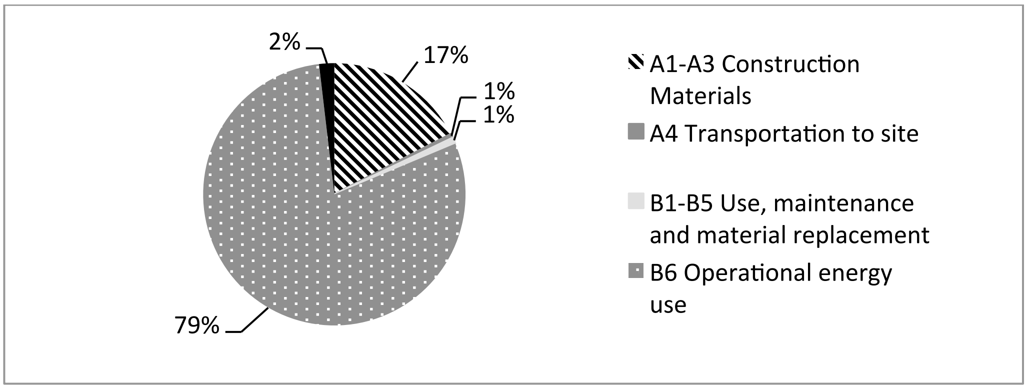

Figure 2 *The share of total GWP caused in different building life-cycle stages.*

As construction materials account for the largest share of embodied GHG emissions, 85 % for the case project, the building life-cycle stages A1-A3 are looked into in more detail. Material production related emissions were calculated using the three previously mentioned LCA tools. The results obtained for different building elements using the three tools are presented in table 2 below in carbon dioxide equivalents. As ILMARI automatically totals the emissions caused by transport of materials to the construction site with the emissions caused by materials manufacturing processes, the life-cycle stage A4 is also included in the case of ILMARI.

Table 2 *Greenhouse gas emissions in kg CO_2 eq caused by construction materials*

Building element	SimaPro	360Optimi	ILMARI
Foundations	5,98E+05	4,99E+05	7,15E+05
Ground floors	1,68E+06	8,16E+05	1,18E+06
Structural frame	1,65E+06	1,97E+06	1,88E+06
Facades	4,11E+05	5,40E+05	3,76E+05
Roofs	1,70E+05	4,58E+05	6,28E+05
Internal dividers	1,81E+05	3,70E+05	4,24E+05
Total	**4,69E+06**	**4,66E+06**	**5,20E+06**

As can be seen in table 2, building frame and ground floors cause most emissions according to results obtained using all three tools. Building frame causes most emissions according to 360Optimi and ILMARI, but the results obtained using SimaPro suggest that the ground floor causes slightly higher emissions. Due to the function of the building as large vehicle maintenance centre, the building ground floor needs to support heavy loads of truck and bus traffic inside. The reinforced concrete floor slab in the industrial spaces is partly even 300 mm thick. Foundations are the third most important element accounting for approximately the same share of GWP emissions (11-14 %) regardless of the tool. Also the share of internal dividers is relatively close (4-8 %) when calculated with all three tools. Most variance happens for the share of ground floors which for 360Optimi is 17 % and for SimaPro 36 %. Roofs and internal dividers seem to account for the smallest part of environmental impacts over the whole building life cycle regardless of selected tool.

4. Discussion

To answer the first research question of environmental life cycle impacts of an industrial building in Finland, the overall lifecycle greenhouse gas emissions of the case study building reach 2.68E+07 kg CO_2 eq. The material related embodied impacts are 5.51E+06 kg CO_2 eq and operational impacts 2.13E+07 kg CO_2 eq. Embodied life cycle impacts proved to present 21 % of overall life cycle impacts of the case building while operational impacts cover 79 %.

In figure 4, the embodied life cycle global warming potential of the case building is presented together with GWP of 19 other case buildings assessed in nine existing research studies. Since, there were no examples in previous research of an industrial building LCA, the results obtained in this study are compared with those of office and residential building LCAs. As can be seen in figure 4, the results of the study seem to be in line with previous research. Both the GWP value of 439kg CO_2 eq/m^2 for embodied impacts and the 29.3 CO_2 eq/m^2 ,year for operational impacts settle in the mid-range of the chart.

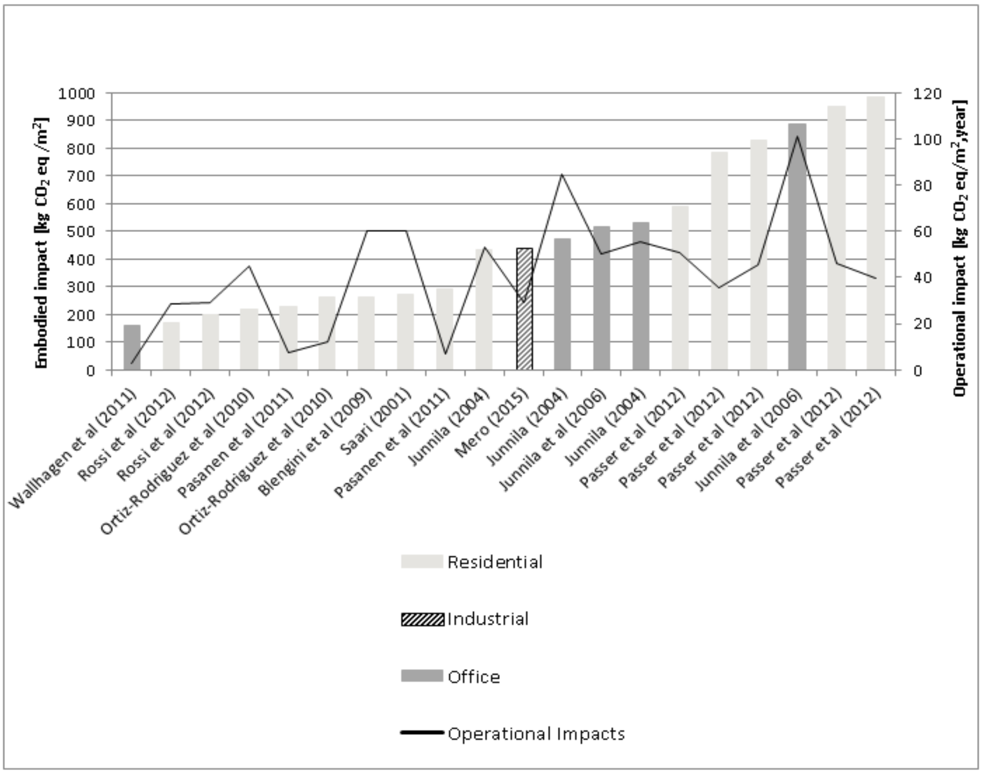

Figure 3 *Results of industrial building LCA in comparison with residential and office buildings*

It must be kept in mind that the studies are not comparable due to the differences in their scopes and the differences in studied buildings. Multiple reasons may explain why the results between studies vary. Scope of each LCA is determined to serve the goal of the study. Also the type of reported building area varies when some discuss net floor area (Passer, et al., 2012) (Blengini, 2009), others gross floor area (Junnila, 2004) and few heated area (Pasanen, et al., 2011).

As the LCA of the case building was conducted as process LCA, there are some fundamental limitations to the preciseness of the results obtained mainly due to the earlier mentioned truncation error and the decision made to exclude some of the building systems from the analysis. To recapitulate the main issue in truncation error is that the system boundary is limited when it comes to upstream activities in supply chain of construction materials production. Another issue in result preciseness is representativeness of the data in the three databases compared to the actual case building.

5. Conclusions

Based on the research results, industrial building life cycle impacts are similar to those of office and residential buildings. Most important when assessed in global warming potential are the use phase operational impacts followed by construction material production. In order to reach lower environmental impact over the whole building life cycle, most attention should hence be paid on efforts reducing operational energy use or the emission intensity of energy production. Of construction materials, most important elements are the building frame and ground floors followed by foundation structures. The share of embodied and operational emissions of the overall emissions is in line with previous research as was visualized in figure 4. Industrial buildings seem to prove no exception to office and residential buildings.

The LCA software industry has developed multiple software tools to calculate environmental life cycle impacts of buildings. Not all tools require extensive knowledge on LCA. Three LCA software tools were utilized in this study to quantify embodied environmental impacts of an industrial building. Considering the third and final research question, the results obtained using those three different tools proved to be similar but to still include some differences. The construction material production emission results varied from 4.66E+06 obtained using SimaPro to 5.20E+06 kg CO_2 eq obtained using ILMARI.

All tools prove same building elements to cause biggest impacts even though there are differences whether the building frame or ground floors cause higher emissions. As the same bill of quantity of construction materials was applied in each tool, difference in results can be concluded to be caused either by differences in the database each software tool uses or their impact assessment methodology. For example the greenhouse gas intensity of material production of different construction materials vary between the databases the tools use. It seems that the variances between databases for different materials are evened out when the whole building is analysed. Difference in greenhouse gas intensity of production of construction material might also be due to the selection of material within the database each tool uses.

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Carbon Emissions of Deluxe Hotels: An Empirical Investigation in Hong Kong

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Abstract

Hotels, which are part and parcel of the tourism industry, utilize resources for their round-the-clock operations. Deluxe hotels, in particular, consume substantial resources in order to satisfy the demands of upmarket patrons. Aimed at investigating the greenhouse gas emissions (commonly known as "carbon emissions") of deluxe hotels and their relations with the hotels' maintenance costs, a study was conducted based on empirical facilities management data. To gather reliable data of hotels' characteristics, utilities consumptions and maintenance costs, face-to-face interviews were held individually with the representatives of 12 hotels in Hong Kong. Based on the Hong Kong government's guidelines on quantification of carbon emissions, the collected data were processed to determine the emissions arising from resources consumptions of the hotels. Indirect emissions resulted from the use of electricity purchased from power companies dominated the carbon emissions of the hotels. Emissions due to the use of water and the associated waste water treatment were negligible. Among the characteristic parameters, gross floor area was found to be a better normalization factor for the emissions. Carbon emission was negatively correlated with capital project cost, implying that appropriate input of resources for facilities improvement could mitigate the emission. While these findings are useful information for hotel operators and facilities managers, further effort is needed to include more hotels in the analysis in order to obtain more representative results.

Keywords: Carbon, energy, greenhouse gas, hotel, maintenance cost, resources.

1. Introduction

Buildings are major consumers of energy (IPCC, 2007; WBCSD, 2009). With a remarkably high density of buildings, Hong Kong is among the energy-intensive cities. In parallel to the rise in energy use and resources consumptions for activities in buildings, the greenhouse gas emissions (GHGs) of Hong Kong have continued to increase (EPD, 2012), exceeding the levels of many developing countries (IEA, 2009).

In order to help the quantification of GHGs (commonly known as "carbon emissions") of buildings, the Environmental Protection Department and the Electrical and Mechanical Services Department have jointly published a set of guidelines (EPD-EMSD, 2010). Unlike some overseas places where reporting of carbon emissions has become a regulatory requirement, it is not mandatory for building owners or facilities managers to report the carbon emissions of their buildings in Hong Kong (Lai, 2014). In fact, implementation of carbon audits has not been a common practice (Lai et al., 2012).

Around the world there have been various studies on carbon emissions of hotels (Filimonau et al., 2011). Besides purely theoretical studies, some empirical research works have been carried out using record data of buildings. In the study of Jiang and Tovey (2009) where nine commercial buildings in China were covered, the yearly carbon emissions associated with their electricity consumptions were around 158 kg/m^2. In Singapore, Wu et al. (2010) analyzed the carbon emissions of 29 hotels and showed that their carbon intensity ranking is sensitive to the denominator used for normalization. The study of Huang et al. (2015), which considered scope 1 and scope 2 emissions under the GHG Protocol (WRI-WBCSD, 2004), found that the annual average carbon emission level of Taiwanese luxury hotels was 132 kg/ m^2. In Hong Kong, a pilot carbon audit was carried out on a typical hotel (Lai et al., 2012) and the hurdles to making the audit complete include: lack of proper record of resources consumed by facilities; optional reporting of carbon emissions due to mobile combustion sources; and unavailability of record data pertaining to commercial tenants in the hotel.

Despite the difficulties in empirical carbon audits, a detailed comparative study covering not only GHG emissions due to energy use but also those arising from the use of other resources was conducted on three archetypes of hotels (Lai, 2015), each of which being an archetype of its own class: 5-star, 4-star and 3-star. In order to further investigate the carbon emissions of hotels, an extended research project was commenced. And because maintenance costs are often not fully understood (Chimack et al., 2006), their effects on reducing carbon emissions were examined under the project. As reported in the following, facilities management data of 12 hotels were collected. After describing the research methodology of the project, analyses made on the data collected are explained and discussed. At the end of this article are conclusions drawn from the analysed results and further works needed in the future.

2. Methodology

2.1 Scope and data collection

The scopes of carbon emissions covered in the study are summarized in Table 1. For Scope 1, the emissions are due to combustion of stationary and mobile sources. Scope 2 embraces emissions resulted from consumptions of purchased electricity and gas. Whereas the guidelines of EPD-EMSD

(2010) provide that it is optional to report other indirect emissions, Scope 3 emissions due to the use of water and associated treatment of waste water were included in the scope of the study. Quantification of such emissions necessitates record data of the corresponding utilities consumptions.

Table 1: Scopes of carbon emissions covered

Classification	*Emission activities*
Scope 1	• *Stationary sources combustion* • *Mobile sources combustion*
Scope 2	• *Consumption of purchased electricity* • *Consumption of purchased gas*
Scope 3	• *Consumption of fresh water* • *Treatment of waste water*

In order to identify the amounts of maintenance expenditures of the hotel buildings and investigate if such expenditures affect the volumes of the buildings' carbon emissions, cost items including those for engaging maintenance staff, covering repair and maintenance works, and financing capital projects such as renovation or improvement works (e.g. for replacement of energy inefficient equipment) were required. Because utilities consumptions and maintenance costs are often regarded as sensitive information (Lai et al., 2008), it is important to build up trust with representatives of the hotels before requesting them to provide the needed data. As such, a face-to-face interview was held with each of the representatives in order to collect reliable data. For utilities consumptions, the data collected include the hotels' annual consumptions of electricity, town gas, diesel oil and water. For maintenance costs, the interviewees were requested to provide their annual total maintenance expenditures, with breakdowns of staff payroll, repair and maintenance cost, and capital project cost. In addition, characteristic information about the hotels, including their class, building age, gross floor area, number of guestrooms, occupancy rate and number of guests, was collected.

2.2 Quantification of carbon emissions

The procedures and formulas used for calculating the amounts of carbon emissions of the hotels, which are based on the above-mentioned guidelines (EPD-EMSD, 2010), are described in the following.

Similar to the steps taken in an earlier study (Lai, 2015), the amount of carbon dioxide (CO_2) emitted from stationary and mobile sources of fuel combustions, which belong to Scope 1 carbon emissions, were obtained by inputting the amounts of fuels used and the emission factor of CO_2 for the respective fuel types into equation (1). Based on the same amounts of fuels used and by equations (2) and (3), the emitted amounts of methane (CH_4) and nitrous oxide (N_2O) were calculated.

$$E^C_{CO_2} = \sum_{f=1}^{f=F} \sum_{t=1}^{t=T} A_{f,t} \times F_{(CO_2)f} \tag{1}$$

$$E^C_{CH_4} = \sum_{f=1}^{f=F} \sum_{t=1}^{t=T} A_{f,t} \times F_{(CH_4)f} \times G_{(CH_4)} \tag{2}$$

$$E^C_{N_2O} = \sum_{f=1}^{f=F} \sum_{t=1}^{t=T} A_{f,t} \times F_{(N_2O)f} \times G_{(N_2O)} \tag{3}$$

Referring to the amount of electricity purchased from the respective power company (i.e. Hong Kong Electric Company or China Light and Power Company) during the reporting period, the corresponding amount of carbon emissions under Scope 2 was determined by equation (4). Likewise, the amount of emission due to the use of gas (i.e. town gas supplied by The Hong Kong and China Gas Company Limited) was calculated using equation (5).

$$E_{CO_2}^{E} = \sum_{t=1}^{t=T} A_{(E)t} \times F_{(E)t} \quad (4)$$

$$E_{CO_2}^{G} = \sum_{t=1}^{t=T} A_{(G)t} \times F_{(G)t} \quad (5)$$

For Scope 3 carbon emissions, the amounts of CO_2 emitted from the use of electricity for processing the fresh water consumed were determined by equation (6). Similarly, those emitted from the use of electricity for processing the resultant sewage were calculated by equation (7), where the default emission factor is dependent on whether the water was used by restaurants or for catering services (equation (8)).

$$E_{CO_2}^{W} = \sum_{t=1}^{t=T} A_{(W)t} \times F_{(W)t} \quad (6)$$

$$E_{CO_2}^{S} = \sum_{t=1}^{t=T} A_{(W)t} \times F_{D|(W)t} \quad (7)$$

$$F_{D|(W)_t} = C_a \times F_{(S)t} \quad (8)$$

The total maintenance cost of the hotels, consisting of maintenance staff cost, repair and maintenance cost, and capital project cost, was calculated using equation (9).

$$C_T = \sum_{t=1}^{t=T} C_{(S)t} + C_{(R)t} + C_{(P)t} \quad (9)$$

Notations for the above equations:

$A_{(E)t}$ = amount (kWh) of electricity used in the t^{th} period
$A_{f,t}$ = amount (litre) of the f^{th} type of fuel used in the t^{th} period
$A_{(G)t}$ = amount (unit; 1 unit = 48 MJ) of gas used in the t^{th} period
$A_{(W)t}$ = amount (m^3) of fresh water used in the t^{th} period
C_a = activity-dependent factor (0.7 for restaurants and catering services; 1.0 for other commercial, residential and institutional purposes)
$C_{(P)t}$ = capital project cost (HK$) in the t^{th} period
$C_{(R)t}$ = repair and maintenance cost (HK$) in the t^{th} period
$C_{(S)t}$ = maintenance staff cost (HK$) in the t^{th} period
C_T = total maintenance cost (HK$)
$E_{CH_4}^{C}$ = CH_4 emission (kg) due to stationary or mobile sources of fuel combustions
$E_{CO_2}^{C}$ = CO_2 emission (kg) due to stationary or mobile sources of fuel combustions
$E_{CO_2}^{E}$ = CO_2 emission (kg) due to use of purchased electricity
$E_{CO_2}^{G}$ = CO_2 emission (kg) due to use of purchased gas
$E_{CO_2}^{S}$ = CO_2 emission (kg) due to processing of sewage
$E_{CO_2}^{W}$ = CO_2 emission (kg) due to use of fresh water
$E_{N_2O}^{C}$ = N_2O emission (kg) due to stationary or mobile sources of fuel combustions
$F_{(CH_4)f}$ = emission factor of CH_4 for the f^{th} type of fuel

$F_{(CO_2)f}$ = emission factor of CO_2 for the f^{th} type of fuel
$F_{D|(W)t}$ = default emission factor (kg/m^3) of electricity consumed associated with the amount of sewage processed in the t^{th} period
$F_{(E)t}$ = emission factor of electricity used in the t^{th} period (specific for individual power companies)
$F_{(G)t}$ = emission factor (kg/unit) of gas used in the t^{th} period
$F_{(N_2O)f}$ = emission factor of N_2O for the f^{th} type of fuel
$F_{(S)t}$ = emission factor (kg CO_2-e/kWh) of electricity consumed associated with the amount of sewage processed in the t^{th} period
$F_{(W)t}$ = emission factor (kg CO_2-e/m^3) of electricity consumed associated with the amount of water used in the t^{th} period
f = 1, 2, …, F (assigned to the f^{th} type of fuel; F = total number of fuel types)
$G_{(CH_4)}$ = global warming potential of CH_4
$G_{(N_2O)}$ = global warming potential of N_2O
t = 1, 2, …, T (assigned to the t^{th} period; T = total number of time periods)

2.3 Correlation analysis

After the above calculations of carbon emissions and maintenance costs, the Pearson product-moment correlation coefficient (r), which is a measure of the correlation between different pairs of independent variable (X) and dependent variable (Y) under investigation, was computed using Equation (10), where each of the tested datasets [(x_1, ..., x_n); (y_1, ..., y_n)] contains n items. The value of r ranges between -1 and +1, with -1 indicating total negative correlation, 0 for no correlation, and +1 for total positive correlation.

$$r = \frac{n\sum_{i=1}^{i=n} XY - \sum_{i=1}^{i=n} X \sum_{i=1}^{i=n} Y}{\sqrt{[n(\sum_{i=1}^{i=n} X^2) - (\sum_{i=1}^{i=n} X)^2][n(\sum_{i=1}^{i=n} Y^2) - (\sum_{i=1}^{i=n} Y)^2]}} \quad (10)$$

3. Results and Discussion

3.1 Characteristics and utilities consumptions

Data of 12 deluxe hotels were collected and the major characteristics of the hotels are summarized in Table 2. None of the hotels was newly completed; on average the hotels were about 15 years old, with the newest and the oldest being 2 and 27 years old respectively. Ranging from 14,975 to 60,493 m^2, the mean gross floor area of the hotels was 46,533 m^2. In total, there were 5,300 guestrooms in the hotels. The mean (442) and median (457) number of guestrooms were comparable. Reflecting a generally high user demand, the mean annual occupancy rate was 82.6% and the rate of the most popular hotel was as high as 90.0%. In terms of number of guests, the lowest was 74,241 per year while the highest amounted to 378,815 per year, or 1,038 per day.

Table 2: Age, scale and occupancy of the hotels

	Mean	*Median*	*Min.*	*Max.*	*S.D.*
Age (year)	*15.3*	*16.5*	*2*	*27*	*8.8*
Floor area (m^2)	*46,533*	*48,783*	*14,975*	*60,493*	*12,215*
Guestroom (nos.)	*442*	*457*	*113*	*602*	*135*
Occupancy rate (%)	*82.6*	*84.4*	*65.0*	*90.0*	*7.8*
Guests per year (nos.)	*265,420*	*270,027*	*74,241*	*378,815*	*85,860*

The main energy sources of the hotels were diesel oil, town gas and electricity. Seven of the hotels used diesel oil for cooking or heating purposes and the mean annual consumption was 313,422 litres (Table 3). Town gas was used for the same purposes in all the 12 hotels. Varying from 10,757 to 1,152,438 units (1 unit = 48 MJ), the mean annual consumption level of town gas was 280,460 units. The last, but not the least, energy source was electricity. All the hotels used it for running electrical installations and, on average, 16,558,556 kWh was consumed per year per hotel. In addition, water is an indispensable utility for all the hotels. Altogether they consumed over 2.1 million m^3 of water a year, with the smallest annual consumption being 43,305 m^3 and the largest being 297,000 m^3.

Table 3: Annual utilities consumptions of the hotels

	Mean	*Median*	*Min.*	*Max.*	*S.D.*
Diesel (litre)	*313,422*	*26,615*	*0*	*1,081,260*	*423,608*
Town gas (unit)	*280,460*	*221,692*	*10,757*	*1,152,438*	*299,540*
Electricity (kWh)	*16,558,556*	*15,304,937*	*4,434,537*	*30,305,782*	*7,113,756*
Water (m^3)	*175,567*	*181,618*	*43,305*	*297,000*	*67,544*

3.2 Carbon emissions

Scope 1 carbon emissions consist of direct emissions resulted from combustion of diesel oil and town gas at stationary sources in the hotels. The amounts of such direct emissions, which cover various greenhouse gases (CO_2, CH_4 and N_2O), were determined using Equations (1) to (3). As summarized in Table 4, the annual amount of carbon emission due to the use of diesel oil varied from over 2.8 million kg CO_2-equivalent (CO_2-e) to nil (where diesel oil was not used). Town gas was used in all the hotels and the resultant amount of carbon emission under Scope 1 was on average 716,017 kg CO_2-e per hotel.

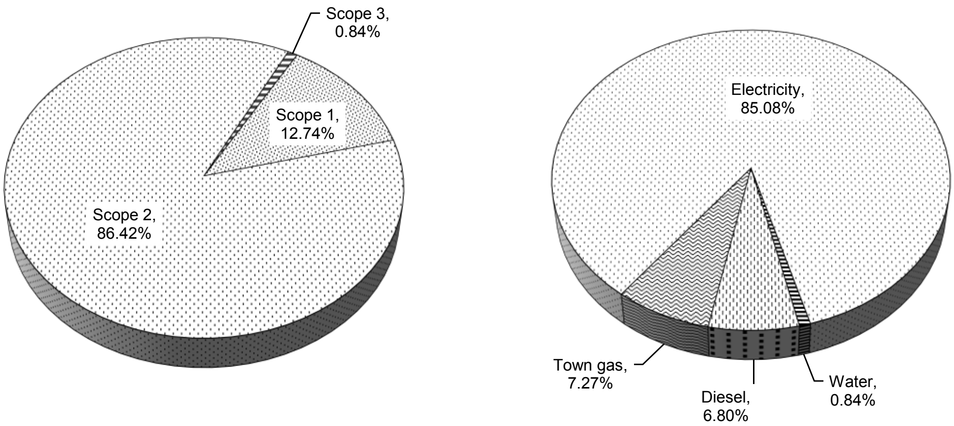
Belonging to Scope 2 (i.e. energy indirect emissions) are carbon emissions due to consumption of purchased electricity and town gas, which were determined using Equations (4) and (5) respectively. Clearly, electricity was a dominant energy source for the hotels; its consumptions gave rise to a mean annual emission level of over 10.2 million kg CO_2-e, and the median level among the hotels, exceeding 10.1 million kg CO_2-e, was comparable. When compared with the Scope 1 counterpart, the carbon emissions due to consumption of purchased town gas under Scope 2, between 6,176 kg CO_2-e and 661,591 kg CO_2-e, were significantly less.

Table 4: Summary of annual carbon emissions (in kg CO_2-e)

	Mean	Median	Min.	Max.	S.D.
Scope 1- Diesel	*820,160*	*69,645*	*0*	*2,829,437*	*1,108,496*
Scope 1 - Town gas	*716,017*	*565,980*	*27,464*	*2,942,179*	*764,728*
Scope 2 - Electricity	*10,262,336*	*10,143,168*	*3,503,284*	*17,171,440*	*4,226,174*
Scope 2 - Town gas	*161,007*	*127,269*	*6,176*	*661,591*	*171,960*
Scope 3 - Water	*101,864*	*105,374*	*25,126*	*172,319*	*39,189*

Emissions resulted from the use of water, under Scope 3, were obtained using Equations (6) to (8). Ranging between 25,126 kg CO_2-e and 172,319 kg CO_2-e, the mean and median levels of this category of emissions have the same order of magnitude as those of town gas under Scope 2.

Based on the total amounts of carbon emissions of the hotels, the proportions of the three scopes of emissions were worked out, as shown in Figure 1(a). Scope 2 emissions, representing over 86% of the total emissions, were dominant. In contrast, the proportion of Scope 1 emissions was small, and that of Scope 3 was even less. When categorized by energy source type, most (over 85%) of the carbon emissions were resulted from the use of electricity. The proportion of emission due to consumption of town gas, at about 7%, was a distant second. A slightly lower proportion (6.8%) of the total emission was produced from using diesel oil. The use of water added a negligible amount to the total emission.



(a) *(b)*

Figure 1: Proportions of carbon emissions

3.3 Normalization of carbon emissions

As observed from the major characteristics above (Table 1), the sampled hotels varied in age, scale and occupancy. Making direct comparisons between the amounts of carbon emissions of hotels with different ages would not be fair because their facilities' conditions and hence their required amounts of resources consumptions may be different. For hotels with different sizes, it is obvious that comparing their raw amounts of carbon emissions would not be fair. Likewise, a hotel with a higher occupancy is expected to consume more resources than one with a lower occupancy. As the former hotel would have a larger amount of carbon emissions, it would be unfair to compare its carbon emission with that of the latter hotel.

For the above reasons, it is necessary to identify an appropriate parameter for normalizing the amounts of carbon emissions before they could be compared and analysed further. To this end, an initial step was taken to figure out the proportions of the three scopes of carbon emissions normalized by different factors that are of potential influence on the amounts of emissions. As the results in Table 5 show, the proportions for the case where the emissions were without normalizations (i.e. the base case) were: 12.74% (Scope 1), 86.42% (Scope 2) and 0.84 (Scope 3). For the cases where the emissions were normalized by floor area and number of guestrooms of the hotels, the proportions were not largely different from those of the base case. The largest differences from the base case values were found with the case where annual number of guests was used as the normalization factor. But such differences, ranging from -6.5% (Scope 1) to +1.0% (Scope 2), were not substantial.

Table 5: Proportions (%) of normalized carbon emissions

	Normalization factor			
	None	*Floor area (m^2)*	*No. of guestrooms*	*Annual no. of guests*
Scope 1	*12.74*	*12.71*	*12.31*	*11.91 [-6.5%]*
Scope 2	*86.42*	*86.47*	*86.88*	*87.28 [+1.0%]*
Scope 3	*0.84*	*0.83*	*0.81*	*0.81 [-3.6%]*

Note: Values in square brackets are differences from the base case values.

Further to the above step, a series of trials were carried out by preparing scatter plots of the hotels' total carbon emissions against their ages, scales and occupancies. Not different from the anticipated result, the total carbon emissions of the hotels generally increase with their number of guestrooms (Figure 2). Nevertheless, the R^2 value of the best-fit trend line for this scatter plot was low, at 0.2445 only. Another scatter plot, as shown in Figure 3, was made by showing the distribution of the total carbon emissions against the hotels' gross floor areas. An upward trend similar to that in the preceding figure was noted. Whereas both number of guestrooms and gross floor area can represent the scales of the hotels, the goodness of fit of the trend line for the scatter plot based on gross floor area was significantly higher (R^2 = 0.4507).

A further trial of scatter plot was made by showing the total carbon emissions of the hotels against the numbers of guests they received (Figure 4). Although this plot exhibits also an upward trend, the rise in the emissions with increase in number of guests was relatively gentle and the R^2 value of the trend line was only 0.1745. Given that occupancy rate is an alternative parameter that can reflect user demand, data of the hotels' occupancy rates as well as their total carbon emissions were used to prepare another scatter plot. But as shown in Figure 5, no apparent trend was observed.

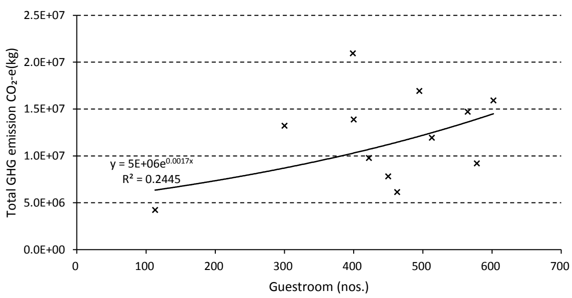


Figure 2: Total carbon emission against number of guestrooms

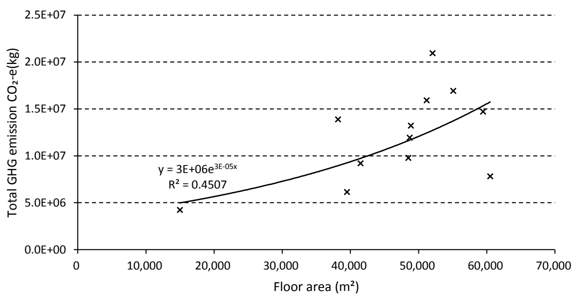


Figure 3: Total carbon emission against gross floor area

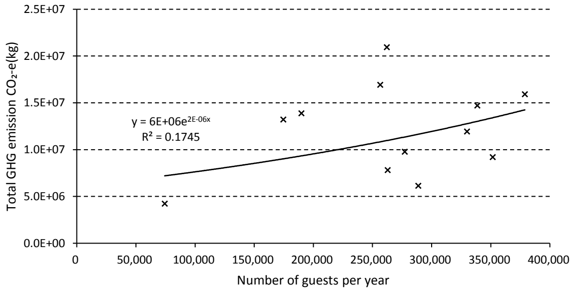


Figure 4: Total carbon emission against number of guests

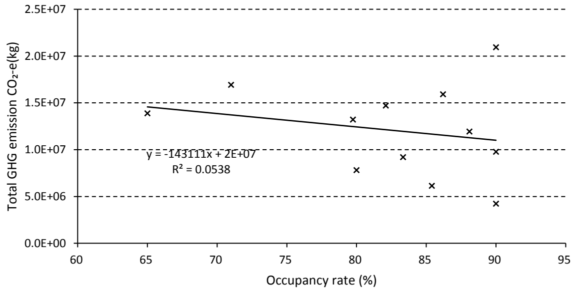
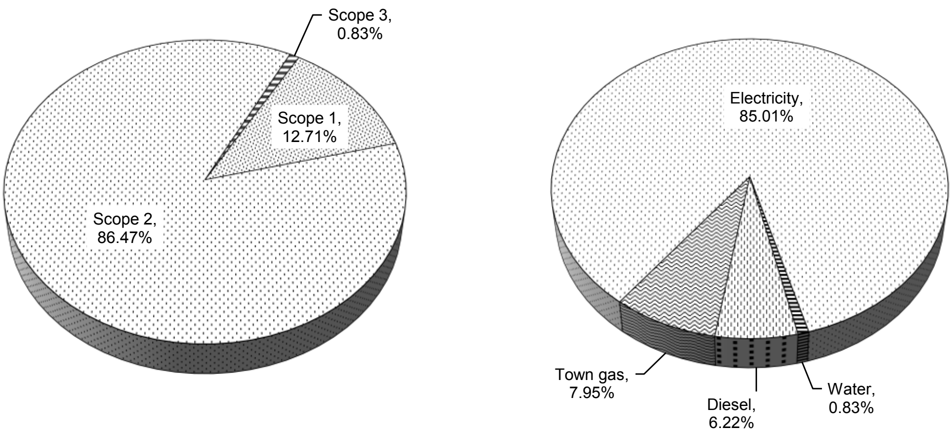


Figure 5: Total carbon emission against occupancy rate

From the above trials, it can be concluded that the total carbon emissions of the hotels vary more closely with their gross floor areas than the other three parameters (i.e. number of guestrooms, number of guests, and occupancy rate). On this basis, gross floor area was selected as the parameter for normalizing the carbon emissions, and the normalized emission values were used in the ensuing analyses.

Based on the total amounts of carbon emissions normalized by the gross floor areas of the hotels, proportions of the three scopes of emissions were calculated. Emissions belonging to Scope 2, as shown in Figure 6(a), contributed to over 86% of the total emission, which is almost the same as that shown in Figure 1(a). The contribution due to Scope 1 activities was comparatively small, at about 12%. The proportion of Scope 3 was negligible.

As for the normalized carbon emissions categorized by energy source, the proportion resulted from the use of electricity was dominant, at about 85% (Figure 6(b)). Similar to the results shown in Figure 1(b), the proportions of emissions due to the use of town gas, diesel oil and water were relatively small.



(a) *(b)*

Figure 6: Proportions of normalized carbon emissions

3.4 Maintenance cost and its relation with carbon emission

Of the 12 hotels, 11 provided data of maintenance staff cost and repair and maintenance cost. Data of capital project cost for covering improvement work (e.g. installation of energy saving devices) were available from eight of the hotels. On average, the capital project cost and the repair and maintenance cost, at about 9.8 million and 9.6 million respectively, were comparable, and they made up the majority of the total maintenance cost. But the minimum, maximum and standard deviation values show that the variations in capital project cost were larger.

Table 6: Annual maintenance costs (HK$) of the hotels

	Mean	*Median*	*Min.*	*Max.*	*S.D.*
Repair & maintenance [n=11]	*9,641,863*	*7,900,000*	*1,700,000*	*18,414,369*	*5,426,597*
Capital project [n=8]	*9,849,487*	*6,937,611*	*1,191,000*	*23,000,000*	*7,765,165*
Maintenance staff [n=11]	*6,731,237*	*6,240,000*	*4,287,780*	*12,000,000*	*2,349,788*
Total maintenance [n=8]	*26,357,122*	*28,281,514*	*13,813,362*	*35,000,000*	*7,130,428*

In order to test whether the amounts of carbon emissions were dependent on the resources spent on maintenance for the hotels, Equation (10) was used to compute the Pearson product-moment correlation coefficient (*r*) for different pairs of maintenance cost items and scopes of carbon emissions. For this part of computations, values of normalized maintenance costs (HK$/$m^2$) and normalized carbon emissions (CO_2-e/m^2) were used. The results, as summarized in Table 7, show that there was no perfect correlation between any pair of the parameters. The only case where a significant correlation was found was between capital project cost and Scope 3 emission (r = -0.7096). The correlation was negative, meaning that the amount of Scope 3 emission decreased with increase in capital project cost. This suggests that the capital projects probably covered improvement work for reducing water use, thus leading to drop in Scope 3 emission (Equations 6 to 8).

Table 7: Pearson r coefficients between maintenance costs and carbon emissions

	Scope 1 emission	*Scope 2 emission*	*Scope 3 emission*	*Total emission*
Repair & maintenance	*0.1302 [0.7028]*	*0.1281 [0.7074]*	*0.0173 [0.9598]*	*0.1462 [0.6680]*
Capital project	*-0.1746 [0.6793]*	*-0.3743 [0.3609]*	*-0.7096 [0.0487*]*	*-0.3644 [0.3749]*
Maintenance staff	*-0.2366 [0.4836]*	*0.3796 [0.2496]*	*-0.1535 [0.6522]*	*0.2876 [0.3911]*
Total maintenance	*0.2307 [0.5825]*	*0.3966 [0.3306]*	*-0.0603 [0.8873]*	*0.3891 [0.3408]*

*Notes: Figures in square brackets are significance values; *correlation is significant at the 0.05 level (2*-tailed).

On the other hand, it was anticipated that a larger input of resources for repair and maintenance work would help improve the performance of facilities in the hotels, leading to reduction in the corresponding carbon emissions. Likewise, maintenance staff with a higher remuneration would perform better in operating the facilities, thereby minimizing the amounts of resources used and hence their carbon emissions. But these anticipations were not supported by the above results, as there were no significant correlations between the remaining pairs of parameters.

4. Conclusions

Reliable data of 12 deluxe hotels were collected through face-to-face interviews with the hotels' representatives. Among the three scopes of carbon emissions studied, Scope 2 emissions dominated as the hotels relied heavily on the use of electricity purchased from power companies. On average, the amounts of emissions resulted from the use of town gas and diesel oil were comparable. Water consumptions and the associated sewage treatment accounted for a negligible portion of the total carbon emissions.

Using different factors to normalize the carbon emissions led to different results. When compared with number of guestrooms, number of guests and occupancy rate, gross floor area was found to be a better normalization factor for the emissions.

The cost of capital projects and that for repair and maintenance accounted for the majority of the hotel's maintenance expenditures. The finding that there existed a significant, negative correlation between capital project cost and carbon emission shows that appropriate input of resources for improving the facilities in the hotels could mitigate carbon emission. As the representativeness of the above results is limited by the number of hotels covered so far, it is necessary to include more samples in the analysis in future.

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Part I: Environmental Opportunities and Challenges

1. Sustainability Assessment
2. Nature and Outdoor Conditions

Building community resilience within involuntary displacements by enhancing collaboration between host and displaced communities: A literature synthesis

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Abstract

Improving resilience through empowerment of communities is becoming a much sought after strategy for community level disaster preparedness. Community resilience is the ability of a community to bounce back to its operational equilibrium after a hazardous stress. This ability builds up over time based on many underlying factors such as community's age distribution, food supply, livelihood, population stability, indigenous knowledge, and communication capacity. Often, these factors make communities different from one another and define their level of resilience to disasters and other hazardous stresses.

Involuntary relocations alter the equilibrium position and stress absorbing ability of a community by merging two (or more) communities with different resilience equilibrium positions. In this case, resilience of these communities towards potential disasters could be disturbed. Therefore, when involuntary relocations are to be exercised, maximising the potential and collaboration of the communities is essential to enhance the overall resilience of the communities involved. Accordingly, this paper aims to develop a conceptual model to integrate possible mechanisms to build community resilience within involuntary settlements by enhancing collaboration between host community and displaced community.

This study was conducted through a comprehensive literature review to investigate the research question: 'How involuntary settlements alter the resilience of the communities in Sri Lanka?' It has been found that the operational equilibrium of host and displaced communities would make a shift immediately after relocation, because introduction of a new community will alter the context of all the influencing factors of a community's resilience. That shift would also be higher for the displaced community compared to the host community.

Consequently, the prospects for the people who have been expelled from their habitual residence are often uncertain as they are forced to live in a place among people with different culture and behaviour. Furthermore, economic status, social settings and psychological aspects could also act as stress factors that affect the resilience of the community. It is challenging to build community resilience between two communities, which are different from one another. Besides, time and financial constraints often act as barriers for resettlement planners to consider such aspects during relocation planning. Therefore, an integrated approach to build community resilience needs to be incorporated in the policy design and decision-making of relocations by drawing possible linking mechanisms that facilitate collaboration between communities

Keywords: Community resilience, Involuntary relocations, Host communities, Displacements

1. Introduction

The rate of Internally Displaced Persons (IDPs) who have been displaced within national boundaries is increasing considerably without drawing much attention of the world. International Organization for Migration (2004) defines IDPs as ‘persons or groups of persons who have been forced or obliged to flee or to leave their homes or places of habitual residence, in particular as a result of or in order to avoid the effects of armed conflict, situations of generalized violence, violations of human rights or natural or human-made disasters, and who have not crossed an internationally recognized State border’ (pp.32-33). Major reasons for the internal displacements are conflicts, consequences of change in the land usage, and natural disasters (Betts, 2009). People without the ability and/or wealth to move away from any of these three situations are known as trapped population (Foresight, 2011). The government, relevant local authorities, or non-governmental organisations relocate this trapped population to safeguard against the negative effects of disruptive events. In contrast to the voluntary displacements, these involuntary relocations are not self-selected or self-motivated (Cao, Hwang, & Xi, 2012).

Generally, involuntary relocations aim at improving the lives of the trapped population. Also, ‘Guiding principles on internal displacements’ (United Nations, 2004) states in its Principle 7 that, the authorities undertaking such displacement shall ensure, to the greatest practicable extent, that proper accommodation is provided to the displaced persons, that such displacements are effected in satisfactory conditions of safety, nutrition, health and hygiene, and that members of the same family are not separated. However, involuntary relocation often acts only as a temporary relief and fails to ensure IDPs’ long-term modes of livelihood (Perera, Weerasoori, & Karunarathne, 2012).

Immediate consequences of involuntary resettlements have an effect on both displaced community and host community. Host community is defined herein as the community in whose neighbourhood the displaced people are relocated (Kabra & Mahalwal, 2014). For example, social disintegration and severe impoverishment are some of the immediate consequences of involuntary displacements, which affect the economy of the region (Cernea, 1995). According to Cernea (1995), IDPs have higher possibilities to experience eight negative consequences: landlessness, joblessness, homelessness, marginalisation, food insecurity, increased morbidity, social disintegration, and loss of access to common resources (Xi, Hwang, & Drentea, 2013). Therefore, the host community often blames the IDPs for their economic losses.

Further, cultural, regional, and ethnic differences between host and displaced communities often trigger discrimination and racism in their day-to-day life (International Committee of the Red Cross, 2011). Consequently, the prospects for the people who have been expelled from their habitual residence are often uncertain as they are forced to live in a place among people with different, culture and behaviour (Berry, 1997). Furthermore, economic status, social settings and psychological aspects could also act as stressors that affect the resilience of the community.

Every community has a level of resilience towards disasters. In general, resilience refers to the ability of a system to return to its equilibrium position after a disturbance (Proag, 2014). The term community resilience refers to the capacity and the ability of a community to return to its equilibrium position using community resources after unexpected disruptive events (Magis, 2010). Resilience of a community builds up based on many underlying factors over the time. Those factors include the community's age distribution, food supply, livelihood, housing stock construction quality, population stability, indigenous knowledge, infrastructure availability, and communication capacity (Cutter, Ash, & Emrich, 2014). These factors make communities different from one another.

Involuntary relocations make a community to displace involuntarily and another community to host involuntarily (Kabra & Mahalwal, 2014). Operational equilibrium of these communities would make a shift immediately after relocation, because introduction of a new community will alter the context of all the influencing factors of a community's resilience. Also, that shift would be higher for the displaced community compared to the host community. It is challenging to build community resilience between two communities, which are different from one another. Besides, time and financial constrains often act as barriers for resettlement planners to consider such aspects during relocation planning (Perera et al., 2012).

Sri Lanka is a country that experienced all types of displacements (Das, 2008). According to the Ministry of Resettlement Reconstruction and Hindu Religious Affairs Sri Lanka (2015), around 45,000 IDPs are yet to be resettled in Sri Lanka. On the contrary, Internal Displacement Monitoring Centre (IDMC), an international non-governmental humanitarian organisation stated that, as of 2015 around 73,700 IDPs remain to be resettled in Sri Lanka. These figures show that a considerable number of IDPs are yet to be resettled in Sri Lanka, although the actual number has not been established owing to practical difficulties.

A number of case studies in Sri Lanka (Das, 2008; Manatunge, Herath, Takesada, & Miyata, 2009; Perera et al., 2012; Takesada, Nakayama, & Fujikura, 2009) also provided evidence to the effect that the incompatible community integration would affect the community resilience and slow the rate of recovery process. Therefore, the importance of collaboration between the host and displaced communities needs to be drawn upon in addressing the economic, social, cultural and psychological consequences of involuntary relocation projects in Sri Lanka. Furthermore, an integrated approach to community resilience by drawing mechanisms to facilitate collaboration between communities needs to be incorporated in the policy design and decision-making.

2. Literature Review

This study was conducted through a comprehensive literature review to investigate the research question: 'How involuntary settlements alter the resilience of the communities in Sri Lanka?' Peer reviewed journal papers, official reports, conference proceedings, and books have been referred in order to gather the data for this study. Collected data were analysed and synthesised to draw conclusions.

2.1 Disaster-induced relocations

Disasters have been defined in different ways depending on the contexts and disciplines. Combs, Quenemoen, Parrish, and Davis (1999) defined disasters as ‘a time and place specific event that originates in the natural environment and the resulting disruption of the usual functions and behaviours of the exposed human population’ (p.1125). However, this definition doesn’t reflect the severity of the event. United Nations International Strategy for Disaster Reduction (UNISDR, 2009) defines disasters as ‘a serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its own resources’ (p.9). This definition represents the same as Comb’s with a special emphasis on severity of the event. Drawing from the above definitions, disasters can be defined as disruptions that put the community in need for external assistance for recovery. For the purpose of this research, UNISDR’s definition has been adopted as the definition for disasters.

EM-DAT: The International Disaster Database (2015) classifies the disasters based on its technicality as natural disasters and technological disasters. It further subdivides the natural disasters into geophysical, meteorological, hydrological, climatological, biological, and extra-terrestrial. As well as, it subdivides the technological disasters into industrial accidents, transport accidents, and miscellaneous accidents. However, an older classification by Robinson (2003) suites this article more as it is classified based on the time taken for the displacement. Robinson (2003) classifies the disasters into two main types: natural disasters and man-made disasters. It can be further divided into five subcategories (Refer Table 1). Among these types, sudden impact disasters and complex emergencies trigger immediate displacements, whereas the other types of disasters give time for a planned relocation. These categories need to be handled differently, because the people who have been displaced due to sudden impact disasters and complex emergencies might live in temporary shelters soon after the disasters. Therefore, government needs to pay immediate attention in order to reduce their vulnerability and to ensure their wellbeing.

Table 1: Disaster types that induce displacements

Natural Disasters	*Sudden impact disasters*	*Flood, earthquake, storm, volcanic eruption, landslide, tsunami*
	Slow-onset disasters	*Drought, famine, environmental degradation, deforestation, pest infestation, desertification*
	Epidemic disasters	*Cholera, measles, dysentery, respiratory infections, malaria*
Man-made Disasters	*Industrial/technological disasters*	*Activities that lead to pollution, spillage of hazardous materials, explosions, and fires*
	Complex emergencies	*War, internal conflict, human rights violation*

Source: (Robinson, 2003)

Disaster types recommended by Robinson (2003) can be categorised as shown in the Figure 1 depending on the urgency for displacement. Disaster types that are written in the grey box (Figure 1) could trigger immediate displacement or eventual displacement depends on the severity. People who have been displaced because of disasters that trigger immediate displacement would move to temporary shelters. If resettling in the same habitual residence is impossible, relevant authorities relocate them to another location permanently or semi-permanently.

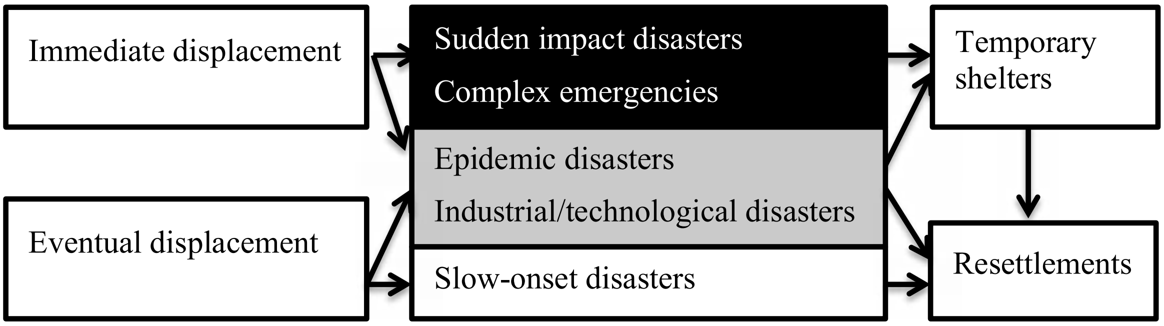

Figure 1: Urgency of displacements and disaster types

However, there are so many challenges associated in planning and implementing relocation programmes. Time is often not sufficient for proactive planning and community consultations, as it requires immediate decisions (Badri, Asgary, Eftekhari, & Levy, 2006). On one hand, living and adopting a new environment is always a challenge for the displaced persons and on the other hand hosting a new community is a challenge for the host population.

2.2 Community Disaster Resilience

Literature on disaster management is intertwined in multi-discipline approach bringing together scholars from different areas (Beggan, 2011). Progressively, the knowledge and practices of disaster resilience have been highlighted in recent past. Community disaster resilience is the ability of a community to bounce back to its operational equilibrium, while retaining its structure and identity, using common resources after an unexpected hazardous stress (Magis, 2010). However, Manyena, O'Brien, O'Keefe, and Rose (2011) argue that, the community will be in the same vulnerable state at which it has already been before the disaster, if the community bounced back to its same operational equilibrium position. Therefore, disaster resilience should be the ability of the community to bounce forward to a better position. Similarly, Aldunce, Beilin, Handmer, and Howden (2014) stated that, bouncing back to the same position is almost impossible, because disasters alter some of the characteristics which determines the equilibrium position of the community. Based on those arguments, community disaster resilience can be defined as the ability of a community to bounce forward and adopt changes within the possible minimum time using common resources while returning its essential attributes after a hazardous stress.

Generally, resilience is a system which build upon several subsystems (Holling, 1973). Similarly, disaster resilience of a community also builds up over time based on several subsystems such as social, economic, institutional, infrastructure and built environment, and community capital (Cutter, Burton, & Emrich, 2010). Researchers have identified four dimensions (4Rs) of resilience that build the properties of subsystems' resilience (Bruneau et al., 2003; Cimellaro, Reinhorn, & Bruneau, 2010). They are Rapidity, Robustness, Redundancy, and Resourcefulness (Refer Table 2).

Table 2: Four dimensions of resilience

Rapidity	*The capacity to meet priorities and achieve goals in a timely manner in order to contain losses and avoid future disruption*
Robustness	*The capacity to meet priorities and achieve goals in a timely manner in order to contain losses and avoid future disruption*
Redundancy	*The capacity to satisfy functional requirements in the event of disruption, degradation, or loss of functionality*
Resourcefulness	*The capacity to identify problems, establish priorities, and mobilize resources when conditions exist that threaten to disrupt some element, system, or other unit of analysis*

Source: (Bruneau et al., 2003, pp. 737-738)

Proag (2014) illustrated operational equilibrium/ desired functionality level as a steady state in his study. However, functionality of a community is not an outcome but a process (Cox & Hamlen, 2015). Therefore, the community's operational equilibrium cannot always be illustrated as a steady state. Because, the factors that build up the resilience will keep on changing over the time and space. Based on these facts it can be presumed that the resilience of a community cannot be equally distributed among the whole community. Further, Berkes, Colding, and Folke (2003) stated that, considering resilience within a particular time span, a single steady state is impossible whereas multiple stable states are possible. These multiple states can be the level of resilience in different aspects such as economic resilience, social resilience, ecological resilience, and built environment related resilience of a community. Within a given time, the equilibrium of a particular sector of resilience can be a single steady state. It can be illustrated as shown in the Figure 2. The recovery curve that is the equilibrium curve after the disaster can be altered depends on several factors such as intensity of the disaster, availability of resources, construction recovery, and amount of business interuption. Cimellaro et al. (2010) argues that, it is difficult to predict the tendency of recovery as it depends on several factors subject to the type of disaster, level of interuption, and state of the commuinity. Also, any forms of alterations in the community would change the tendency of their recovery.

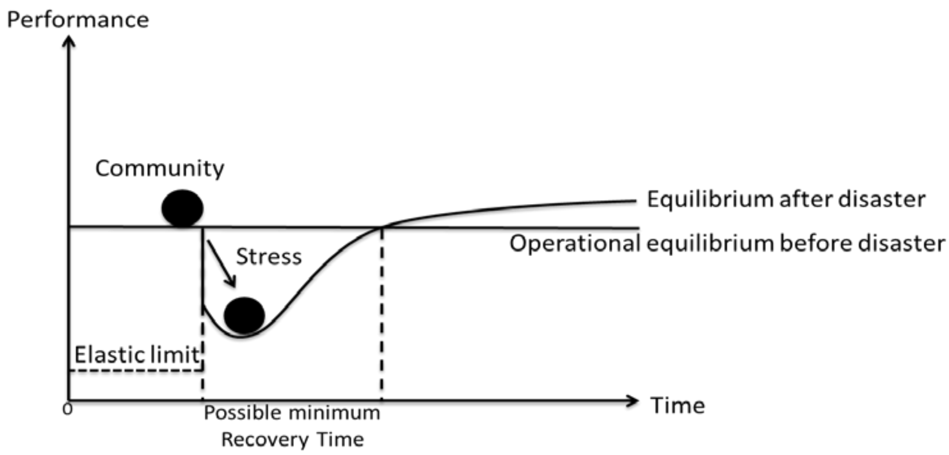

Figure 2: Resilience of a particular sector of a community

2.3 Involuntary relocations and community disaster resilience of Sri Lanka

Involuntary relocation alters the equilibrium position and stress absorbing ability of a community by introducing another community, which has a different equilibrium position. In this case, resilience of these two communities towards potential disasters could be disturbed (Refer Figure 3). Therefore, maximising the potential and collaboration of the communities is essential to enhance the overall resilience of the communities. Therefore, this research focuses on building community resilience within involuntary settlements by enhancing collaboration between host community and displaced community in Sri Lanka. Sri Lanka experienced a variety of displacements. Recent Sri Lankan case studies (Das, 2008; Manatunge et al., 2009; Perera et al., 2012; Takesada et al., 2009) encountered different issues that slowed the process of recovery after involuntary resettlement.

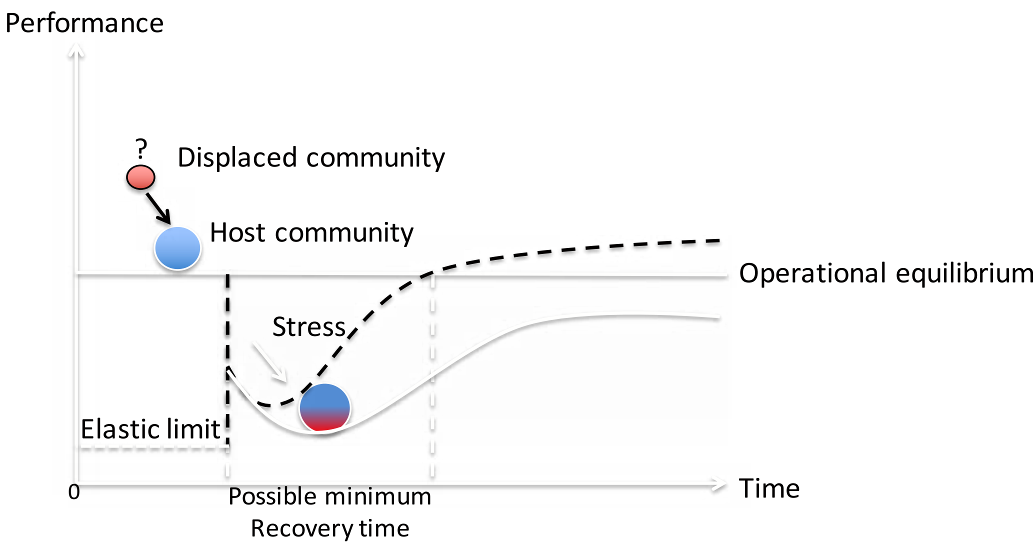

Figure 3: Resilience of a particular sector of a community after the relocation

Case 1

In 1977 the Government of Sri Lanka accelerated the Mahaweli multipurpose project to generate hydroelectric power, store and divert water for irrigation, downstream water regulation for flood control, develop human settlements, and provide physical and socio-economic facilities to settlements. This project forced around 3400 families including 900 families who are from areas prone to earth slips to relocate (Manatunge et al., 2009). However, settlers did not express satisfaction about the arrangements for more than two decades, which is a very slow recovery (Takesada et al., 2009). Takesada et al. (2009) claim that the inequality between host and displaced communities as the obvious reason for the slow recovery. Because, 60% of the settlers received only marginally productive tea plots, inexperience of the settlers within the tea plantation created a big difference in income between non-settlers and settlers shortly after relocation. This difference preventing them from acting as a community and the displaced population expressed dissatisfaction in common engagements.

Case 2

Similarly, in 2005, 1083 Tsunami affected households were relocated in Hambantota under the Siribopura resettlement-housing programme. Perera et al. (2012) stated that the income of the settlers after resettlement did not show considerable improvement. Further, the authors identified that, owing to resettlement as well as market failure generated by the absence of formal land right, 30% of the settlers lost their jobs especially farming related jobs and self-occupation. Moreover, the authors claim that the socio-cultural values were insufficiently linked with the economic and real estate aspects, which is the basis for the sustainable resettlement (Perera et al., 2012). Therefore, account has also to be taken of the change in living environment leading to conflict between the life style of the displaced and the changed environment in which they have been relocated.

Case 3

Recently, the Government of Sri Lanka entered into an agreement with the Government of India to build a coal power plant in Trincomalee and it is expected to be completed by 2017 (Ceylon Electricity Board, 2013). The project requires around 2795 acres of land, which may contribute to involuntary relocations in future, of which a substantial fraction could be in new and hitherto unfamiliar built environments.

3. Discussion

Case studies show that Sri Lankan resettled communities experienced certain issues that slow the process of their recovery. According to the case studies, the major reason is incompatible community integration. Consequently, this affects successful community integration and community resilience. However, the relocating agents have often overlooked these issues owing to time limitations, drawbacks in the policies, and financial unpreparedness (Magis, 2010). Also, potential future relocations identified in Sri Lanka through recent statistics (IDMC, 2015;

Ministry of Resettlement Reconstruction and Hindu Religious Affairs Sri Lanka, 2015). Therefore, need exists within Sri Lankan context to integrate compatible community collaboration to build community resilience. Government of Sri Lanka made several legislations and policies to execute the relocations legally and effectively. However, governments/relocation agencies adopt a top down approach by following certain procedures considering the laws, regulations, and expectations from the communities. These procedures do not include any measures to ensure the resilience of the community as a whole.

Cernea (1995) described eight economic consequences of displacements, which leads to impoverishment of the displaced persons. They are landlessness, joblessness, homelessness, marginalisation, increased morbidity, food insecurity, loss of access to common property, and social disarticulation. However, in planned relocation programmes relocating agents provide land and houses for the re-settlers. Therefore, landlessness and homelessness problem cannot exist in this context. The likely occurrence of other problems is subjective to specific cases. However, the poverty of the displaced persons cannot be denied. As Maldonado (2012) stated, IDPs suffer economically, even though all their losses have been restored.

From the study conducted by Nicassio and Pate (1984) based on the relocation of Indochinese refugees, some of the severe social problems of re-settlers can be related with planned relocations. They are, painful memories of disaster and departure, job skills and placement related issues, lack of ethnic support, cultural difference, and difficulty in practicing religion. These issues for the IDPs cannot be as severe as identified by refugees. However, it is relevant up to a certain extent depends on the level of difference between both the communities.

In some cases displaced community's economic, social characteristics affect the host community. In 1990, around 100,000 people from a particular ethnic community have been expelled from the north of Sri Lanka to the district called 'Puttalam' due to ethnic strife. Over the time, some cultural and social practices of the IDPs such as dowry system, dressing styles, have begun to influence the host community (Thalayasingam, 2009). Thalayasingam (2009) further states that the educational performance of IDP children was higher compared to the host children. Also, IDPs of Puttalam gave more importance to the education and that encouraged the local host community children to follow secondary and territory education.

However, displaced and host communities developed some clashes among themselves and displaced community has been marginalised by the host community out of fear of losing resources, government job allocation and educational quota (Brun, 2009). A common tendency can be observed based on the case studies (Brun, 2009; Thalayasingam, 2009) is, host community welcome the displaced persons at the beginning and by the time they withdraw their assistance owing to the fear of loosing resources. The reason being, migration process can be a benefit for a certain group and a loss for another group. It is difficult to identify the people who are vulnerable and who are in need. Therefore, all the assistance and benefits are given for all the displaced persons without any discrimination. This might create an imbalance in the society and lead to tension and jealousy among local people (Brun, 2009). These issues restrict both communities to act as a community and make them vulnerable to future disasters. Furthermore, disaster resilience of the community in terms of availability of temporary shelters, food supply, and evacuation plans might get affected and make both communities vulnerable to future disasters.

4. Conclusions

Disasters sometimes make lands unfit for human habitation and forces its residents to move away from it. It is government's responsibility to relocate the trapped population to another safe environment. Disaster-induced involuntary relocations are rather common in Sri Lanka. However, displaced and host communities face many problems related to economic, social, and cultural incompatibilities that could slow the recovery process. (Das, 2008; Manatunge et al., 2009; Perera et al., 2012; Takesada et al., 2009). Also, this can alter the equilibrium level of the community and disturb the disaster resilience of the community. Governments/relocation agencies adopt a top down approach by following certain procedures considering the laws, regulations, and expectations from the communities. Whereas, the ideal approach is the bottom up in which communities engaged in the decision-making. Following the ideal approach is often not practical as the government is given only limited time and resources. Therefore, finding a middle ground by connecting both the mechanisms is necessary to reduce relocation failures and to enhance quick recovery.

A conceptual model (Refer Figure 4) was developed integrating the top down and the bottom up approaches in order to find out the middle ground.

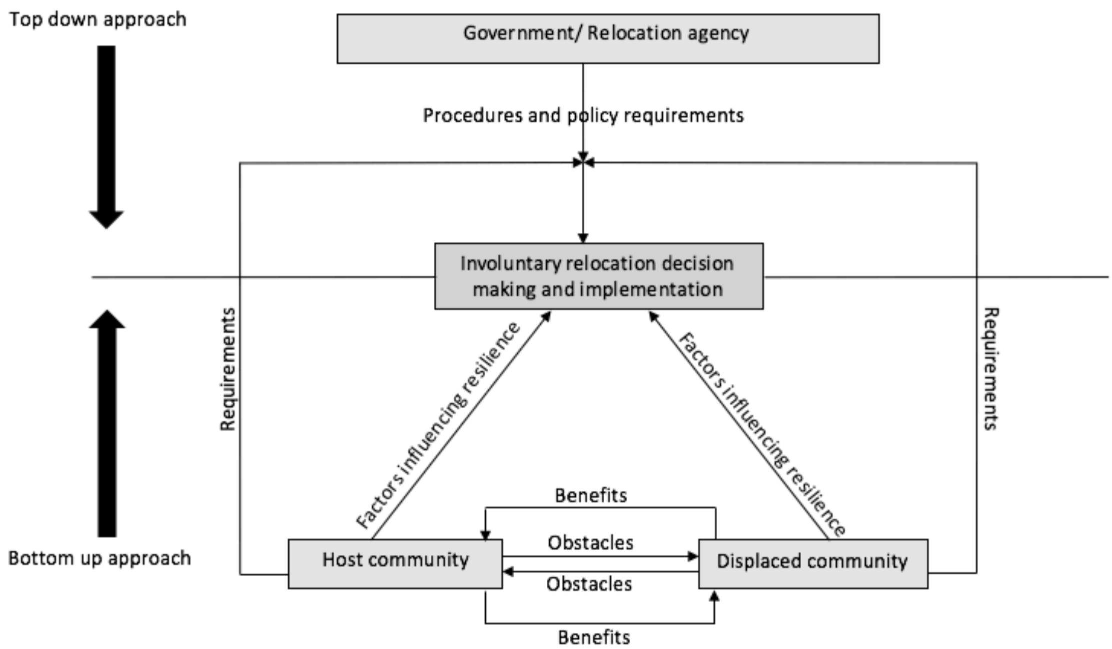

Figure 4: Conceptual model

The model shows that how relocation decision has been taken (top down approach) and how it is expected (bottom up approach). The government or the relocation agencies usually have procedures and policy requirements that needed to be followed during relocations. Also, they will consider the requirements of the communities up to a certain extend as the time and financial constraints restrict them. Similarly, host and displaced communities may have their own expectations towards the government. Also, they may have benefits and obstacles for having another community in their midst. Both the approaches have their own pros and cons. In order to achieve the benefits of both the approaches, a middle ground approach, compromising both the parties, need to be taken for a successful implementation of relocations, and to build a resilient community.

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Impact of living plants on the indoor air quality in a large modern building

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Abstract

The purpose of this paper is to investigate the use of living plants in enhancing the indoor air quality (IAQ) and the general indoor environment within a large modern open-plan office building with a central atrium design and a building management system (BMS) in place. Poor indoor air quality was measured within the building, primarily due to the low relative humidity during the winter months. Previous literature suggests that the incorporation of plants in buildings helps to regulate relative humidity whilst also bringing perceptual benefits and potentially reducing short-term sickness absence.

The investigation was developed through quantitative and qualitative data. The quantitative element involved the use of experimental and control zones within the building, selected on the basis of orientation, user density and users' work roles. Plants were selected based on the transpiration rates of various commercially-available species. Relative humidity was continuously monitored using data loggers with half-hourly logging intervals for a duration of six months. Carbon dioxide gas concentration was measured using a dedicated hand-held sensor. Qualitative user perception data was gathered through the use of a structured questionnaire distributed to staff members working in each of the experimental and control zones.

Initial findings suggest that the plants have not instigated the positive effects on IAQ that were expected. The recorded data on relative humidity displayed only non-significant variations between the experimental and control zones. These findings are attributed, in part, to the atrium design, which results in a substantial volume of air within the building, leading to cross-contamination and excessive dilution of the introduced humidity as a result of plant transpiration. The study extends the previous, mainly laboratory-based, investigations to a real working environment. However, this introduces a range of other experimental factors, thus impacting the results.

Implications for further research and practice include the extension of this research approach to consider a wider selection of buildings studied over a longer period of time, taking further account of seasonal fluctuations and the impact of additional variables present in real working environments. The practical value of this study is evident through the sustainability aspect provided by the potential of indoor plants to reduce carbon emissions of the general built environment through the elimination or reduction in use of energy and capital-intensive humidification air-conditioning systems.

Keywords: relative humidity, thermal comfort, air quality, indoor plants

1. Introduction

Over the past three decades, the indoor air quality in commercial and domestic buildings has been widely investigated with studies focusing on respiratory irritants such as nitrogen and sulphur dioxides and carcinogens such as asbestos, formaldehyde and other volatile organic compounds (VOCs). A number of authors have also investigated the percentage relative humidity (%*RH*) in indoor air which represents the ratio of the percentage of water vapour held by the indoor air to the equivalent saturation level at a given temperature. Arundel et al. (1986) and Nagda and Hodgson (2001) reported that indoor humidity is not typically classified as an indoor contaminant. However, a number of studies (Wyon et al., 2002; Wolkoff and Kjaergaard, 2007; Wan et al. 2009) and building design guides (CIBSE, 2005&2006) recommend an indoor %*RH* in the range of 40 to 60%. Humidity levels below 40%*RH* are undesirable due to negative health implications whilst humidity levels above the maximum recommended value are undesirable due to a combination of health and building damage implications. As reported by CIBSE (2006), humidity levels lower than 30%*RH* could only be acceptable for limited periods of time. CIBSE also reported that at these humidity levels, occupants could be prone to allergies and respiratory illnesses due to dust and other airborne particles.

At significantly low levels of indoor humidity, Bron et al. (2004) reported a change in the precorneal tear film in humans which results in a slight discomfort in the eye (dry eyes) while Doty et al. (2004) reported a sensory irritation of the upper airways. Wyon et al. (2002) reported that human skin exposed to 15%*RH* was significantly drier than the same skin exposed to 35%*RH*. Wyon et al. associated the latter health symptoms with the classic definition of sick building syndrome. More recently, Wolkoff and Kjaergarrd (2007), reported that the health implications of indoor humidity are complex and have not been widely investigated. This is due to the fact that the influence of the relative humidity on the combined impact of VOCs and other indoor contaminants is not well-understood. Low humidity levels are also associated with the susceptibility to electrostatic shocks. This is due to the fact that the body voltage is a function of the indoor air %*RH*. Therefore a drop in the %*RH* results in an increase in the body voltage (CIBSE, 2006). CIBSE reported that carpeted office buildings equipped with underfloor heating could be susceptible to electrostatic shocks due to significantly dry carpets. Hence, a lower limit of 55%*RH* is recommended for such buildings.

Higher levels of humidity are mostly the result of poor ventilation and significant evaporation from moisture sources such as bathrooms, kitchens and indoor plants. Such levels of humidity could lead to condensation on the internal walls, which could result in mould, microbial and house dust mite growth (CIBBSE, 2005). In colder climates, as typical to countries in Northern Europe, heated only buildings could experience prolonged periods where the indoor humidity falls below the recommended lower value of 40%*RH*. This happens as the ability of air to hold water vapour is a direct function of the temperature. Therefore, as the outdoor air is heated to the indoor room temperature, the ability of this air to contain water vapour is enhanced with a resultant drop in the percentage relative humidity. Consequently, humidification systems are incorporated in heating systems to top-up the resultant indoor %*RH*. However, in most European Union countries, the maintained indoor %*RH* levels are not stipulated through statutory laws or regulations and therefore, due to financial implications, most buildings do not make use of humidification systems.

The humidification of indoor air is typically achieved through mechanical means whereby water is heated to steam and mixed with the supply air to the building. This could result in a significant financial outlay with a further negative impact on the building's carbon footprint. In fact, for each 10kg of water vapour per hour required for humidification, circa 7.22kWh of gas is consumed, with an equivalent carbon footprint of 1.61 $kgCO_2$ (DEFRA, 2015).

As reported by Lee et al. (2002) the indoor air quality is also a strong function of the indoor carbon dioxide (CO_2) concentration. Humans exhale CO_2 and therefore, occupied indoor spaces are characterised with concentrations of CO_2 gas which are higher than the concentrations found in the outdoor air. Usha et al. (2012) reported that high levels of indoor CO_2 concentrations are associated with a poor indoor air quality which could lead to health issues such as headaches and mucosal irritations, slower work performance, and increased employee absence. Moreover, Wargocki et al. (2000) concluded that the perceived air quality in an office building was reported to improve with higher ventilation rates. This in turn yielded an improved occupant perception of the indoor air freshness, thus yielding better employee productivity levels as a result of the feel good factor and the reduced sensation of mouth and throat dryness. For this reason CIBSE (2006) recommended a fresh air supply per person between 5 and 8 litres per second which gives an internal CO_2 concentration in the range of 1000 and 1350 ppm. Intriguingly, Fang et al. (2004) reported that the impact on the perceived indoor air quality with lower ventilation rates (10 to 3.5 litres per second) can be counteracted with a reduction in the indoor air temperature and relative humidity (23^{o}C/50%*RH* to 20^{o}C/40%*RH*).

2. The use of indoor plants in buildings

Wolverton (1996) explained that during photosynthesis, plants absorb carbon dioxide from the atmosphere through the stomata (tiny openings on the leaves), while the roots absorb moisture from the soil. Chlorophyll and other tissue in the leaves absorb radiant energy from a light source, which is used to split water molecules into oxygen and hydrogen. Hydrogen and carbon dioxide are used by the plant to form sugars, while oxygen, a by-product of photosynthesis is released into the atmosphere.

Costa and James (1995) reported that plants such as Rhapis palms and Marantas, which need regular misting, or plants with high moisture content could benefit offices with low humidity. Their study found that plants can increase the relative humidity of a non-air-conditioned building by about 5%, although the density of planting required to achieve this was higher than would normally be provided for a commercial office environment. Wolverton and Wolverton (1996) suggested that plants may be used instead of humidifiers to add moisture to homes and offices through transpiration.

Smith et al. (2011) undertook a plant trial in a large open plan office, finding that short-term sickness absence reduced by approximately 50% in the planted experimental area compared to a control area in which absence increased slightly, calculating a net saving for the organisation of approximately £40,000 (GBP). However, they also acknowledged that this trial was limited to one building and, while the results supported the theory of live plants reducing absence rates, they suggested that the true effect of plants is likely to be somewhat less than the near 50% reduction noted in that trial, recommending further research in that regard. To date, we have not unearthed any significant further research investigating the effect of plants on sickness absence.

Some evidence suggests that plants in buildings may help to reduce ambient noise levels although it is unlikely that they would act as efficiently as construction elements in this regard. Costa and James (1995) contended that they may offer acoustic quieting by absorption. Freeman (2008) also reported that plants may absorb, diffract and reflect sound and this effect will be determined by variables such as the size, species and shape of the plant, as well as its container, top dressing, compost and positioning within the room. Costa and James (1995) also recommended that increased planting densities than those currently used in the industry would be required for indoor plants to be more effective in this regard.

Considerable attention in environmental psychology research has been given to the role of nature. For example, outdoor natural environments and vegetation have been shown to provide several psychological benefits including positive feelings (Sheets and Manzer, 1991), environmental concern (Lutz et al., 1999) and enhanced cognitive functioning in children (Wells, 2000). Whilst it may be impossible to have natural environment settings at many office buildings, research has considered that natural environment views from windows can provide restorative effects from mental fatigue (Kaplan, 1993) and the negative effects of job stress (Leather et al., 1998). Bringslimark et al. (2011) assessed whether office workers compensate for lack of nature views and found that workers in windowless offices were approximately five times more likely to bring plants into their workplace. Plants in the workplace have been associated with improved attentiveness (Lohr et al., 1996), task performance (Shibata and Suzuki, 2001) and reduction in symptoms of sick building syndrome (Gou and Lau, 2012).

3. Methodology

The building considered in the present study is the head office building of a Local Authority in the UK, located in southwest England. This detached building was constructed in 2011 and consists of three floors with a total floor area of circa 10,300 square meters of office space. The latter is predominantly arranged in an open floor design surrounding a central atrium (figure 1) with the main entrance located at the ground floor level. The building has an energy performance operational rating of 'C' with an annual gas and electricity consumption of 73 and 72 kWh/m^2/year respectively. 13.3% of the former and 0.4% of the latter is attributed to renewable forms of energy. Gas is the main fuel used for heating whilst electricity is used for lighting and all other power requirements typical to an office building. The building services are fully linked to a central Building Management System (BMS) which controls the ventilation, heating and the opening and closing of apertures. The building design allows a significant percentage of the required ventilation to be achieved through natural stack ventilation through the atrium. Strategically located CO_2 sensors monitor the indoor air quality with the mean indoor CO_2 concentration maintained at circa 700 ppm. A central HVAC system, located on the roof top, provides heating and supplemental ventilation through floor level diffusers with the winter and summer indoor set point temperatures set at 22^{o}C. No cooling or humidification systems were available. As illustrated in figures 1&2, the double skin south facing façade offers sound insulation from the high-traffic road running along the south side as well as shading to minimise the solar gains during the peak summer months. There were circa 1000 adults working in the building with typical office hours between 8 am and 7 pm whilst the services offered were predominantly of a back office type.

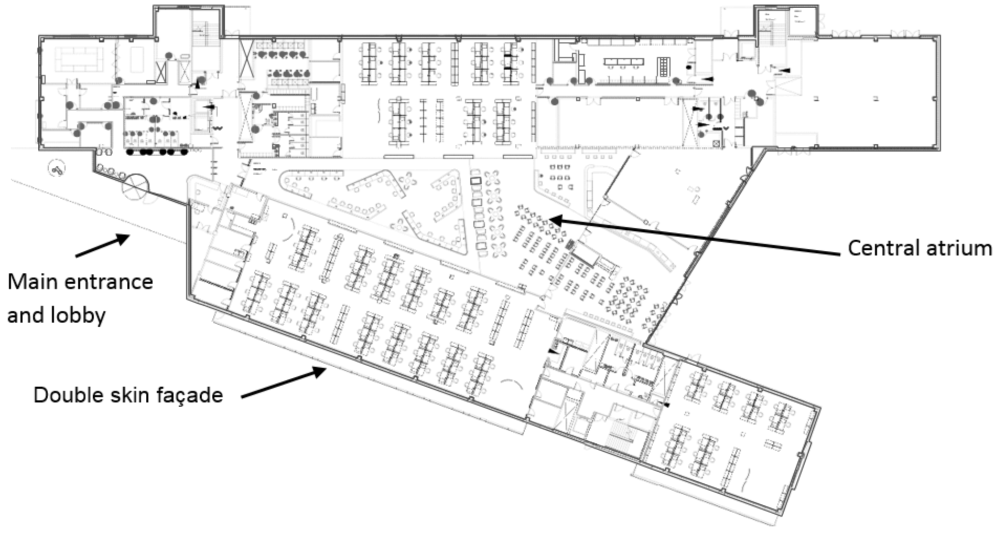

Figure 1: Plan design schematic for the ground floor

Figure 2: Central atrium design and south facing shaded façade

Live indoor plants were installed in this building within the first floor southern section of the building for a period of six months from December 2014 to June 2015. A further two control areas were designated in the ground floor southern section (directly below the experimental zone) and the first floor northern section (across the open atrium from the experimental zone). Following a similar methodology to that of Smith et al. (2011), these areas were selected due to them being of similar size and occupied by approximately the same number of people, doing similar jobs.

The plants used were selected mainly for their transpiration rate, according to Wolverton (1996) as well as factors such as ease of maintenance, light requirements, size, shape and general aesthetic qualities (Smith et al., 2011) as advised by a professional indoor planting company. They supplied and maintained the plants throughout the trial period for the reason that previous research has shown that the plants must be in the optimal condition for them to be successful in regulating the indoor climate within buildings (Costa and James, 1995; Smith and Pitt, 2011).

The plants used are detailed in table 1 and these were installed at a density a little greater than under normal commercial conditions, leading to the experimental zone being relatively densely planted.

These included 30 floor-standing plants as well as a range of 24 smaller desk bowls, mainly positioned on shared furniture such as filing cabinets. The plants were all soil-grown and provided without top dressing. According to the advice of the planting company, total transpiration for the experimental zone was expected to be around 21 litres of water per 24 hours. Maintenance of the plants including watering, dusting and pest control (using natural products) was undertaken every 2 weeks.

Table 1: Plant species installed in the experimental zone

Number	*Container*	*Plant*	*Plant height (m)*
12	*Plastic trough (40cm x 18cm)*	*Spathiphyllum Sensation (Peace Lily)*	*0.35*
12	*Plastic trough (40cm x 18cm)*	*Nephrolepsis (Boston Fern)*	*0.40*
20	*Round plastic (40cm x 43cm)*	*Areca Palm*	*1.80*
10	*Round plastic (40cm x 43cm)*	*Dracaena Janet Craig*	*1.80*

3.1 Relative Humidity

The relative humidity, measured by two column-mounted HOBO UX100-003 humidity sensors in each zone (six sensors in total) with accuracy of ±3.5%, represents the ratio of the actual water vapour density to the saturation vapour density given in equation (1). Readings were taken at half-hourly intervals at each logging point. As illustrated in figure (3), the saturation vapour density is a strong function of the air temperature. Therefore, a unit increase in the air temperature results in an exponential rise in the capacity of air to hold water vapour. Hence, if no extra water vapour is added to the heated air, the %*RH* drops.

$$\%RH = \frac{\rho_{actual}}{\rho_{saturation}} \quad \textbf{(1)}$$

where ρ is the density at actual and saturation conditions in kg/m^3

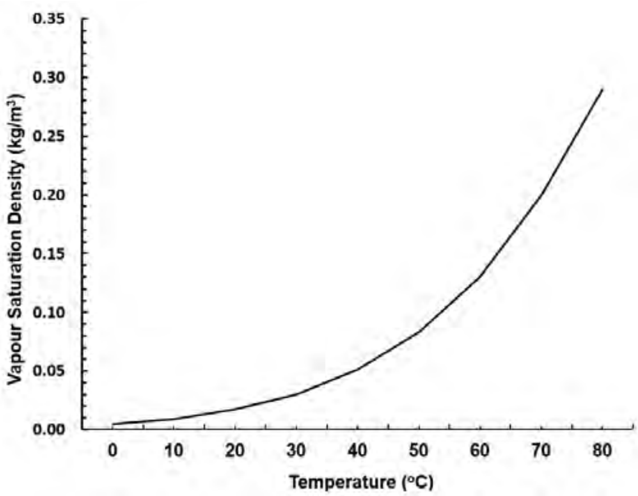

Figure 3: Vapour saturation density with temperature

3.2 Employee perceptions

Employee perceptions were tested using an online questionnaire, which was completed by occupants of the experimental zone as well as the two control zones. The questionnaire asked respondents to consider whether any of the following issues have changed since the beginning of the plant trial with options of improved, stayed the same or got worse:

- Humidity;
- Temperature;
- Background noise levels;
- Light levels;
- Personal space;
- Work area design and layout;
- Privacy;
- Work environment aesthetics.

The questionnaire remained open for a period of two weeks towards the end of the trial in June 2015. Of the respondents who completed the questionnaire, 61 (55.45%) were located in the two control zones, while 49 (44.54%) were located in the experimental zone, giving a total of 110 respondents.

4. Discussion

Figure 4 illustrates the data for the indoor relative humidity and temperature in relation to the outdoor conditions. The total water supplied to the plants over the experimental period was measured as 3822 litres. With a total foliage area of circa $40m^2$, this results in a transpiration rate of circa 21.8 g/hr m^2. Contrary to the expectations of the present study, no significant differences in the relative humidity were measured in the experimental and control zones. This could be attributed to the building design which resulted in significant cross-contamination of the indoor air. Therefore, the open plan atrium design resulted in the mixing of the air in the experimental and control zones. This yielded a significant dilution of the water vapour transpired by the indoor plants located in the experimental zone. Therefore, considering the building design adopted in the present study, our data shows that it will be necessary to populate all the indoor areas with plants in order to achieve tangible results for indoor humidity levels. Furthermore, the recorded mean indoor CO_2 gas concentration was in the range of 850 to 1000 ppm. As reported by Lee et al. (2002) and Usha et al. (2012) such concentrations are considered as indicative of good indoor air quality levels. In fact, CIBSE (2006) recommends a ventilation rate yielding an indoor CO_2 concentration in the range of 1000-1350 ppm. Therefore, our data shows that the results of the present study cannot be attributed to overventilation.

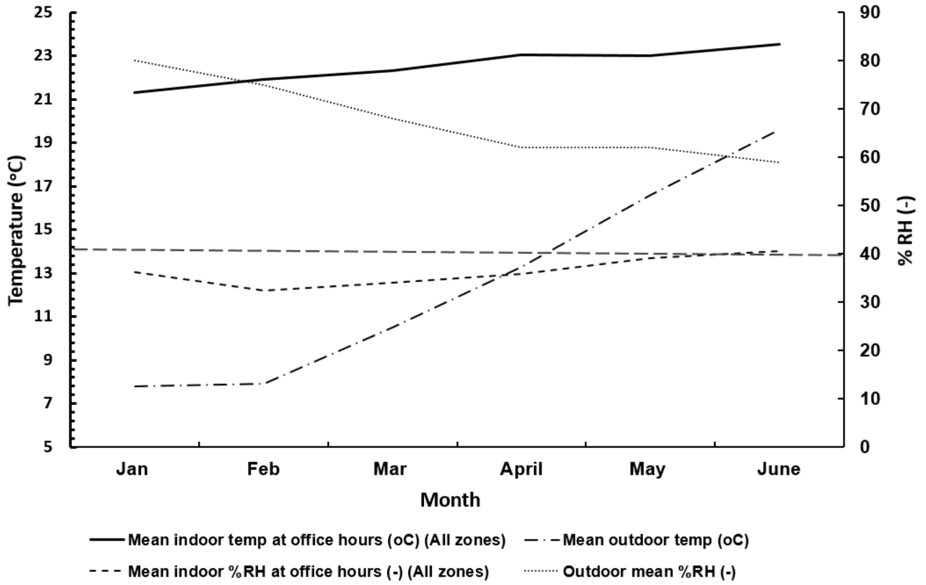

Figure 4: Indoor and outdoor temperature and %RH with the target 40% indoor RH highlighted by the horizontal dotted line

Figure 4 illustrates the trend where the lowest relative indoor humidity levels were recorded during the month of February whilst the highest indoor humidity levels were recorded during the late spring months. As illustrated in figure 3, this trend can be directly related to the relevant outdoor temperatures. Hence, during the month of February, the outside cold air could only hold a small fraction of water vapour at saturation conditions, and therefore, the warming up of this air to room temperature resulted in a significant drop in the indoor relative humidity. As reported by Wan et al., 2009 and CIBSE 2005, the indoor humidity levels should be in the range of 40-60 %*RH*. Therefore, it is evident that during the first four months of the year this minimum threshold was not satisfied.

As anticipated, the qualitative data from the staff survey yielded a noticeable shift in perception within the experimental zone regarding improved indoor relative humidity, although this is at odds with the measured quantitative data. Approximately 27% of respondents in the experimental zone perceived that %*RH* had improved and 65% felt that it had remained the same, with a minority of approximately 4% believing that it had got worse. In the control zones, the majority of respondents reported that relative humidity had remained the same (97%) as shown in figure 5. In accordance with Wargocki et al. (2000) this perceived air quality improvement may yield an improved occupant perception of the indoor air freshness, leading to improved employee productivity levels. A similar trend was noted in regard to temperature, with the experimental zone respondents perceiving improvements in temperature, which is also at odds with the measured data. However, the majority of respondents in all areas perceived that temperature remained the same as shown in figure 6.

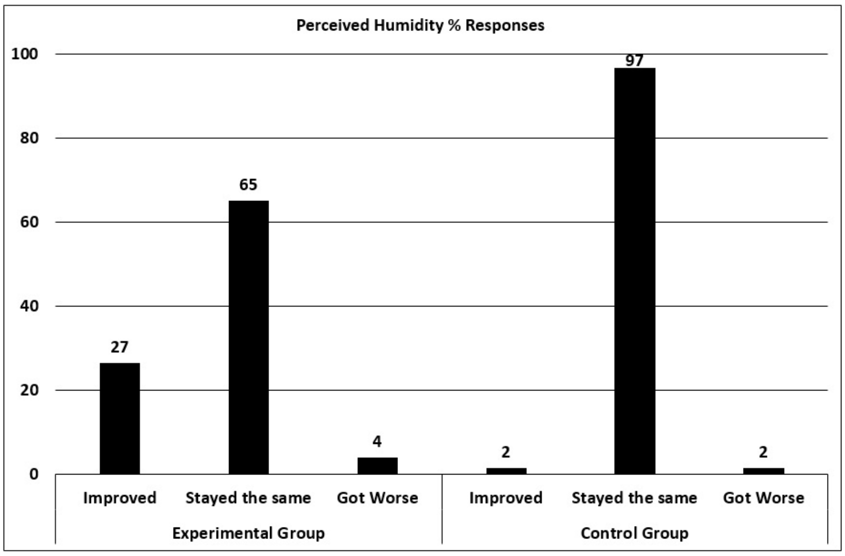

Figure 5: Perceived changes in humidity during the trial

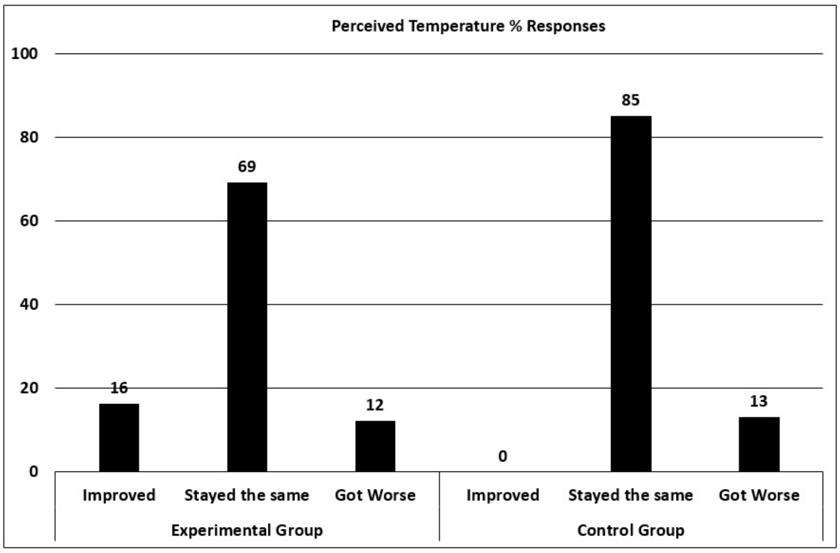

Figure 6: Perceived changes in temperature during the trial

In accordance with research by Costa and James (1995) and Freeman (2008), results suggest an improvement in perceived background noise levels within the experimental area. Although physical measurements of noise levels were not carried out in this research, this may provide an indication of the sound absorption properties of plants in buildings. Of the respondents in the experimental area, 22% perceived an improvement in background noise levels, compared to 0% noting improvement in the control areas as shown in figure 7.

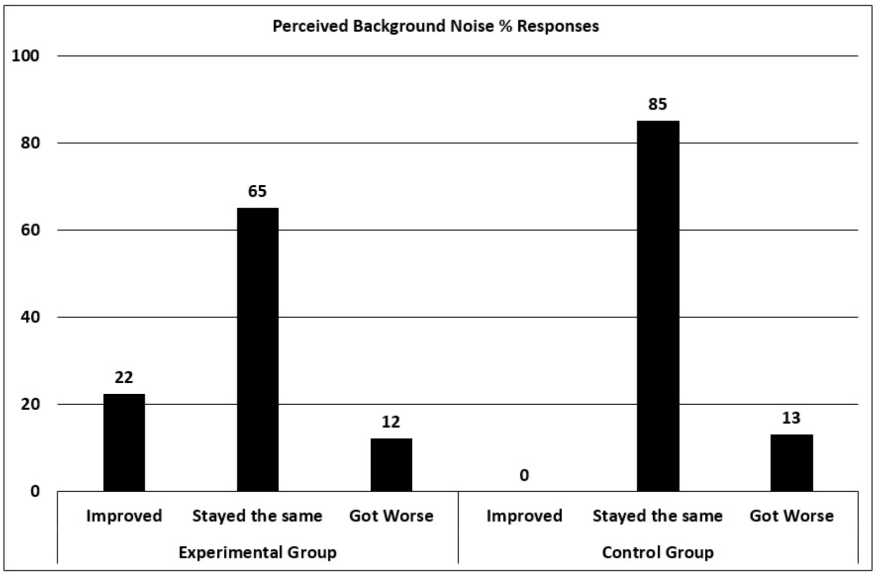

Figure 7: Perceived changes in background noise during the trial

The most significant improvement rate in the experimental area regards office aesthetics as shown in figure 8, with the majority of respondents in the experimental area (45%) perceiving an improvement, although a relatively significant response rate of 20% of respondents in the experimental area also felt that aesthetics got worse, reflecting the subjective nature of office design considerations. This result also supports previous research, which identified a general preference for plants (Smith and Pitt, 2008).

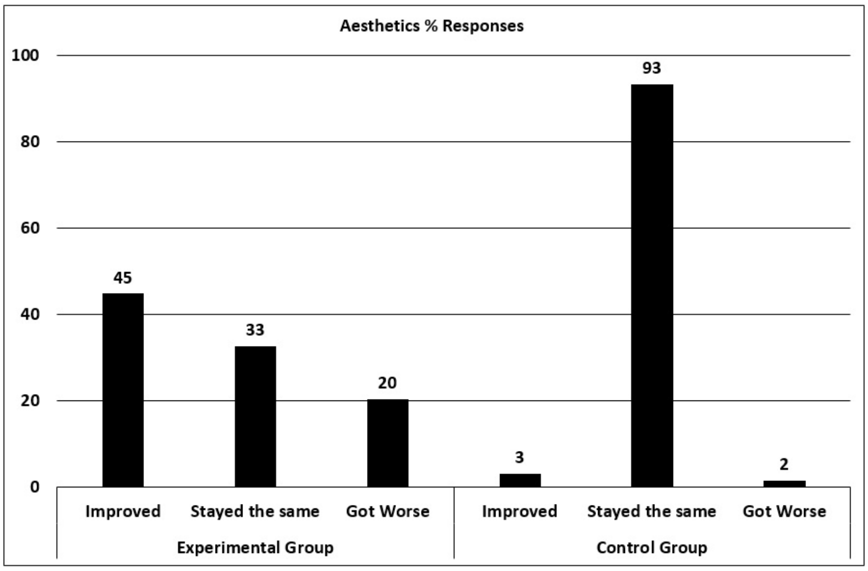

Figure 8: Perceived changes in aesthetics during the trial

Some of the more negative responses regarding plants concerned light levels and personal space, with significant responses from the experimental area suggesting that these had got worse since the beginning of the plant trial, 47% in the case of light and 39% in the case of personal space. This is perhaps unsurprising, given that many of the plants were relatively large, providing shading and potentially reducing natural and artificial light, at the same time as taking up floor and surface space.

Regarding design and layout, the majority of respondents in the experimental area and control areas perceived that this had stayed the same (67% and 93% respectively), perhaps suggesting that the plants were not regarded as a design and layout aspect. However, 27% of respondents in the experimental area perceived that this had got worse, possibly in line with the question on personal space.

The result on privacy perceptions was inconclusive for the experimental area, with the majority (76%) perceiving that it had stayed the same and 12% noting an improvement, which may have been due to the plants. However, 10% considered that privacy had got worse. The reason for this is not clear, although results on this question are possibly dependent on location of the respondents in relation to the positioning of the plants. Within the control group, 92% perceived that it had remained the same, while 7% felt it had got worse. As with the experimental group, it is not clear why privacy may have got worse and we are not aware of any further interventions within the office space.

5. Conclusions

The current study has shown that the use of plants to enhance the indoor air quality is a feasible option which could result in both tangible and intangible benefits. In spite of the fact that the measured relative humidity data for the experimental zone failed to suggest a significant rise in the indoor humidity levels, the water supplied to the plants over the test period, together with the typical indoor plant transpiration rates reported in literature, suggests that the transpiration rates are significant. Therefore, when coupled with an improved control of the indoor air flow, the plants have the potential to supplement the indoor relative humidity, thus improving the building comfort and potentially yielding energy savings where humidification systems are installed.

These results also need to be considered in the context of the potential perceptual or psychological effects of plants uncovered in previous studies and supported in this study. Perceived improvements were noted in regard to perceived indoor relative humidity (%*RH*), temperature, background noise levels and aesthetics. However, perceptions of light levels, personal space and privacy got worse in this study.

Further work will be undertaken on the analysis of the air flow patterns in the building through computational fluid dynamics (CFD) techniques. Funding will also be sought for the installation of plants in all the indoor zones. The evaluation of the potential energy savings through the use of plants as a replacement to traditional humidification systems will also be developed. This will be done through the concurrent analysis of the potential transpiration of plants in relation to the water vapour top-up required during the winter months.

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The Choice of Façade Material
- Values and Beauty

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Abstract

With the need for more environmental friendly buildings in mind, the object of the study is to investigate what factors influence the choice of façade materials in a contemporary Norwegian building project. Later years there has been an increased focus on environmental friendly building. Official politic, legislation and official support of different organisations advocating sustainable building aim at affecting the level of sustainability in the building industry. Finding answers to the research question, the article aims to contribute to the picture of to what extend sustainable values affect the decision makers. In this specific case we have looked at seven public projects. The method used consists of a literature research, seven interviews with the respective client project managers and five of the architects. Additionally a study of the different projects' available project documents, was conducted. In some projects, the choice of façade material was influenced by the general guidelines originating from the government, the user, the client or special building programs. For the projects that were examined methods such as LCC calculations, greenhouse gas accounting and LCA analysis, with the respective tools LCCweb.no, klimagassregnskap.no and SimaPro, were part of the basis for decision-making for facade claddings. For some projects, these analyses and calculations were used only due to documentation requirements, and thus had no major impact on the decision-making. For other projects, they were used to evaluate alternatives on product level. The findings in this investigation shows that sustainability, aesthetics and cost are considered to be the most important factors influencing the choice of façade material. The participation in different sustainability programs do seem to have influenced the evaluation and choice of façade material, both through developed processes and the required use of tools aimed at measuring. The decision makers conclude on a spectre of materials such as different wood solutions and bricks. The explanation for this is partly the projects' different functions, partly how the different project groups execute and evaluate the environmental analysis, and partly the differences in project goals.

Keywords: Sustainable, decision making, façade material

1. Introduction

In the first century BC, Vitruvius wrote about architecture, and is known for the criterions on which to judge good architecture; firmitas, utilitas and venustas – durability, utility and beauty (Vitruvius and Rowland 2007). Vitruvius also wrote about economy and the balancing of cost and common sense in the construction. Resent research has been done to investigate how architects evaluate architecture, and in respect of the façade Vitruvius' criterions are still valuable (Volker 2010). In the later decades, daylight and the use of glass has been considered an important quality, especially in school buildings (Wu and Ng 2003), although recently – at least in Norway – a focus on environmental issues has led to less emphasis on daylight (Houck 2015). The façade is a crucial part of the building design. It not only gives a signal of a building's function and content, but also often, intentionally or unintentionally, reflects a client's values. Functionally the façade works as a climate shield and weather protection. The façade can have a transparent, less transparent and close appearance. Traditionally, the choice of facade material has been linked to parameters like construction, available materials, design and cost efficiency. More recent factors to consider are energy solutions and environmental aspects.

The research question in this article is:
- What factors influence the choice of façade materials in contemporary public Norwegian building project?

The research is limited to look at the choice of façade materials for office buildings and buildings for education within two different public clients; Statsbygg, and Undervisningsbygg. Statsbygg is the Norwegian government's property developer. Undervisningsbygg is the Oslo public building agency for school buildings. Project leaders and architects who have participated in to seven building projects are interviewed about the process and considerations leading to the final choice of façade material. The Norwegian building industry consist of different participants who may have different interests, but who at the same time are dependent on each other. The different participants' experience and competence is mainly developed through the execution of building projects. Parallel governmental financed organisations are working to affect the building industry to develop more sustainable and environmental friendly buildings. Limited to the decisions on façade materials, this paper will look into to what degree such organisations and public programs succeed to play a role when it comes to the decision making in a project. It has been out of the boundaries of this investigation to look at how the different environmental tools have been used. E.g. if the GHG calculations have included production, transportation and embodied CO_2 in materials, and operational energy.

2. Theory and framework

2.1 Previous research

Denizou at al have investigated the choice of material for larger urban buildings. The purpose has been to find the mechanisms behind the choice of materials with emphasis on wood. Main findings are that public framework can affect the choice of building materials. The research group recommends to emphasize pilot projects as a tool to achieve more knowledge and acceptance towards the use of wood in future urban building projects (Denizou, Hveem et al. 2007).

In 2012 the Statsbygg, the Norwegian Directorate of Public Construction and Property, ordered a report from Rambøll to investigate what arguments are used to choose other building materials than wood, and to examine when in the building process wood is deselected (Rambøll 2012). Main findings in this research are 1) that requirements related to building materials may be incorporated in public zoning plans, and 2) the participant who influence the most on the choice of material depends on the project procurement arrangements.

A Norwegian research, based on a questionnaire answered by 285 architects, indicate that the architects` intentions to use structural timber in urban buildings is influenced by attitudes towards using structural timber in buildings three to five stories or more. The findings also show that the architects' preference towards the use of structural timer is related to previous experience with the use of structural timber in urban construction (Bysheim and Nyrud 2008).

2.2 Public framework and programs

Currently there exists different initiatives and building programs supporting and promoting more environmental friendly building. Generally one could say that for the investigated projects, all the clients have environmental aspirations. These aspirations are operationalized through the cooperation with the different frame work initiatives.

Framtidens byer – Cities of the future – was founded in year 2008, and is a cooperation between the state, the private sector, and thirteen biggest cities/municipalities in Norway. The goal is to reduce the use of energy, reduce carbon dioxide emissions, improve the city environment and adaption to climate change (Kommunal- og moderniseringsdepartementet 2014).

FutureBuilt is a part of Cities of the future. The vision of the program is to develop high quality sustainable buildings and city areas of the 13 member cities. The program emphasize high quality architecture close to public transport. The National Association of Norwegian Architects is responsible for the managing and operation of the program. The program runs from year 2010 to 2020. The program not only has a set of requirements to be met by the buildings adopted by the program, but also have mandatory requirements to the development and building process itself such as; architecture competitions, greenhouse gas accounting, user participation processes and Building Information Modelling (BIM).

Framtidens Bygg – Buildings of the future, is a also a part of Cities of the future and is available for 10 more cities than the member cities. The target is to participate in pilot projects, and develop competance and experience in sustainable planning, building and rehabilitaiton of buildings. A set of quality requirements are developed and has to be met for buildings adopted by the programe. (Moe and Waage 2014, Kommunal- og moderniseringsdepartementet 2015). Projects adapted by the program are offered consultant help, seminars, planning tools and working methods. The National Association of Norwegian Architects is responsible for the managing and operation of the program.

ZEB (Zero Emission Building) is a Norwegian national research centre on zero emission building. The goal is to eliminate the greenhouse gas emissions caused by buildings and place Norway in the front of innovation and implementation within the field. The main objective is to develop competitive products and solutions for existing and new buildings. The centre encompasses residential, commercial buildings and public buildings. The ZEB centre has 24 public and commercial partners, and it is organized as a joint unit hosted by the Norwegian University of Science and Technology (NTNU) and SINTEF, geographically located in Trondheim (ZEB 2015). ZEB-COM is a term meaning Zero Emission Buildings – Construction, Operation and Materials (Statsbygg 2015).

Enova was established in year 2001 and is owned by the Norwegian state. The objective of the organization is to promote more environmental friendly consumption and generation of energy in Norway. Enova does this through targeted progammes and support schemes. The enterprise is financed via funds allocated from the Energy Fund. The Energy Fund is financed via a small additional charge to electricity bills. Additionally, the Energy Fund has been allocated the proceeds from "The “Green Fund for Climate, Renewable Energy and Energy Efficiency Measures”. The Green Fund’s capital this year is 35 Billion NOK (ENOVA).

It will be beond the limits of this article to go into the accurate definitions of the different terms like passive house, almost zero energy building (nNEB), zero energy building and pluss energy house. But to explain theese terms very short, a building with passive house standard follows the requirements in the Norwegian standard NS3701:2012 - Criteria for passive houses and low energy buildings. School buildings should use less than 75kwh/a. An “almost zero energy building” (nNEB) definition is proposed in a cooperated report as a building using less than 70% energy then the requirements in TEK10 – the Norwegian building regulation, which means 36 kwh/a for school buildings (Rambøll and Arkitektur 2013). A common definition of the term “pluss energy house” is a building where the building through its lifespan (often used 50-80 years) generates more energy than it consumes during its lifespan, the production of building materials and the construction itself included. FutureBuilt defines plus energy house based on the energy use during the operation (SINTEF-Byggforsk 2014).

2.3 Statsbygg and Undervisningsbygg

Statsbygg manages and operates 2,350 buildings, spread across 600 sites in Norway and abroad. Statsbygg yearly operates about 160 construction projects (Statsbygg 2015). According to Statsbygg, this was the first Norwegian organization in its size in the construction industry having a strategy towards sustainable building including reduction of greenhouse gases. Todays strategy focus on redusing the energy consumption in buildings, reduction of greenhouse gases and the limitation of materials containing substances hazardous to the environment . Long term goals are among others, zero energy buildings and reduced environmental footprint. Short term goals are the use of EPD – environmental product declarations for minimum ten products, the limitation of envrionmental hazardous substances in materials and the limitation of materials from not renewable resources (Statsbygg 2014).

Being the Oslo public building agency for school buildings, Undervisningsbygg manages, operates and maintain 1,3 million m2 of building area. Undervisningsbygg manages 750 buildings, and constructs yearly for about 235 million euros (Undervisningsbygg 2014?). According to Undervisningsbygg's strategy document on sustainability 2012-2015, the three main focus areas are energy use, waste and the use of environmental friendly materials (Undervisningsbygg 2012). In the period 2012-2015 Undervisningsbygg plans to use BREEAM in pilot projects, but non of the investigated projects are using BREEAM.

3. Method

The methods used are literature study, case studies, and interviews. Public projects were chosen as case studies, and the two collaborating public building organisations were Statsbygg and Undervisningsbygg. The case study of consists of seven Norwegian public building projects, some finished, and some still in the planning process during the study, see table 1. In depth interviews have been conducted with 12 clients and architects involved in the projects (table 1). An interview guide was developed for the interviews. The first part of the interview aimed at mapping general information about the informer, the organisation and the actual project. The second part of the interview was related to the façade itself; the factors influencing the choice of material, and what participant affecting and deciding the material, and lastly when in the process the choice was made. The interviews were conducted by two persons, one interviewing, the other taking notes. Additionally, the interviews were recorded. The processed texts (in Norwegian) were mailed to the participants for control. Additionally project documents has been examined; Policy documents, Technical documents, reports on LCC, LCA, GHG calculations and the use of EPD (Environmental Product Declarations).

The choice of case studies is the result of a cooperation with Statsbygg (SB) and Undervisningsbygg (UB), and is as followed:

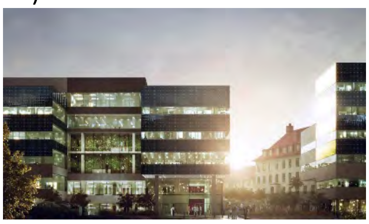
	Function	M2	Client	Status May 2015	Contract type	Project leader/ Architect
1	Police station	3170	SB	Building process	Turnkey	PL1/Arch. not available
2	Research	7475	SB	Planning	Alliance with turnkey	PL2/ARCH2
3	Office, teaching	1250	SB	Planning	Alliance with turnkey	PL3/ARCH 3
4	Office	49700	SB	Planning	Traditional contracting	PL4/ Arch. not available
5	School	11680	UB	Planning	Turnkey	PL5/ARCH5
6	School	9677	UB	Finished	Turnkey	PL6/ARCH6
7	School	9750	UB	Under construction	Turnkey	PL7/ARCH7

Table 1: Investigated projects

1)

2)

3)



4)

5)

6)

7)

Fig.: 1) Vabakkjen (Link Arkitektur), 2) Framsenteret (pka Arkitekter), 3) Campus Evenstad (Ola Roald Arkitektur), 4) Folkehelseinstiuttet (Ratio Arkitekter), 5) Brynsengfaret skole (HRTB Arkitekter), 6) Bjørnsletta skole (L2 Arkitekter), 7) Lillohøyden skole (Planforum Arkitekter)

4. Results

All the investigated projects turned out to have strategic goals concerning sustainability. 5 of the 7 projects were part of Fremtidens Bygg, FutureBuilt or ZEB. In four of the projects, this has resulted in a passive house energy standard requirement. Two of the projects have expressed energy requirements on the level of zero, or close to zero energy use and are considered pilot projects by the client. One project has the goal to be a so called plus energy house.

The majority of the interviewees consider the construction of the outer wall and the façade material as two independent building elements. The interviewees were coherent in their opinion about the process leading to the final façade material. During the conceptual planning, the material was chosen in general terms, e.g. wood or stone. In the detail planning a more specific product was chosen, and then later the exact way of execution, formats and fixing was decided.

All project used the tool LCCweb.no (Life Cicle Cost). Mostly, this executed by the client, but also in some cases by the contractor. In some projects, the LCC calculations played an important role in the decision of façade material. In one project, local building regulations required brick, and therefore an LCC analysis could not be crucial. GAG analysis, using the tool klimagassregnskap.no, were executed in all of the projects, but would not necessarily be crucial. In project 7, a GHG analysis was executed to fulfil the requirements in the contract, but had no practical influence on the choice of materials. The GHG calculation includes material, operational energy use, operational transport, energy use and transport in the building phase. All projects used EPDs as a tool, and applied this on the façade material. The results show, that despite all projects having ambitious sustainability goals, a variety of façade materials such as wood, fiber concrete and bricks were chosen.

The interviews show that the choice of façade material was highly influenced by the environmental ambitions and also the program the project was part of.
PL1: “The project went from passive house standard to plus house standard during the process.”
PL2: “In an early phase of the project, it was decided to reduce the greenhouse gas emissions with 50%. This affected the choice of façade material.”
PL 5: “As a consequence of being a Future Built project, changes may happen.”
PL 6: “Gradually the project became a Future Built project, and therefore a strong focus on sustainability. As a result of this process, the façade material was changed.”
ARCH 6:”For a Future Built project, not only the architectural aspects count in the choice of material, but also the material has to prove to be sustainable.”

Statsbygg, Undervisningsbygg and the respective programs had “sustainability” procedures linked to the different design stages. Mostly the interviewees regarded these systems as valuable, and were satisfied with the systematic and also predictable approach. But also there were critical statements as PL4: “decisions need long processes. You need a parliamentary resolution to continue. This can also be a weakness.”

Some of the interviewees mentioned concerns about the outer wall thickness linked to passive house demands. In most cases the informants consider the choice of façade material as independent from the outer wall construction. The exception in this investigation is the project 3 Campus Evenstad, where the outer wall is constructed in one piece; a cross laminated timber (CLT)/insulation sandwich (80 mm CLT, 310 mm wood fiber insulation, 60 mm CLT).

Table 3 shows the different material choices in the investigated projects. Four of the projects have concluded to use wood as the main façade material. In two projects – both schools, it was decided to use brick, and in one project fiber cement cladding. The interviewees in the two brick projects were the opinion, that despite a high GHG footprint, brick would score well the longer the life span of the LCC calculation. Especially in rough-use environments like schools, brick was considered a good choice. In project two, the client was sceptical to the use of wood due to the rough use of school, but decided to use Accoya and not brick.

Of the four projects where wood was chosen as the main façade material, the involved interviewees meant that wood the main challenge of wood was durability. Of the three school projects in this investigation, only one project has chosen a wooden façade. "It should not be "legal" to use wood in school buildings," one interviewee said, due to the rough use. The four "wood" projects choose different types of products; accoya, Kebony, pine (panels) and CLT. In one project also solar panels were chosen. This was made possible due to funding by Enova. Also the client wanted to test this technology/material and learn from it. Also in project two and six brick was considered seriously. PL 2 said,"a GHG evaluation of brick with a 60 year building life span turned out positive compared to wood. A holistic conclusion was necessary to exclude brick." PL6 said a wide range of materials were assessed, but brick was not possible to choose due to the GHG footprint.

Project	Program	Ambition	EPD	GHG	LCC	Main façade material
1	Framtidens bygg	Passive house and later plus house	Yes	Yes	Yes	Untreated ore pine
2	Framtidens byer	Passive house, Pilot Project	Yes	Yes. Operation, Materials, Transport	Yes	Kebony
3	ZEB-COM	Zero energy, use of timber, pilot project	Yes	Yes. Construction, Materials, Operation	Yes	Cross laminated timber
4	FutureBuilt	Passive house, maybe close to zero	Yes	Yes. GHG reduction 50%	Yes	Fiber concrete
5	FutureBuilt application	Close to zero energy house (nNEB), pilot project.	Yes	Yes.	Yes	Brick, integrated solar panels
6	FutureBuilt	Passive house (first school in Oslo)	Yes	Yes. Operation, Material, Transport	Yes	Accoya
7	.	Passive house	Yes	Yes	Yes	Brick (requirement in the zoning plan)

Table 3: The different projects and their choice of façade material

Factors for choosing façade material

Figure 2 shows how the interviewees have answered on the question on what factors were emphasized when choosing the façade material in the project. The most frequently mentioned factors are sustainability (11), aesthetics (9) and cost (8).

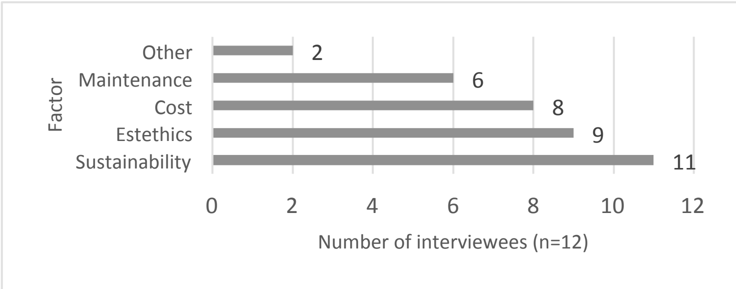


Figure 2: Factors emphasized when choosing façade material

In some projects, the choice of façade material was influenced by the general guidelines originating from the government, the user, the client or special building programs. For the projects that were examined, methods such as EPD analysis, LCC calculations, greenhouse gas accounting and LCA analysis (only project 3) were part of the decision-making for facade claddings. For this purpose the respective tools LCCweb.no, klimagassregnskap.no and SimaPro were used. For some projects, these analyses and calculations were used only due to documentation requirements, and thus had no major impact on the decision-making. For other projects, they were used to evaluate alternatives on product level. In projects with a clear focus on GHG, brick could not be an option according to the interviewees. Also the interviewees were the opinion that in projects with only documentary requirement and not specific measurable goals, there is room for more holistic interpretations and decisions. Also, in some projects LCC analysis are executed on the type of material, but not used to compare the same type of material, but for different products.

5. Discussion

The findings in this investigation shows that sustainability, aesthetics and cost are considered to be the most important factors influencing the choice of façade material. In this research sustainability seem to be a factor as important (or more) than aesthetics. We have to have in mind, that the sustainability goals in each project are measurable, whereas aesthetics are not. However, a possible future research question is to investigate to what degree the conception of beauty is in change. More simple expressed; how can something be beautiful if it is not sustainable? If the architects' or clients' conception of aesthetics change to correspond with sustainable solutions, then there will be no contradictions between the two parameters aesthetics and sustainability.

When the term or factor "sustainability" is broken down into different elements, it becomes clear that the projects have different ambitions. The use of LCC and GAG analysis vary, and also the importance in the decision making. In all of the investigated projects, an EPD analysis of the façade material is executed to determine the final façade material product. The difference in energy ambitions can partly be explained by the difference in building year; Bjørnsletta was the first passive house school in Oslo. Campus Evenstad, if the project reaches its goals, it will be the first ZEB-COM building in Norway. So, even if Bjørnsletta is not defined as a pilot project, and has lower ambitions than Evenstad – which is called a pilot project, they are both "first off" projects in their context. In the Statsbygg report of Rambøll, one conclusion was that the participant who influence the most on the choice of material depends on the project procurement arrangements. However, in this research there are different project procurement arrangements, but all very ambitious. Maybe the question of which participant influence the most is of less interest – as long as there are ambitious and measurable sustainability goals, and a culture or framework on how to work with this aspect.

When analysing what factors influence the choice of materials, it becomes clear, that not only the economical, aesthetical and sustainable (and other) factors play a role, but also the project process itself. A finding is that the process itself affects the decision making. Probably this is the most important tool to develop not only technical goals for a project, but also a culture on how to think, discuss and approach sustainable goals. Although not part of the investigation, it should be reflected on the importance the sustainable framework programs play as facilitator on sustainability. Denizou at al's research showed that public framework can affect the choice of building materials. The findings in this paper supports these findings.

The use and impact of calculations and analyses of EPD, GHG, LCC, and LCA may have a potential for improvement. The findings show, that these factors play very different roles in each project.

6. Conclusions

The findings in this investigation shows that sustainability, aesthetics and cost are considered to be the most important factors influencing the choice of façade material. Also for the architects, sustainability at least as important as aesthetics.

Based on the findings in the seven investigated cases, the participation in different environmental programs do seem to have influenced the evaluation and choice of façade material, both through developed processes and the required use of tools aimed at measuring. Bysheim and Nyrud's findings showing that the architects' preference towards the use of structural timer is related to previous experience with the use of structural timber in urban construction (Bysheim and Nyrud 2008) may also apply on other parts of the building and its solutions. This means, that the framework programs like FutureBuild, ZEB and others not only play an important role for the specific projects, but may also contribute indirectly to improve future projects through former participants.

All investigated projects had environmental ambitions. Still the decision makers conclude on a spectre of materials such as different wood solutions and bricks. An explanation for this is the difference in the projects' requirements and incoherent use of LCC, LCA, EPD and GHG calculations and analyses. Although the different projects even use the same calculation tools, the project processes and goals are still different. Each tool can be used in different ways and the results are in some cases more advisory. In other projects quantitative goals have to be achieved. In one case the requirements in the zoning planning overrule conclusions based on sustainable criteria. Different building functions may also lead to different choices of materials. In this investigation some clients and architects were very sceptical to the use of wood facades for school buildings.

Further research may assess to what degree participants in projects within a public frame work program influence sustainability goals, project processes and decisions in future projects. Have the public frame work influenced the participants' attitude towards sustainable building solutions. Another interesting research question is to what degree the architects' aesthetic judgement and values are influenced by the knowledge of sustainability values and solutions.

7. Acknowledgments

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The effect of climate change on the amount of wind driven rain on concrete facades

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Abstract

Private and public buildings built of concrete make up 34% of the whole building stock in Finland, of which almost 40% is now 30-50 years old. The financial and functional impact on Finnish society of this aged building stock is critical because one third of the country's population lives in these apartment blocks. There is a rising national concern on increasing maintenance needs of Finnish building stock. It has been concluded that new conceptual approaches to tackle the problem are acutely needed. The main reasons for facade degradation in the Finnish climate are freeze-thaw weathering of concrete and corrosion of reinforcement induced by carbonation of the surrounding concrete. A common denominator in every mechanism is water in varying forms. It can either work as a passage for harmful substances, e.g. chlorides, cause damage by its phase changes (freeze-thaw) or cause dissolution of substances in concrete. Two recent projects conducted by Finnish Meteorological Institute and Tampere University of Technology, have shown that future climate conditions in Finland are likely to get worse in terms of durability of structures exposed to climate. Precipitation during the winter season is going to increase while the form of precipitation is going to be increasingly water and sleet. At the same time, the conditions for drying are going to get worse. Thus, the deterioration rate of structures will accelerate in the most of Finland if maintenance and protection actions are neglected. To simulate the effect of changing climate conditions, it has been studied how the amount of wind-driven rain (WDR) on facades may change in future climate based on a greenhouse gas scenario. The study was conducted by comparing typical Finnish suburban concrete block build in 1970's in two different locations (coastal area and inland) at current climate and in 2050 and 2100. Based on the study the amount of WDR will increase more in coastal areas than in inland and will be more focused on south and south-west directions. The total increase in WDR will be approx. 15%, while the greatest increase (50%) will be faced by the westward facades in coastal area.

Keywords: Climate change, wind-driven rain, modelling, concrete

1. Introduction

47% of Finland’s national property consists of the existing building stock. Thus, the maintenance and protection of the existing building stock are highly important for the welfare of the nation which makes the study of adaptation to climate change of existing building stock significant from the economic and also sustainability point of view. In Finland its significance is emphasized due to buildings’ exposure to severe weather conditions.

A significant part of the Finnish building stock is relatively young and homogenous compared to the rest of Europe. A considerable number of envelopes of the precast concrete buildings erected 1960s and ‘70s have come near the end of the service life largely due to weathering. Thus, it is important to explore the possible climate change scenarios considering their effect on critical outdoor conditions for deterioration of structures, for the repair need of existing building stock and for the timing of repair actions.

Despite the rather young age of the precast building stock, several problems have been encountered in their maintenance and repair. Considering their technical service life, those buildings have in common e.g. highly durable frames but durability problems with facades and balconies exposed to Nordic outdoor climate. Thus, the durability properties of concrete buildings have not been adequate. The structures have deteriorated due to several different mechanisms whose progress depends on many factors related to structures, exposure and materials, which lead to widely varying service lives.

Based on the latest research conducted at Tampere University of Technology (TUT), the durability properties of existing concrete façades and balconies have been found to be poor (Lahdensivu et al. 2010, Lahdensivu 2012, Pakkala et al. 2014). The material properties related to freeze-thaw resistance of concrete and cover depth of reinforcement rarely fulfil the requirements of national building codes. However, despite the insufficient durability properties of concrete, damage that can be seen visually are relative rare.

Visual damage of concrete façades and balconies has a strong correlation with precipitation, wind directions during the rain and freeze-thaw cycles directly after the rain events (Lahdensivu 2012). The increasing amount of precipitation has been shown to have a strong correlation with the rate of the two most important deterioration mechanisms of Finnish outdoor concrete structures: carbonation induced corrosion of reinforcement and freeze-thaw deterioration (Köliö et al. 2014, Pakkala et al. 2014). In this paper the effect of climate change on the amount of wind driven rain on concrete facades is studied to assess the differences of climatic loads at variable locations and façade orientation.

2. Background

2.1 Finnish concrete facades

Since 1970s almost all prefabricated concrete structures in Finland are based on the Concrete Element System (Seppänen & Koivu 1970). That open system defines, for instance, the recommended floor-to-floor height and the types of prefabricated panels used. In principle, the system allows using the prefabricated panels made by all manufacturers in any single multi-storey building.

The concrete panels used in exterior walls of multi-storey residential buildings were, and still are, chiefly prefabricated sandwich-type panels with thermal insulation placed between two concrete layers. Facade panels are made up of two relatively thin reinforced concrete layers connected to each other by steel trusses. The outer layer is generally supported by the inner layer. Sandwich facade panels are connected to the building frame by the inner layer, usually by means of cast concrete joints and reinforcement ties.

2.2 Quality of concrete

The concrete grade used for concrete facade panels and most structural members of balconies has been C30/37 since the late 1980's in Finland based on the guidelines for durability and service life of concrete (Concrete Association of Finland 1989). Earlier the grade was C20/25. The cement used for concrete panels is mostly CEM I (42.5 N) (ordinary Portland cement) because of the good early strength it gives to concrete which allows rapid formwork rotation at the precast panel plant. White cement, CEM I (52.5 R), is also used in facade panels if necessary, but its share of total use is marginal.

The freeze-thaw resistance of the concrete is conducted by air-entrainment of fresh concrete. and it can be determined by testing a protective pore ratio (p_r). In 1976 Concrete Codes started to recommend the protective pore ratio of 0.15 which means that at least 15% of all pores are never filled by capillary water. At the Concrete Code 1989, the protective pore ratio was lifted to reach at least 0.20. Protective pore ratio $p_r < 0.10$ can be considered to make concrete non-freeze-thaw-resistant in Finnish outdoor climate (Lahdensivu 2012).

The success of air-entrainment of concrete used in facades and balconies have been studied by Lahdensivu (2012) from the thin section analysis results of the samples in the BeKo database (buildings built 1960-1995). Based on the study the freeze-thaw resistance differs considerably between various surface types of facades. Pakkala et al. (2014) studied buildings built after the requirement of protective pore ratio of 0.20 has been demanded and presented that only approx. 50% of the precast panels have met the freeze-thaw resistance requirements.

Lahdensivu (2012) presented that visually observable reinforcement corrosion damage existed in 59% of the examined facades. 54% of damage was local and extensive corrosion was found only in 5.7% of the facades. The corrosion damage was almost solely due to carbonation (Lahdensivu 2012).

2.3 Deterioration rate of concrete facades

The deterioration rate and need for repair of existing outdoor concrete structures, especially concrete facades and balconies, have been monitored by systematic condition assessments over 20 years. Lahdensivu (2012) studied in his doctoral thesis the deterioration of prefabricated concrete element buildings at present climate. His studies were based on 947 condition assessment reports made on buildings built 1960 – 1996 (Lahdensivu et al. 2010). He studied the changes on quality requirements, dominating deterioration mechanisms, their progress on present climate based on climate data produced by the Finnish Meteorological Institute (FMI) and effect of a geographical distribution on them. The most essential results were:

- There is a significant lack of quality with concrete structures, also with structures made according to current concrete code,
- The most significant deterioration mechanisms have been carbonation induced corrosion and freeze-thaw weathering,
- The most significant climatic causes for damage have been wind-driven rain and freeze-thaw cycles within few days after the rain events,
- The deterioration rate has been faster in coastal areas than in inland.

Two recent studies by Köliö et al. (2014) and Pakkala et al. (2014) studied rates of carbonation induced corrosion of concrete reinforcement and freeze-thaw weathering of concrete facades, respectively, at the projected future climate. Köliö et al. presented that the increase of precipitation decelerate the carbonation rate and thus the initiation phase of reinforcement corrosion while the increase in CO2 level has a greater opposite impact. On the other hand, the increase of precipitation amount and temperature accelerate the active corrosion phase. Pakkala et al. concluded e.g.:

- Amount of precipitation will increase significantly until the end of the century and relatively more at inland than at coastal areas,
- Amount of freeze-thaw cycles after rain events will decrease significantly after 2050's at southern Finland but remains almost at the same level at inland,
- The amount of precipitation is almost the same at coastal areas and inland but at coastal areas the rate of freeze-thaw weathering is higher because of the annual average wind speed is higher, thus more of the precipitation will shower the vertical surfaces,
- The WDR load is both at present and at future significantly concentrated on south-west, south and south-east orientated facades and its relative increase is greater than the increase of precipitation because of the higher wind speed during the rain,
- Concrete can be durable in the Nordic climate if it has been properly air-entrained.

2.4 Climatic conditions in Finland

Although Finnish climate is relatively steady considering the latitudes, it still varies significantly from the mild and relatively rainy coastal area to the drier inland. However, the

Finnish building stock is mainly concentrated in the few biggest cities and surrounding growth areas. Finland can be divided into four main areas based on climatic differences and concentration of population: the coastal area, southern Finland, inland and Lapland, see figure 1. (Pakkala et al. 2014)

Figure 1: Finland can be divided into four main areas based on climate and concentrations of population. (Pakkala et al. 2014)

2.5 Climate change projections

Climate change as such has been studied worldwide for a long time. In this context, climate change refers to global warming caused by an increase in greenhouse gases, especially carbon dioxide (CO_2). Climate change will affect the geographic and seasonal distribution of precipitation, wind conditions, cloudiness, air humidity and solar radiation. Modelling of future climate is based on alternative scenarios of greenhouse gas and aerosol particle emissions. In the scenarios, different assumptions are made about the future development of population growth, economic development, energy production modes, etc.

The ACCLIM (Jylhä et al. 2009) and FRAME (Vinha et al. 2013) projects have shown that future climate conditions in Finland are likely to get worse in terms of durability of facades and other structures exposed to climate. According to the data of the ACCLIM project, precipitation during the winter season is also going to increase while the form of precipitation is going to be increasingly water and sleet. At the same time, the conditions for drying are going to get worse. Thus, the deterioration rate of structures will accelerate in most of Finland if maintenance and protection actions are neglected. (Lahdensivu 2012)

The FMI examined in the ACCLIM project the different climate models and built models for observing Finnish climatic conditions and adaptation to climate change. In all greenhouse gas emission scenarios, based on three IPCC (2007) scenarios for the evolution of greenhouse gas and aerosol particle emissions, the average temperature rises at a constant rate until 2040. Differences between the scenarios start to emerge only after the middle of the century, see figure 2. (Jylhä et al. 2009)

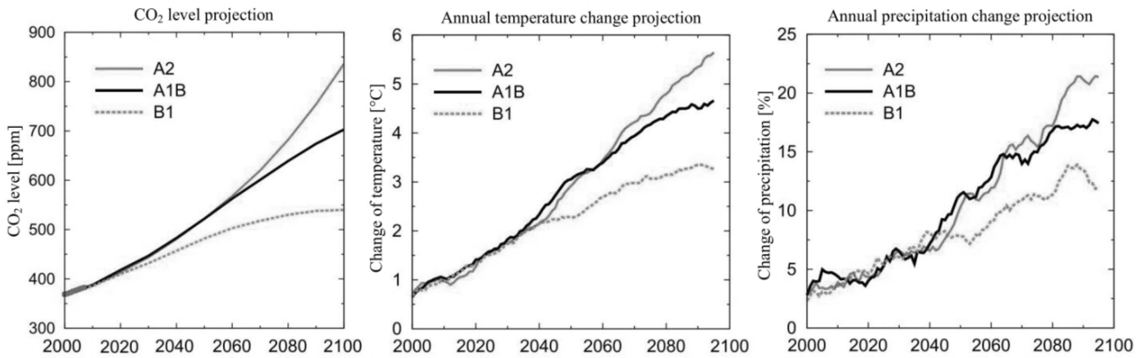

Figure 2: Projections for (a) CO2 level, (b) annual mean temperature and (c) precipitation change in 2000–2100, in relation to the mean of the reference period 1971–2000. The curves depict 11 year running means, averaged over Finland and the responses of 19 global climate models (Ruosteenoja et al. 2013). Projections are given separately for the three greenhouse gas scenarios A2, A1B and B1 (IPCC 2007).

In the REFI-B project (Jylhä et al. 2013) the FMI also forecast the climates of the four regions (coastal area, southern Finland, inland, Lapland) in three periods (2030, 2050 and 2100). The forecasts are based on an average of 19 different models which are all based on greenhouse gas emission scenario A2. The A2 scenario involves a situation where greenhouse gases are assumed to increase significantly − it is a sort of worst-case scenario. The FMI also has other significant greenhouse gas emission scenarios: A1B (quite large emissions) and B1 (small emissions). (Ruosteenoja et al. 2013).

2.6 Modelling of wind-driven rain

Wind-driven rain (WDR) striking building facades has been the focus of several studies in the last decades as mentioned by Blocken & Carmeliet (2004). The moisture load resulting from the WDR depends not only on rainfall intensity and wind speed, but also on raindrop trajectories around buildings. That increases the complexity of the phenomenon greatly.

The standard SFS-EN ISO 15927-3 (2009) presents a factor I_{WA} (Wall annual index) which can be used to estimate amount of precipitation collected by a free-standing driving-rain gauge in flat open country to present the amounts of precipitation that impacts on a real wall. The wall annual index is highly simplified simulation for assessing the WDR against building facades. There are other methods to model the WDR as is mentioned by Blocken and Carmeliet (2004, 2010), e.g. CFD model. It takes into account more precisely the distribution of the WDR in different areas of the facades. Although the wall annual index is simplified method, it gives adequate results for e.g. comparing different locational effects on the amount of wind driven rain on facades. Compared to CFD modelling it underestimates the amount of wind driven rain near the top of the façade but overestimates the amount on the top 2.5 metres with high buildings and low rain intensity. The higher the rain intensity the more it underestimates the amount of wind driven rain. The underestimation increases near the edges of the building. With rain intensities from 10 mm/h to 30 mm/h the wall annual index gives adequately corresponding results with CFD modelling in the vertical middle line with high and low rise vertical buildings and tower buildings. (Blocken et al. 2010).

3. Material and methods

3.1 Research material

Present and future climate projections and their effects on weather conditions critical to concrete degradation have been prepared by the Finnish Meteorological Institute (FMI). The data used in this study are hourly interpolated observations of temperature, wind speed, wind direction and amount of precipitation over 30 years (1980–2009). The future climate projections, based on the A2 scenario, were calculated by FMI to represent hourly data for a similar period in 2050 and 2100. The calculations of this study focus on two locations, the coastal and the southern Finland areas, although both collected and forecast data are also available for other locations.

The locations of the buildings used in this study are set to the same areas as the climate data mentioned above. Imaginary Finnish suburban city blocks, shown in the figure 3, are located at the coastal area and at the southern Finland. The climate observations, both collected and projected, are from Helsinki-Vantaa and Jokioinen. Two types of buildings were studied, both represented typical Finnish multi-storey residential building of 1970's with 2 staircases. The other one was 4- and the other 8-storey.

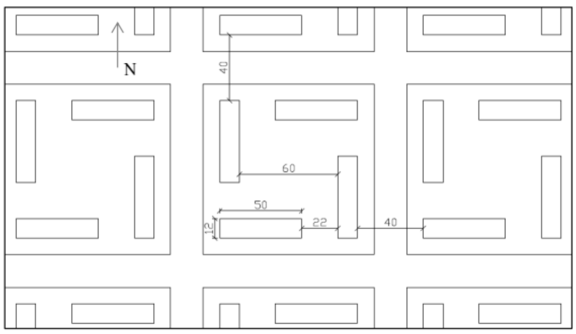

Figure 3: Simplified Finnish suburban street plan with repetitive blocks.

3.2 Modelling of wind-driven rain

The Wall annual index I_{WA} is presented at the standard SFS-EN ISO 15927-3 "Hygrothermal performance of buildings. Calculation and presentation of climatic data." (2009) as follows:

$$I_{WA} = I_A C_R C_T O W \quad (1)$$

, where I_A is the airfield annual index, C_R is a terrain roughness coefficient, C_T is a topography coefficient, O is an obstruction factor and W is a wall factor. The airfield annual index I_A is defined as:

$$I_A = \frac{2}{9} \frac{\sum v r^{\frac{8}{9}} \cos(D-\theta)}{N} \quad (2)$$

where v is hourly mean wind speed [m/s], r is hourly rainfall total [mm], D is hourly mean wind direction from north [°], N is number of years for which data is available and the summation is taken over all hours for which $\cos(D-\theta)$ is positive.

The roughness coefficient depends on the height above the ground and the roughness of the terrain in the direction from which the wind is coming, i.e. is there an open sea, a farm land, a suburban area or an urban area in the upwind direction. The coefficient C_R at height z is calculated as follows:

$$C_R(z) = K_R \ln\left(\frac{z}{z_0}\right) \qquad \text{for } z \geq z_{min} \qquad (3)$$

$$C_R(z) = C_R(z_{min}) \qquad \text{for } z < z_{min} \qquad (4)$$

This study uses only the terrain categories *I* and *III* see table 1.

Table 1: Terrain categories and related parameters. (SFS-ISO 15927-3 2009)

Terrain category	*Description*	K_R	z_0	z_{min}
I	*Rough open sea; lake shore with at least 5 km open water upwind and smooth flat country without obstacles*	*0.17*	*0.01*	*2*
III	*Suburban or industrial areas and permanent forest*	*0.22*	*0.3*	*8*

The topography coefficient takes into account the increase of mean wind speed over isolated hills and escarpments near the building subjected to the study. The research assumes the studied buildings are located at flat surroundings when the topography coefficient $C_T = 1$.

Obstruction factor depends on the horizontal distance to the nearest obstacle which is at least as high as the wall subjected to the study, see table 2. The wall factor is, in the case of flat roof multi-storey building, 0.5 for the top 2.5 m of the wall and 0.2 for remainder.

Table2: Obstruction factor. (SFS-ISO 15927-3 2009)

Distance of obstruction from wall [m]	*4 – 8*	*8 – 15*	*15 – 25*	*25 – 40*	*40 – 60*	*60 – 80*	*80 – 100*	*100 – 120*	*over 120*
Obstruction factor O	*0.2*	*0.3*	*0.4*	*0.5*	*0.6*	*0.7*	*0.8*	*0.9*	*1.0*

4. Results and discussion

Figures 4 and 5 show the amount of the WDR hitting facades facing various directions by using the driving rain index I_A (see eq. 2) for different wind directions in the coastal and southern Finland areas, respectively. The wind directions are given in degrees from north in 10° increments. The figures give the present indices (30 year average, 1980–2009) and projections for future climates in 2050 and 2100. Figure 6 shows wind direction related relative change of the amount of WDR compared to present climate.

Figures 4, 5 and 6 show clearly that south and south-west-facing facades will get significantly more WDR. The same phenomenon has been noted in condition assessment studies where the most deterioration has been observed on south-facing facades and balconies. By the end of the century, wind driven rain will increase approx. 30% in both areas. At inland the increase will be 40% (Pakkala et al. 2014).

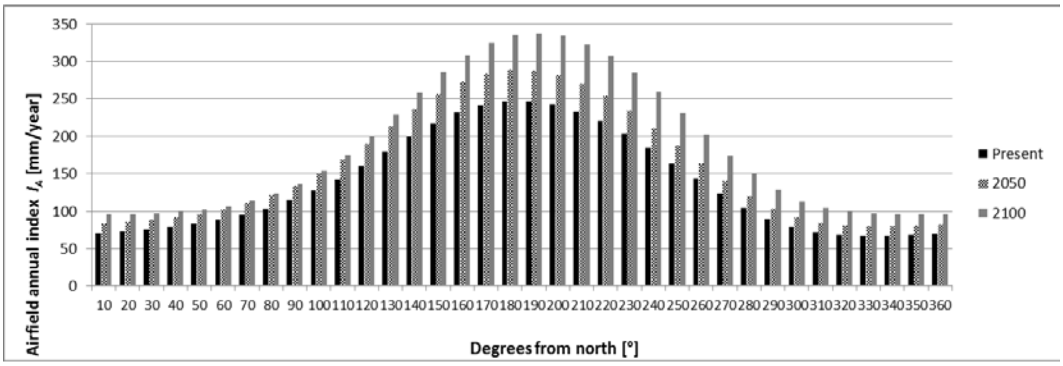

Figure 4: Airfield annual index vs. wind direction of present and future (2050, 2100) climates in the coastal area. (Pakkala et al. 2014)

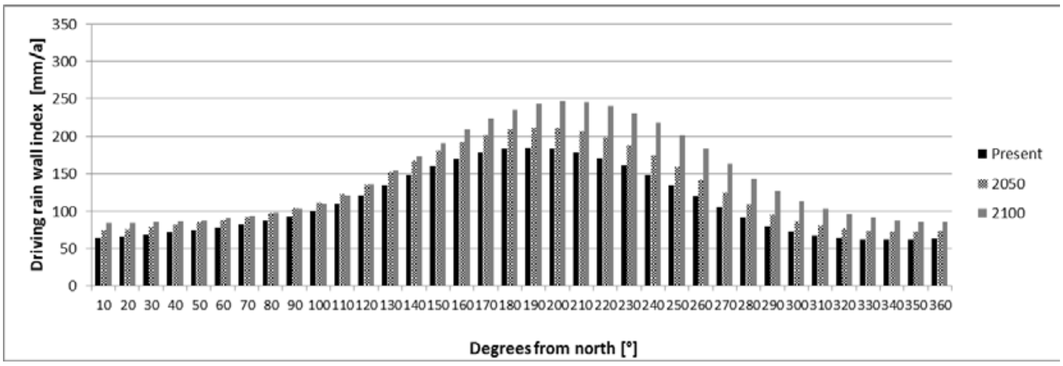

Figure 5: Airfield annual index vs. wind direction of present and future (2050, 2100) southern Finland climates.

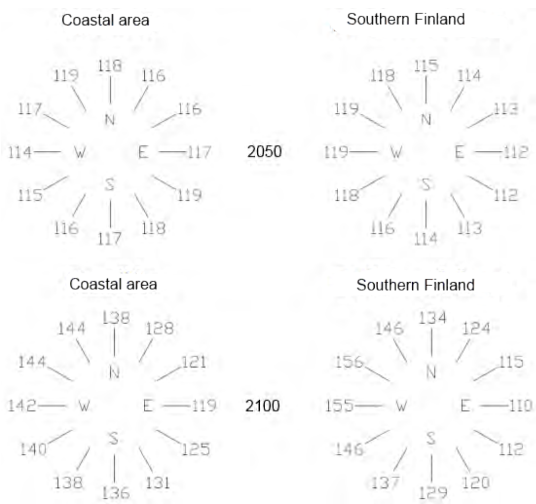

Figure 6: Relative change of the amount of WDR compared to present climate from different wind directions.

The study showed that the height of the building does not have significant impact on the amount of WDR. At the top 2.5 m of 8-storey building an increase at the amount of precipitation compared to 4-storey building is 10% at the coastal area and 20% at southern Finland. At the lower parts of the facades the amount of WDR is in practice the same.

Depending of the façade orientation the amount of WDR is 50 – 90% higher at the coastal area compared to southern Finland, see figures 7 and 8. The highest difference is at the northern facades. The most significant reason for the difference is, as it has been presented before, the higher airfield annual index, i.e. the wind speed during the rain events. Other significant factor is the chosen terrain category. If the terrain category is chosen to be the same with both studied areas, the difference would be 10 – 40%. The south-faced facades can be subjected to 3.5 times higher WDR load than north-faced facades.

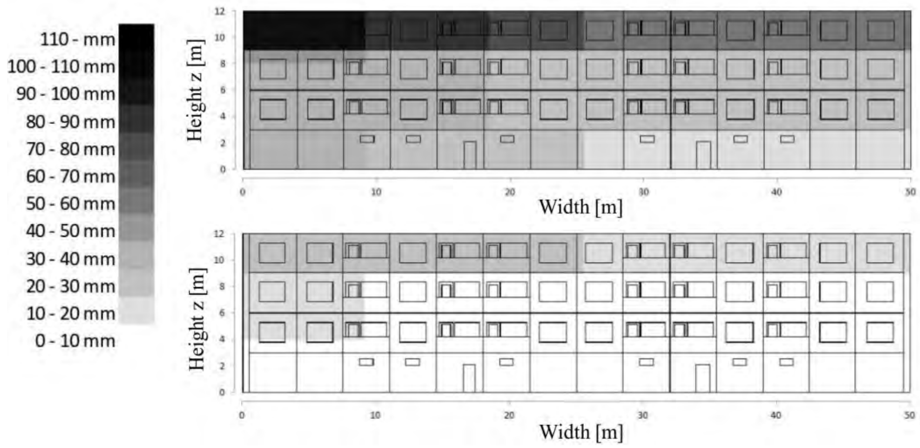

Figure 7: Annual amount WDR on south-faced façades at coastal area (above) and southern Finland (below) at present climate.

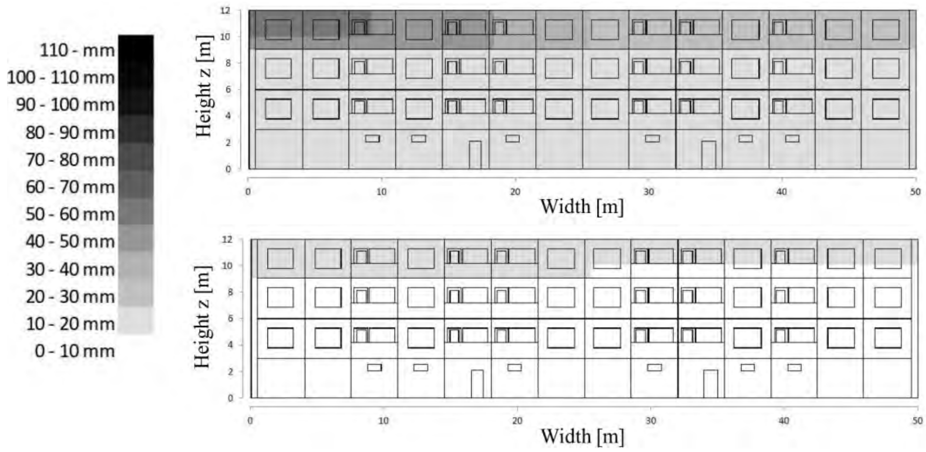

Figure 8: Annual amount WDR on north-faced façades at coastal area (above) and southern Finland (below) at present climate.

5. Conclusions

Precipitation has been shown to have an effect on all of the major deterioration mechanisms of outdoor concrete structures. The future climate conditions in Finland are likely to get worse in terms of durability of structures exposed to climate because precipitation during the winter season is going to increase while the form of precipitation is going to be increasingly water and sleet. At the same time, the conditions for drying are going to get worse. Thus, in this study the changes of the wind-driven rain (WDR) on facades were studied at two different locations. In addition, the effect of façade orientation was studied.

The main results were:

- The amount of WDR is significantly higher at the coastal area than at southern Finland,
- The relative increase of the amount of WDR is higher at the coastal area because of the increasing wind speed during the rain,
- The south-faced facades are exposed to 3.5 times higher WDR load than north-faced facades,
- The top part of the facades are exposed to significantly higher WDR load than the lower parts,
- WDR will be more concentrated on south and south-west directions until the end of the century,
- The most significant factors for high WDR load are the wind speed during the rain event and the openness of the terrain near the studied building.

The method for calculating WDR is simplified, yet it gives adequate results for e.g. comparing different locational effects on the amount of wind driven rain on facades. The main defect of the method is an underestimation of WDR near the edges of the building.

Based on the study it can be concluded that at the future climate it is highly important to take into account the surrounding terrain and locational and microclimatic aspects during planning and with material choices. It should be taken into account that open areas, e.g. at the coastal line, cause significant and increasing WDR load on the facades. In addition, the top part of south and south-west-faced facades should be shielded from rain, e.g. with longer eaves.

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Housing Reconstruction Following the 2012 Nigerian Floods: Was it Built Back Better?

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Abstract

The recently agreed Sendai Framework for Disaster Risk Reduction 2015-2030 calls for reducing the exposure and vulnerability of communities and thus preventing the creation of new disaster risks. It specifically identifies the need to use post-disaster reconstruction to "Build Back Better" and thus emphasizes the strategic importance of housing reconstruction in achieving disaster resilience. In the 2012 flooding in Nigeria, 7.7 million people were affected, 363 fatalities were recorded and approximately 600 000 houses were damaged or destroyed. This disaster greatly worsened an already existing housing deficit thereby placing huge pressure on all levels of government to address the sharp increase in housing demand.

This research assesses the performance of the post-flood housing reconstruction programme in Lokoja, Kogi State, Nigeria. It identifies the efforts made to enable affected communities to achieve improved disaster resilience after the event and compares these to the Build Back Better expectations under the new Sendai Framework.

Qualitative data were collected from stakeholder interviews, project documents and reports and personal observations in the field. The findings indicate that, while some aspects of Build Back Better were implemented in this particular case, others were not and so the reconstruction programme in Lokoja fell short of the Sendai Framework's Build Back Better expectations.

Keywords: Build Back Better, built environment, construction management, housing, post-disaster reconstruction

1. Introduction

The new Sendai Framework for disaster risk reduction 2015-2030 (SFDRR) sets out distinct targets and priorities for action with the intention of reducing disaster losses. The framework focuses on addressing global disaster risk drivers in order *to effectively protect vulnerable persons, communities and countries.* The SFDRR also aims to strengthen community and environmental resilience to disasters (UNISDR 2015) and outlines guiding principles and essential responsibilities for states and institutions. It emphasises the engagement of all-of-society and all state institutions in disaster risk reduction practices (Wahlström 2015).

The SFDRR outlines seven global targets that are expected to be achieved by the end of the next decade (UNISDR 2015). It further identifies four priorities for action to substantially reduce disaster effects and losses over the next 15 years. The priorities for action are:

1. understanding disaster risk;
2. strengthening disaster risk governance;
3. investing in disaster risk reduction;
4. enhancing disaster preparedness for effective response and to "Build Back Better" in recovery, rehabilitation and reconstruction.

This study is focused on the fourth of these priorities for action and, specifically, achieving "Build Back Better". The case of a Nigerian housing reconstruction programme following the flooding of 2012 is considered in terms of the "Build Back Better" expectations under the SFDRR in order to determine whether the reconstruction programme measured up to these expectations and, if not, what recommendations can be made for future initiatives.

In section 2, the Build Back Better concept and its elements are described in detail. In section 3, the background to the reconstruction efforts following the 2012 flooding in Nigeria is presented. The methodology for this research is described in section 4 and its findings are presented and discussed in section 5. Section 6 of the paper sets forth conclusions and recommendations.

2. The Build Back Better Concept

The Build Back Better (BBB) concept seems to have originated following Hurricanes Mitch and George in the Americas in 1998 when USAID and its partners agreed to reconstruct affected buildings using techniques and standards to enable the resilience of structures. The measures adopted included: incorporating environmental and geological analysis into designs; encouraging the utilization of effective land-use planning; creating social and economic opportunities for affected communities; and ensuring effective monitoring and coordination by the donors (USAID 1999; Reliefweb 2006). However, BBB gained global attention and adherence during the reconstruction of Aceh, Indonesia, following the Indian Ocean earthquake and tsunami in 2004 (Lyons 2009).

The post-disaster context offers an exceptional opportunity to develop an improved and resilient built environment and BBB advocates the utilisation of this opportunity for the identification of underlying and new disaster risk factors and proposes the systematic incorporation of long-term mitigation measures into reconstruction (Kennedy *et al*. 2008). In addition, BBB emphasises the inclusion of disaster-hit communities in reconstruction processes to create livelihood support and opportunities that facilitate long-term resilience for communities (Lyons 2009).

Several reconstruction guidelines (including FEMA 2000; Clinton 2006) aimed at “Building Back Better” exist but these are not necessarily consistent and this can cause confusion. Consequently, Mannakkara and Wilkinson (2013; 2014) reconceptualised the guidelines to produce a comprehensive framework that considers the physical, social and economic conditions of communities in post-disaster reconstruction and recovery. The authors categorised the themes into three basic elements that represent the BBB concept:

1. Risk reduction;
2. Community recovery; and,
3. Implementation.

These three elements are broken down and further discussed in the following sections.

2.1 Risk Reduction

Risk reduction focuses on minimizing the damage caused by disaster. This includes measures put in place to minimize vulnerability, improve the capacity and resilience of communities (IFRC 2012). Such measures have been classified as structural and non-structural.

Structural Measures: Structural measures involve improved design, establishment and enforcement of building codes and construction guidelines, strengthening of structures exposed to hazards and implementation of effective construction practices (Wamsler 2006; Bosher *et al.* 2007).

Non-structural Measures: Non-structural measures include hazard-based land use planning and vulnerability analyses, discouragement of development on high risk areas, the creation of buffer zones, relocation of settlements to protected zones, public enlightenment campaigns regarding hazards, vulnerability, risk reduction and the development of resilience to disasters (Wamsler 2006; Shaw and Ahmed 2010).

2.2 Community Recovery

Community recovery emphasises the creation of sustainable employment and livelihood support programmes for affected communities (Clinton 2006). It involves measures aimed at the restoration and improvement of social and economic conditions for the affected communities. Community recovery measures are classified into social recovery and economic recovery (Mannakkara and Wilkinson 2014).

Social Recovery: Social recovery refers to the need for disaster victims' physical, psychosocial and cultural well-being to facilitate recovery (Lyons 2009; Mooney *et al.* 2011). Social recovery calls for collaboration between the professionals involved (e.g. psychologists, designers) and the community. Besides attending to mental health challenges, psychological support should be provided to improve communities' adaptive capacity to disasters (Mooney *et al.* 2011).

Economic Recovery: Economic recovery concerns the return of businesses and local economies to stability following a disaster (Chang and Rose 2012). It includes access to subsidized loans and business grants, provision of equipment, seedlings to support farmers, education and skill acquisition programmes to allow affected communities to participate in reconstruction activities and to provide them with the means for sustainable livelihoods (James Lee Witt Associates 2005; NEMA 2013; UN OCHA 2013)

2.3 Implementation

Implementation describes the processes by which risk reduction and community recovery is executed. It involves a number of sub-themes that transmit the BBB concept efficiently. The sub-themes as categorized in Mannakkara and Wilkinson (2013) are stakeholder coordination, legislation and regulation, community consultation and, monitoring and evaluation.

Stakeholder Coordination: Stakeholder coordination deals with the organisation of stakeholders involved in reconstruction projects. The BBB concept recommends the creation of a central body that will effectively coordinate stakeholders involved in reconstruction and recovery (Moe and Pathranarakul 2006).

Legislation and Regulation: BBB recommends supportive laws and regulations that are instituted and enforced in order to reduce disaster risk and to create an enabling environment for managing the reconstruction and recovery processes (Clinton 2006; Le Masurier *et al*. 2006).

Community Consultation: The BBB concept emphasises the involvement of affected communities in reconstruction (James Lee Witt Associates 2005). Community consultation enables reconstruction projects' outcome goals to be better aligned with community needs and thus it facilitates acceptability (ALNAP, 2011).

Monitoring and Evaluation: To ensure successful reconstructed, detailed management plans should be formulated with long-term monitoring schemes to ensure that all the intended risk reduction measures are duly incorporated (Clinton 2006; Moe and Pathranarakul, 2006). Lessons learnt should be documented and adapted in future projects.

3. The 2012 Nigerian floods

The 2012 floods affected 30 of the 36 states in Nigeria and resulted in devastating property losses with about 600,000 houses damaged or destroyed. 363 fatalities were recorded and over 7.7 million people affected (IFRC, 29 Sep 2012; UN OCHA, 15 Nov 2012).

Responding to the disaster, the national government provided relief funds to affected states and to some federal agencies for disaster response, relief and rehabilitation. Non-governmental organisations and corporate bodies also supported the victims with relief materials and financial assistance. Some state governments initiated mass housing schemes to ameliorate the disaster effects on housing and to enable affected communities to recover.

Lokoja, the administrative capital of Kogi State was chosen as an ideal case study area for this research because it was severely affected by the 2012 floods and has since benefited from recent housing reconstruction and community recovery projects. Lokoja is located at the confluence of the rivers Niger and Benue. Community members within Lokoja are largely farmers and are often affected by floods that cause considerable damage to their properties.

In Lokoja, about 1700 houses were affected by the flooding, some of which were reconstructed while others on the flood plain were to be demolished and the affected community relocated (News24 2013). In April 2013, the Kogi State government initiated the construction of 272 housing units for the 2012 flood victims with priority being given to affected property owners.

4. Methodology

Qualitative data were collected from the literature, interviews, project documents and reports and personal observations in the study area. 31 semi-structured interviews were conducted in October and November 2015 with representatives of stakeholders involved in the housing reconstruction and recovery programme.

Representatives of national level agencies and non-governmental organisations as shown in Table 1(a) were interviewed to compile a detailed description of national efforts towards community recovery. At the state level, agencies responsible for managing the government's efforts towards risk reduction, housing reconstruction and community recovery were identified and each of these agencies (described in Table 1(b)) were interviewed to recount their perspectives of the recovery programme. The head of the Farmers Association at the state level also gave details of the disaster effects and efforts made by stakeholders to enable the recovery of affected farmers.

At the project level, supervisory engineers and the contractors involved in the housing reconstruction projects gave an account of the contractor-driven housing production processes. Representatives of owner-driven reconstruction - building-owners who were relocated and affected tenants - also give an account of their participation and efforts.

Representatives of local governments were also interviewed to describe local government's efforts and their inclusiveness in the recovery process. Representatives of the local community, the residents of the new housing scheme, were interviewed to gain an understanding of their involvement and opinions. Descriptions of these local level interviewees are provided in Table 1(c).

Table 1(a): Profile of Interviewees at National Level

Interview Code (C)	*Description*	*No. of Interviews*
C1	*National Emergency Management Agency (NEMA)*	*1*
C2	*Manager, National Inland Waterways (NIWA), Lokoja*	*1*
C3	*Researcher, NASRDA*	*1*
C30	*Representative, The Nigerian Red Cross Society*	*1*
C31	*OXFAM, Nigeria*	*1*

The information received from the interviewees was validated through triangulation. This was done by verifying questions from other interviewees and available project documents and literature. Personal details of the interviewees were kept confidential to encourage the reliability of the information received. Data collected were encoded according to the elements and sub-elements of BBB which were described in section 2 above. The findings and analysis are presented in section 5 as a narrative based on this thematic categorization (Kvale 2007).

Table 1(b): Profile of Interviewees at State Level

Interview Code (C)	*Description*	*No. of Interviews*
C4-C5	*Managers, State Emergency Management Agency (SEMA)*	*2*
C6	*Head, Town Planning and Development Board, Kogi State*	*2*
C7	*Head, Department of Building Control, Kogi State*	*1*
C8	*Manager, Ministry of Land, Housing, Urban Development*	*1*
C9-C10	*Supervisory personnel/Engineers (Post-flood Housing)*	*2*
C11-C12	*Contractors, Post-flood Housing*	*2*
C13	*Manager, Ministry of Environment and Natural resources*	*1*
C17	*Head, Kogi State Farmers Association*	*1*

Table 1(c): Profile of Interviewees at Local Level

Interview Code (C)	*Description*	*No. of Interviews*
C14	*Development officer, Lokoja Local Government*	*1*
C15	*Development officer, Ajaokuta Local Government*	*1*
C16	*Development officer, Kogi Local Government*	*1*
C18	*Community representative, Lokoja Local government*	*1*
C19	*Community representative, Adankolo Local government*	*1*
C20	*Community representative, Koton-karfi Local government*	*1*
C21-23	*Residents, New Housing Estate*	*3*
C24-26	*Owner-built housing reconstruction and rehabilitation*	*3*
C27-29	*Tenants affected by flood (without allocation)*	*2*

5. Findings

Based on the analysed data, the study findings are presented and discussed under each of the three elements of Build Back Better and their corresponding subthemes.

5.1 Disaster Risk Reduction

Structural Measures: According to C7-C10, the government adopted a contractor driven-approach for the construction of new buildings due to the need for quick delivery. C6, C7 and C8 reported that the buildings were designed to the structural standard and took account of the soil conditions and environmental challenges of Lokoja. According to C7, no new building code was established, rather existing codes and construction guidelines were enforced with inspections carried out and approvals issued at prescribed developmental stages for all new development. In addition, quality assurance mechanisms and procedures were established to ensure quality control in reconstruction. C7 identified the quality management procedures established included material quality and specifications checks, multi-department/agency inspections and regular monitoring and supervision.

According to C7, C8 and C9-C10 some contractors who were politically well-connected did not comply with the established quality management standard. C7 emphasised that they were given executive fiat and operated without applying the laid-down quality management procedures with the excuse that they were following a superior order that emphasized quick delivery. Although, beneficiaries had just been allocated their dwellings, wall cracks and damped walls were observed confirming that quality procedures were compromised (Figures 1a and 1b). C9-C10 mentioned that some contractors lacked the capacity to do a good quality job, but were awarded contracts due to their influence.

Figure 1(a) and (b) Figures showing visible defects on newly constructed houses for Post-2012 flood victims in Lokoja, Kogi State, Nigeria.

For owner-driven housing reconstruction, C24 reported that his building was destroyed by the flood but since it was not located within the buffer zone, a new design submitted was approved by the town planning board. C24 mentioned that the reconstruction of the building was often inspected by supervisors from the board to ensure compliance with building guidelines.

The authors observed a lack of drainage channels in the new scheme which exposed the settlement to flood risk due to run-off. However, C13 reported that new drainage channels are being constructed while old ones are being rehabilitated within the Lokoja metropolis to reduce flood risk. In addition, C13 and Tribune (June 26 2015), reported that a shoreline protection and embankment project alongside the river bank is being built to protect some high-risk communities from exposure to flood risk and to serve as a recreational area and park.

Non-structural Measures: A number of non-structural risk reduction measures were undertaken by the government. After the event, risk and multi-hazard vulnerability assessments were carried out and a flood risk map was produced (Aderoju *et al.* 2014). Another study identified the location to site the new housing scheme for relocated victims (Isa *et al.* 2015).

According to C5 and C7, only affected property owners with valid documents were relocated from high risk zones while new developments were barred and buffer zones which were earlier created were now enforced. However, C19, C22 and C23 reported that "we were relocated without provision for basic facilities like schools, hospitals and connecting roads to the town".

C5 reported that National Meteorological Agency and Nigeria Inland Waterways Authority provided early warnings that gave notice of the significant rise in water level to the community through the State Emergency Management Agency (SEMA). All of C4, C5, C13 and C14-C16 mentioned that before, during and after the flooding, SEMA conducted public enlightenment campaigns on vulnerability to flood risk, disaster preparedness and response using all media channels.

5.2 Community Recovery

Social Recovery: C30 reported that assistance was provided by the Nigerian Red Cross Society in the form of relief materials, health, hygiene promotion and, most importantly, the provision of psychosocial support to help traumatized victims work through their experiences. According to C4 and C5 teams of medical experts and psychologists were deployed to various internally displaced persons camps to attend to the medical and psychological needs of the victims.

In terms of housing reconstruction, C21-C23 reported that they were not adequately involved in the housing design and reconstruction process so that the houses provided to them had inadequate numbers and sizes of rooms. It was observed that non-property owners were not given consideration in the allocation of housing. Although, C27-29 mentioned that they were given some money to rent dwellings.

Economic Recovery: According to C22 and C5, grants of NGN50,000 were given to property owners. C14, C15 and C16 emphasised that some money was given to flood victims as relief to ameliorate the effects of property loss. In addition, livelihood support programmes were implemented by NGOs with the distribution of seedlings and fishing nets, while training and capacity building programmes were conducted on risk reduction and disaster resilience (UN OCHA, 01 April 2013).

5.3 Implementation

Stakeholder Coordination: Following the 2012 disaster, a Flood Relief Management Committee, headed by the Deputy Governor's office was set-up to coordinate stakeholders involved in reconstruction and recovery. C7 and C8 reported that the committee coordinated recovery operations, procurement and monitored reconstruction progress and performance. C4 and C5 mentioned that training and capacity development programmes were organised for management personnel to build disaster management capabilities and to enhance the management of the reconstruction and recovery process. However, C18, C19 and C20 mentioned that they were only involved in the distribution of relief items to the locals.

Legislation and Regulation: According to C6, C7 and C8, no new legislation or regulations were established. Rather, existing regulations regarding buffer zones were now enforced. C6 and C7 stated that the enforcement of the existing land use acts and building regulations would ensure that disaster risks are reduced.

Community Consultation: According to C18-C20 they were shown designs of the buildings to be reconstructed and taken to the housing reconstruction site during implementation (News 24 2013). We were given no choice but to accept what the government provided since we were getting it for free. C22 and C23 complained that the new houses are too small.

Monitoring and Evaluation: C6, C7 and C8 stated that lessons learnt from the housing reconstruction projects initiated by government were documented. C8 further mentioned that lessons learnt are applied in an on-going bond-housing project (of 500 units). However, C8 noted that the Post-2012 recovery projects initiated by the government are still in progress.

5.4 Summary of Findings

Disaster Risk Reduction – Structural Measures – BBB *not achieved*: Some measures were taken (embankment construction) but non-conformance with quality management procedures during construction and the lack of drainage channels left the new buildings vulnerable.

Disaster Risk Reduction – Non-structural Measures – BBB *achieved*: Multi-hazard vulnerability analysis, flood-risk mapping and (earlier identified) buffer-zones were enforced. Housing was relocated from high-risk zones.

Community Recovery – Social Recovery – BBB *not achieved*: A lack of involvement of owners in relocation planning, building design and construction processes and a lack of consideration for non-owner residents compromised community recovery.

Community Recovery – Economic Recovery – BBB *achieved*: Several successful measures were taken to enable affected communities to recover economically from the disaster.

Implementation – Stakeholder Coordination – BBB *achieved*: A central committee to coordinate stakeholder involvement was set up by the state government. However, the selection of contractors was influenced by politics and local authorities should have been more involved.

Implementation – Legislation and Regulation – BBB *achieved*: Although no new legislation was passed, existing land-use and building development regulations were enforced.

Implementation – Community Consultation – BBB *not achieved*: Inadequate consultation (especially regarding the relocation site, building design types and the construction process).

Implementation – Monitoring and Evaluation – BBB *not achieved*: A systematic approach to monitoring was initially established but this was negated by the political influence which affected reconstruction implementation. Lessons learnt were documented for future projects.

6. Conclusions

The Sendai Framework for Disaster Risk Reduction 2015-2030 calls for priority action to Build Back Better in reconstruction. Using a comprehensive BBB framework as a guide to evaluate the housing reconstruction programme in Lokoja following the 2012 floods in Nigeria, it is evident that considerable efforts were made by government agencies and other stakeholders and, indeed, some of the elements that comprise BBB were achieved (refer to section 5.4). However, other elements of BBB were not achieved. In particular, the non-conformance of some contractors to the established quality management procedures resulted in some poorly constructed housing units and the lack of drainage channels to mitigate flood risk threatens to undermine the reconstruction and recovery programme unless it is quickly remedied. In addition, the non–participation of the affected community in the design and reconstruction of housing and the lack of consideration of non-owners (affected tenants) in the reconstruction and allocation process indicate that this specific example of a recent housing reconstruction initiative falls short of the BBB expectations under the new SFDRR.

This study has used the SFDRR as a reference framework to measure the performance of the Nigerian post 2012 flooding housing reconstruction programme. By doing so, we can recommend specific improvements in terms of:

- structural measures (building quality improvements),
- social recovery and community consultation (inclusion of all affected community members and greater involvement of the community in the design and reconstruction process)
- monitoring and evaluation (putting in place safeguards to ensure that the reconstruction programme is protected from political influence).

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An Overview of Urban Resilience to Natural Disasters in Brazil

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Abstract

The purpose of this work is to analyse how Brazil is promoting urban resilience to natural disasters. Brazil suffers all kinds of disasters due to its great territorial extension, but curiously the one that impacts the most people - drought - is not the one that causes the most casualties - landslides and flash floods. This work was developed based upon literature review on urban resilience, desk research of all relevant topics and statistical data analysis. The main actions for mitigating these disasters' damage were the mapping of risk areas, training courses and a 24/7 monitoring center. The current Civil Defense protection policy is the first federal law focusing on risk mitigation.

Keywords: urban resilience; natural disasters, civil defense, Brazil.

1. Introduction

In 2010, the population of Brazil was just over 200 million inhabitants, with a urbanization rate of 84,36% (IBGE, 2010). The increase in population density in the cities contributed to disaster events becoming more expressive, since a larger number of people has been affected. Most natural disasters that occur in developing countries are triggered by the ever growing population density in risk areas (Sampaio et al., 2013).

Natural disasters are the consequences of natural phenomena occurrences lasting long enough to produce a negative impact on society and infrastructure (Alcántara-Alaya, 2002). EM-DAT (Emergency Events Database) understands disasters as "situation or event, which overwhelms local capacity, necessitating a request to national or international level for external assistance; an unforeseen and often sudden event that causes great damage, destruction and human suffering. Though often caused by nature, disasters can have human origins" (EM-DAT, 2015), plus at least one of the following elements: a) 10 or more casualties; b) 100 or more people affected; c) declaration of state of emergency; or d) request for international assistance.

In Brazil, the main source of disaster data are the emergency situation and state of public calamity decrees, issued by local authorities and recognized by the federal government. The criteria are: disaster intensity, need and availability of resources to be used in order to restore normality (MI, 2007).

Since the establishment of the National Policy for Protection and Civil Defense (*Política Nacional de Proteção e Defesa Civil*, portuguese acronym: PNPDEC), the issue has gained more emphasis due to the understanding by political bodies that disasters can be avoided.

This work was developed based upon literature review on urban resilience, desk research of the National Policy for Protection and Civil Defense and of the Disaster Response and Risk Management Program, and statistical data analysis conducted on official data gathered from the Brasilian Natural Disaster Annual Report, for the year 2012.

2. Urban Resilience

The concept of resilience became known by Holling (1973), who applied it in ecology to study ecosystem dynamics (Janssen et al., 2006). Ecological resilience stands for the ability of a system to keep its functions and controls after being subjected to disturbances (Gunderson, 2000). In an environment - society perspective, when transposing the concept to cities, it is understood that a city is a complex system (social, economical and ecological) that, when struck by external disruptions, is able to return to a previous state of equilibrium or even to improved conditions as a result of adapting and learning from overcoming the event (Adger, 2000; Klein et al.,2003).

According to Lhomme et al. (2013), urban resilience is the ability of a city to recover its functions after suffering a disturbance. Desouza; Flanery (2013) defined urban resilience as the capacity of a city to absorb, adapt and respond to changes. Similarly, UNISDR defines resilience as "the ability of system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions" (UNISDR, 2009). The latter definition was the one adopted in this work because it was understood to be the most complete one.

One of the main characteristic of resilience is the capacity of adaptation that, according to Folke (2006), is the system's capacity to endure and deal with external changes. This work agrees with Klein et al. (2003, p.38) in their definition of adaptation capacity, which reads as "the capacity to plan, prepare, facilitate and implement adaptation measures" in face of natural disasters.

Jabareen (2013) stresses the gap in the literature to measure and evaluate urban resilience, besides the fact that this is a concept developed on multidisciplinary bases and which comprises multiple aspects, just like cities. Although rich analyses are possible, a focus must be established for the current work; such focus is the urban resilience to natural disasters.

3. Natural Disasters in Brazil

Brazil occupies 47.3 percent of the South American continent and borders all other countries, except Ecuador and Chile. It is bounded by the Atlantic Ocean on the east and has a coastline of 7,491 km. Brazil is currently defined in its constitution as a federal republic, composed of 26 states and the Federal District, where its capital - Brasília - is located. The federative units are divided into five regions: South, Southeast, Center West, North and Northeast (Figure 1).

The South region corresponds to 6,77% of the total territory and has an urbanization rate of 84,36% (IBGE, 2010). The most common natural disasters in this region are pluvial floods, flash floods and landslides associated with intense rain, which occurs more frequently from December to March. Other disasters such as drought, windstorms, tornados and coastal floods also occur in the region.

The Southeast region corresponds to 10,86% of the country's area and has an urbanization rate of 92,95% (IBGE, 2010). Like in the South region, the most frequent natural disasters are pluvial floods, flash floods and landslides associated with intense rain, also from December to March. Drought events can occur as well.

The Center West region represents 18,87% of the national territory and its urbanization rate is 88,8% (IBGE, 2010). This is the region with the least of natural disaster events, which are mainly pluvial floods, droughts and forest fires.

The North region comprises 45,25% of the national territory and presents an urbanization rate of 73,53% (IBGE, 2010). This region does not present a dry season and has the highest pluviometric annual indexes, making pluvial floods the most frequent natural disaster. Nevertheless, isolated drought periods and forest fires might also occur.

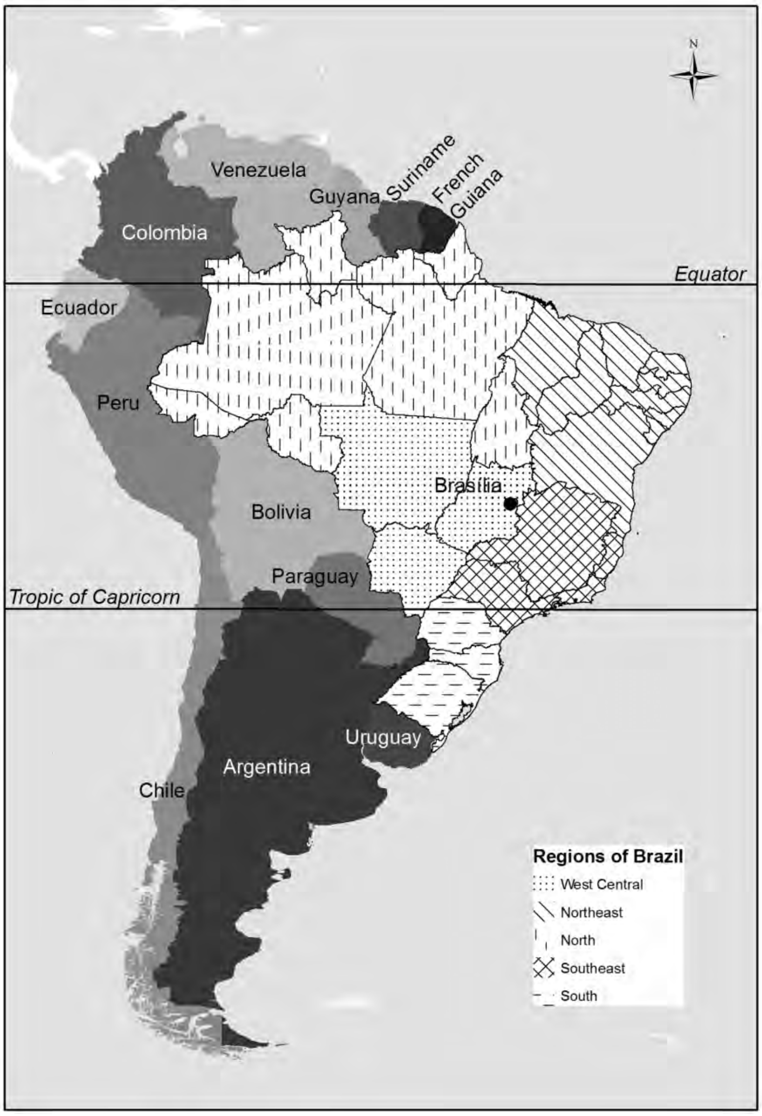
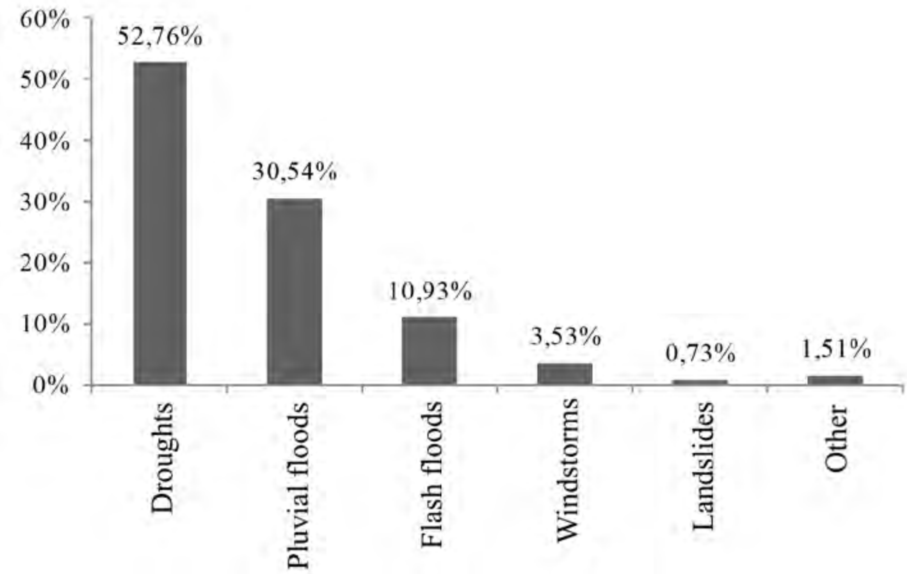


Figure 1 - Brazilian regions and South American countries

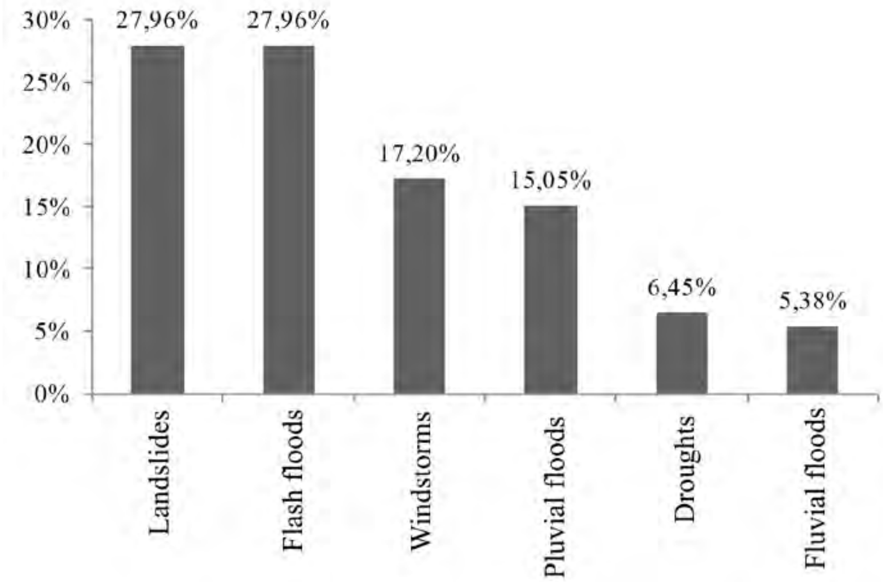
The Northeast region corresponds to 21,25% of the country's territory and has an urbanization rate of 73,13% (IBGE, 2010). This region is home to the greater part of the Brazilian semi-arid climate, which makes drought the most recurrent natural disaster. However, pluvial floods and landslides also occur.

The disasters that affected the Brazilian population in the year 2012 were droughts (52,76%), pluvial floods (30,54%), flash floods (10,93%), windstorms (3,53%), landslides (0,73%) and other (1,51%) according to MI (2012), as shown in Graph 1.

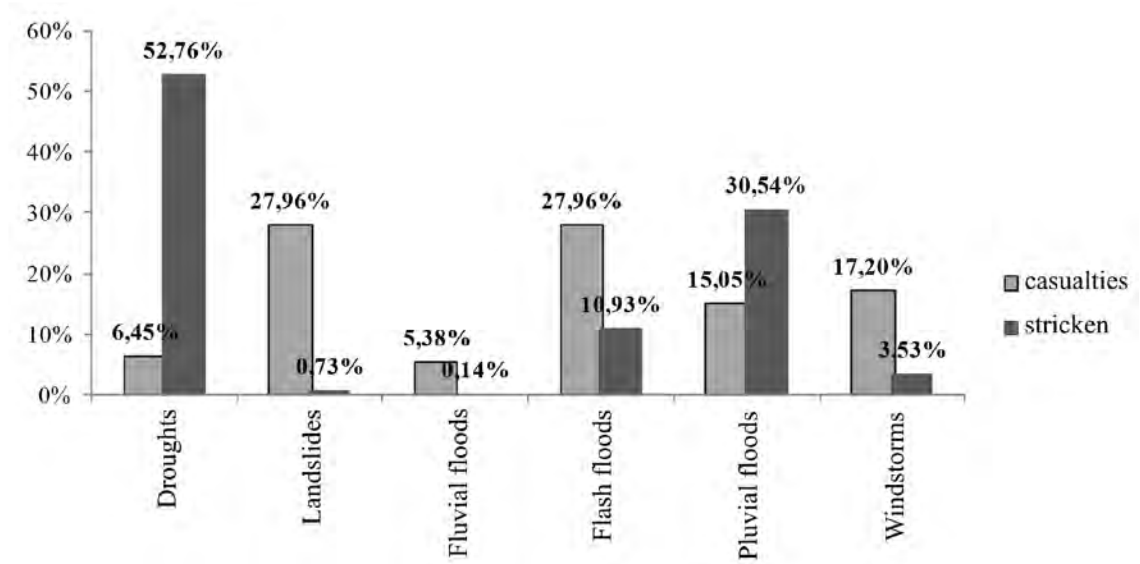


Graph 1 - Distribution of affected people by type of disaster in 2012 (Adapted from the Brazilian Natural Disasters Annual Report, 2012)

Graph 2 shows the percentage of casualties by natural disasters in 2012, as follows: landslides and flash floods (27,96% each), windstorms (17,20%), pluvial floods (15,05%), drought (6,45%) and fluvial floods (5,38%), according to MI (2012).



Graph 2 - Distribution of casualties by type of disaster in 2012 (Adapted from the Brazilian Natural Disasters Annual Report, 2012)



Graph 3 - Comparison of affected people and casualties by type of disaster in 2012 (Adapted from the Brazilian Natural Disasters Annual Report, 2012)

Droughts affect the greatest number of people mainly because they occur more frequently in the Northeast region, which is the poorest region of the country and has 27,83% (IBGE, 2010) of the population.

However, when comparing both graphs side to side, as shown in Graph 3, it is possible to observe that drought, despite affecting the greatest number of people, causes, alongside with fluvial floods, the least number of casualties. The greater share of casualties is caused by landslides and flash floods, since they usually occur in densely occupied areas, especially in the South and Southeast regions - with 14,36 and 42,13% of the population (IBGE, 2010), respectively.

The distribution of natural disasters among the five regions in Brazil, in 2012, was: a) January to May: North region; b) January, March to July and November: Northeast region; c) January to March: Center West region; and d) throughout the entire year in the South and Southeast regions (MI, 2012).

4. Civil Defense

In Brazil, Civil Defense is the institution responsible for planning actions and managing risk concerning natural disasters and technical incidents. The Protection and Civil Defense National System is present in all three government spheres: Federal, State and Municipal. Each level has its own duties and responsibilities and their work is coordinated by the National Civil Defense.

Historically, the Brazilian civil defense has always acted in a reactive manner, i.e. taking measures only after a disaster event. According to Valencio (2010, p.752) the institution had become dedicated to "mainly deal with standard procedures in the disaster response phase, related to scenario coordination and fulfillment of damage evaluation bureaucratic requirements". Two major disasters that took place in 2010 and 2011 exemplify this attitude.

In 2010, the states of Alagoas and Pernambuco, both in the Northeast region, suffered from massive pluvial floods due to strong storms. According to the World Bank report, the indirect and direct costs amount to R$ 1.89 billion in Alagoas state and R$ 1.4 billion in Pernambuco state (World Bank, 2012).

Frota et al. (2010) stress that, in spite of these disasters, the National Civil Defense has still maintained a reactive attitude, with little to no effort being made towards organizing and conditioning State and Municipal Civil Defenses to avoid or mitigate new disasters.

In 2011, the mountainous region of Rio de Janeiro state, in the Southeast region, was hit by several pluvial floods and landslides, also an outcome of severe rainstorms. The losses were estimated at R$ 4.78 billion (World Bank, 2012).

Although landslides are expected in Rio de Janeiro state during summer, preventive countermeasures were far from sufficient, if existent at all. Dourado, Arraes and Silva (2013) classify the State Civil Defense as highly qualified to perform search and rescue operations in landslide events, but poorly developed when preventing such events is concerned.

"The main issue identified in this period is the lack of prevention programs, which is enhanced by political stimuli to the occupation of risk areas and the deficiency in integrated action between state organs and local authorities" (translated from Dourado et al., 2013, p.51).

5. The National Policy for Protection and Civil Defense (PNPDEC) and it Initial Progress

The federal law that provides guidelines to Civil Defense actions is the National Policy for Protection and Civil Defense (PNPDEC), which entered into force in 2012. This policy is composed of prevention, mitigation, preparation, response and restoring actions; with emphasis on the adoption of preventive measures to minimize the effect of disasters, the stimulus for the development of resilient cities and the inclusion of risk mitigation in urban planning.

Partnerships have been established with research and technology institutions and academia, who provided technical and scientific support to natural disaster management, such as the National Center for Monitoring and Disaster Warning (port. acronym: CEMADEN); the Disaster Research and Study Center of Santa Catarina Federal University (port. acronym: CEPED-UFSC); besides other traditional public companies that helped with mapping services, the Brazilian Geological Service (port. acronym: CPRM) and the Technological Research Institute (port. acronym: IPT).

Since the establishment of the PNPDEC policy, a national register of the municipalities that are most susceptible to natural disasters has been made, and for each of these locations two documents are prepared: a chart mapping susceptibility to gravitational mass movements and floods and a geotechnical aptitude to urbanization chart. These two maps aim to provide the Civil Defense and local, state and national authorities with information to assist in adequate urban expansion planning, by pinpointing areas that are fit and unfit to urbanization. Thus, avoiding the increase in risk areas in those cities. (Sampaio et al., 2013)

CEPED-UFSC created a series of capacitating courses in risk management for public administrators and Civil Defense employees, with both theoretical and practical classes. CEMADEN is a 24/7 meteorological, hydrologic and geologic monitoring center.

6. Discussion

According to Marengo (2007), global climate models predict possible changes that would cause intense climate events, such as heat and cold waves, severe storms, floods and droughts. These events would be of particular concern to big cities like São Paulo and Rio de Janeiro, both in the Southeast region.

Though climate change is a global concern, its local effects - such as floods and heat waves - can be most damaging to urban centers, given their elevated carbon dioxide emissions and great concentration of people, economical activities and infrastructures (Romero-Lankao and Dodman, 2011).

The concept of resilience relates directly to the ability of recovering from a disaster in an efficient manner, which can only be done through preventive planning and adaptation. It is necessary to know what disasters might be faced and to create mechanisms that allow lessons learnt to be passed on, which is not about turning a city immune to disasters, but mitigating risks and damages alike.

The first steps of the National Policy for Protection and Civil Defense focus on building the knowledge required to face disasters, and are restricted to preparing technical instruments, training public administrators and Civil Defense employees and 24/7 monitoring. It is still necessary to intensify and amplify the range of actions, mainly concerning raising awareness, improvement of the city infrastructure and fairer urban policies. "[...] a well structured institutional and administrative framework is a prerequisite for a city's sound resilience initiatives" (Malalgoda et al., 2013, p.80).

7. Conclusions

The concept of resilience serves as a guide to measure what to aim to reduce the risk of disasters. Rather than as an end in itself, it is a primordial analysis category in all discussions involving cities and natural disasters.

Data from 2012 showed that a significant share of casualties resulting from disasters occurred in big cities, which can be aggravated by eventual extreme climate events.

So far, the Brazilian Civil Defense was used to act only after disasters, in the response phase. Changing culture is a very slow process, so the current policy, which strongly focuses on preventive actions to resist natural disasters, is a very important first step that must be continued, improved and reinforced in order to create a future risk management culture.

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Understanding the impacts of climate change on cultural heritage buildings: a case of York, UK

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Abstract

Cultural heritage is not only an important part of a country's identity but also a key driver of tourism (which can play an important role in a nation's economic and social resilience). However worldwide heritage buildings are gradually becoming more vulnerable, due to natural decay and deterioration, effects of climate change, and human-induced impacts, such as poor or ineffective maintenance. An increased number of extreme weather events, many of which are associated with the impacts of climate change, are posing significant problems in managing and conserving cultural heritage around the globe. Being exposed to a number of natural hazards and having a great cultural heritage, York (UK) presents a case study that provides the basis for the exploration of the strategies required for the improved disaster risk management of vulnerable heritage buildings. Through the engagement with practitioners responsible for the management of a range of heritage sites, this paper identifies the challenges faced when considering climate change adaptation measures. It argues that improved climate change adaptation and enhanced hazard mitigation strategies, involving a broad range of suitably trained stakeholders, are extremely important considerations when it comes to the assessment, maintenance and conservation of cultural heritage.

Keywords: cultural heritage buildings, climate change, mitigation, adaptation, case study

1. Introduction

Heritage sites are crucial assets for local communities and national states on both social and economic levels (Choi et al., 2010). Despite having stood strong for, in some cases, thousands of years, they remain under constant threat from natural hazards and human-induced threats. While close attention is paid to the protection of human life and livelihood as well as economic infrastructure, the protection of cultural heritage can be somewhat overlooked and under prioritised. A key factor indicating the need to increase the resilience of heritage sites to the impacts of climate change is the particular fragility of their historic fabric (Throsby, 2012), and thus their vulnerability to the effects of climate change and impacts of natural hazards.

Cultural heritage is exposed to a number of risks that can be divided into natural hazards (such as earthquakes and volcanoes), and those related to climate change (such as increased precipitation, flooding, droughts and heat waves). In addition, human-induced threats, which are essentially social and economic in nature and range from increased urbanisation, mass tourism and traffic congestion to industrial air pollution and increasing energy demand, can compound the problem (Jigyasu, 2006). All the risks associated with natural hazards, impacts of climate change, and human-induced threats, put significant pressures on cities and possible conservation efforts of historic urban environments. The increasing vulnerability of heritage sites and their assets is not merely due to increased exposure to hazards and extreme weather events. With increasing urbanisation, many urban heritage sites are now becoming engulfed by dense urban areas with huge concentrations of people and restricted access for emergency vehicles and personnel. Transformation processes in historic settlements are also breaking traditional urban boundaries, disturbing delicate ecological relationships and exposing these settlements to increased disasters and climate-related risks. Furthermore, cities have special climates which, due to complex characteristics, can be very difficult to predict: streets and buildings alter wind patterns and solar radiation, resulting in temperature and humidity changes as well as precipitation and pollutant concentrations.

The increasing pressures on heritage sites' environment, carrying capacity and socio-economic developments are likely to reach a critical point in the near future and require urgent action (UNISDR, 2015). As a consequence of the ever changing environmental and economic climates, heritage sites may currently be exposed to a greater risk from various threats than ever before in history (Croft, 2013). Heritage sites are critical to any community, and the importance of their conservation cannot be understated. Post disaster damage and potential destruction of heritage sites can cause catastrophic emotional damage to communities and residents, the avoidance of such occurring should be viewed with the utmost importance (Spennemann and Graham, 2007). Heritage sites are not merely important on a sentimental level: the economic and social benefits of their conservation have to be considered. They provide communities with character and substance, but the economic value of these sites and the revenue and tourism they bring to communities should also be noted (Choi et al., 2010).

In using York as a case study, this paper will explore current approaches to climate change mitigation and adaptation measures for cultural heritage and discuss the challenges and gaps in these strategies.

2. Types of climate change adaptation and mitigation measures for cultural heritage buildings

Whilst a great range of disaster risk reduction measures exist, not all of them are appropriate for cultural heritage due to their potential negative impacts on their values. However a number of structural and non-structural measures can be utilised if used appropriately taking into account the specific heritage values.

Non-structural activities such as education and training are the most appropriate in the context of cultural heritage. A number of training programmes have been set up that focus on heritage specific engineering techniques: they are designed to train stakeholders in heritage engineering and to equip them with the skills required to continually maintain cultural heritage sites, and sufficiently protect sites from natural hazards and human-induced threats. Hazard mapping is also becoming increasingly popular. For instance in the UK, English Heritage have recently began working with the Environment Agency to map hazards and potential threats around the UK, and is reflected in the UK National Heritage Protection Plan (Davis, 2002). Non-structural adaptation measures for cultural heritage sites also include financial management, visitation practices, and policies.

Structural adaptations are sometimes inevitable; however, they should be avoided where possible due to the risk of altering the fabric of a heritage site. For instance, Jigyasu (2006) highlights that some post-earthquake reconstruction measures in Marathwada region of India led to the destruction of significant components of cultural heritage rather than to protecting them. In the UK heritage sites are not permitted to perform key structural changes or introduce major structural measures. However, structural adaptations can be applied to sites by professional construction stakeholders (Davis, 2002) – this however is not often performed as it requires extra funding. It is also important to bear in mind that structural measures applied within the surrounding landscape might also reduce or increase the probability and the extent of the hazards' impact (Perry, 2015). These measures are to an extent supported by a number of international, regional and national frameworks described in the next section.

2.1 Legal framework and governance for the protection of cultural heritage from climate-induced hazards

In 1954 the first convention designed to draw attention to heritage protection was put in place - the Hague convention for the Protection of Cultural Property in the Event of Armed Conflict (UNESCO, 1954). It outlined that the protection of world heritage and culture from human-induced threats, such as armed conflict, should be a priority on both a national and international level, and further underlined that these sites require safeguarding and treating with the utmost respect. This followed by the establishment of the ICOMOS principles and charters of heritage conservation, which over years have not only extended the scope of cultural heritage beyond select monuments but also conservation approaches beyond mere preservation to management of change.

More recently, the Sendai Framework for Action (SFA) (UNISDR, 2015) marks significant progress with respect to the former policy document on disaster risk reduction (DRR), the Hyogo Framework for Action. Culture is now explicitly recognised as a key dimension of DRR and the need to protect and draw upon the various benefits of heritage as an asset for resilience is more clearly highlighted (Dean and Boccardi, 2015).

The UNESCO World Heritage Committee has recommended that State Parties include risk preparedness as an element in their World Heritage site management plans and training strategies (Paragraph 118 Operational Guidelines). This was extended in 2011 to all cultural heritage sites by highlighting risk management within the Historic Urban Landscape approach that emphasised the necessity of legal compliance and effective integration into national or regional legislation (UNESCO, 2011). In order to ensure the effectiveness it emphasises the particular importance of raising awareness and communicating the benefits of a formalised risk management approach in order to increase political will and to increase the resilience and the safeguarding of the historic cities to the primary and secondary hazards and threats. The risk management system has to consider the costs associated with the impact of disaster and climate change effects on human settlements, economic and social activities, environment, cultural heritage and historical urban properties, and consequentially the benefits of introducing a system for mitigation of risks.

The EU and Member States have also reacted to the challenges posed by climate change and other threats with activities in several fields. Among the most important actions is the setting of a consistent and supportive legal framework for targeting these challenges. The global legal outline shows a complex system where EU has a general legislative competence in the field of environmental management; some specific matters regulated by binding acts, such as Water and Flood directives (Directive 2007/60/EC); a general international system of soft law aimed to improve the resilience of communities, where international bodies and organisations, mainly represented by UNESCO for cultural heritage and UNISDR for disaster reduction, have an important role. Climate change is seen by many governments as a risk multiplier that has influenced shifts in policy that covers natural hazards, thus requiring not only improvements in emergency management, but also in prevention and preparedness (Werrel and Femia, 2015). Accordingly, a number of adaptation and mitigation programmes and strategies have been introduced in the last decade, however the extent to which these initiatives encompass cultural heritage is negligible. With reference to culture, the EU supports cooperation between Member States to conserve and safeguard European cultural heritage and the adoption of incentive measures through special culture programmes and dedicated budget lines, but expressly excludes any harmonisation of laws and regulations of the Member States (art.167 TFEU).

However, recently, following the "Europe 2020 Strategy for a Smart and Sustainable Growth", new EU cultural policies and related funding programmes have considered that special attention should be given to cultural heritage threatened by natural hazards and human induced threats and to propose dedicated plans. Specifically, the European Work Plan for Culture 2015-2018, expressly mentions as a goal to be pursued, a study on risk assessment and prevention to safeguard cultural heritage against natural risks (*OJ 23.12.2014 – C463*).

In the UK, the sole driving force behind the protection, prioritisation and allocation of funding to heritage sites throughout England is centred in the National Heritage Protection Plan (the Plan) introduced in April 2011. The plan consists of two key elements: first, it establishes a framework for determining heritage prioritisation throughout the UK, highlighting which sites require most urgent protection; this will help to increase collaboration of sites and aim to eradicate duplication of works, with the hope of outlining areas which have been overlooked or dismissed. Second, it proposes that action plans would be put in place to address the needs of the aforementioned prioritised sites in the form of resources and funding (English Heritage, 2013). The framework set up throughout this plan consists of four key areas:

- *Foresight:* Identifies potential threats and issues from economic, environmental and historical perspectives; assesses awareness of relevant parties; and gains perspective on issues from within these parties and organisations.
- *Threat:* assesses the risk of all potential natural hazards and human induced threat, and their impact on a site; and establishes strategic action. One of its particular focuses is flooding.
- *Understating:* identifies site-related information in order to understand its vulnerabilities; and prioritises the significance of the sites and the issues they are facing.
- *Response:* sets out response measures including protective, managerial and help and advice oriented measures.

3. Methodology

York has been chosen as a case study city for this paper (it is introduced in the next section). The case study method is deemed appropriate as it allowed focusing on understanding of dynamics presented within a single setting and answering *whether* and *how* questions (Yin, 1994; Eisenhardt, 1989). Whilst a case study cannot offer generalisation, its conclusions can be applied to the development of new theories and concepts, and the revision of existing ones.

An extensive web and literature research was initially conducted to identify any secondary literature. Four site visits from April to June 2015 were then conducted as it helps to obtain valuable insight (Lofland and Lofland, 1995) when discussing the projects and to understand the environment and the context in which the project is taking place. Finally eight semi-structured interviews with a number of key stakeholders involved in the management of the heritage sites were conducted; this was deemed important because the stakeholders' perspective on the process of the project implementation could provide valuable information on existing measures as well as the challenges faced by the heritage sites in the context of climate change. The interviews covered the following aspects: main threats faced by heritage sites, risk assessment and risk mitigation measures, funding, and impact of policies. The interviews were recorded, transcribed and thematically analysed. Thematic analysis was chosen due to the complexity of the dataset and the need for a flexible analytical process to provide a structure (Howitt and Cramer, 2011).

3.1 York case study

York is a historic walled city with a population of 200,000 at the confluence of the rivers Ouse and Foss in North Yorkshire, England, and is the traditional county town of Yorkshire. The city has a rich heritage and has provided the backdrop to major political events in England throughout much of its two millennia of existence. The city offers a wealth of historic attractions, of which York Minster is the most prominent, and a variety of cultural and sporting activities making it a popular tourist destination for millions. The city was founded by the Romans as Eboracum in 71 AD. It became the capital of the Roman province of Britannia Inferior, and later of the kingdoms of Northumbria and Jorvik. In the Middle Ages, York grew as a major wool trading centre and became the capital of the northern ecclesiastical province of the Church of England. Consequently the historic building stock in York is widely variable and noticeable periods of growth can be observed through analysis of historic maps of the city: it ranges from Roman style to the medieval timber framed structures, and there is also a strong Georgian architectural influence (Stephenson and D'Ayala, 2014).

York therefore has a large variety of cultural heritage sites, many of which are prone to climate-induced hazards, and in particular flooding (Hutton and March, 2002). A number of actions are taken by the City of York (and its York Prepared team) in order to reduce the impacts of flooding, as a large number of heritage and historic sites requires protection and prioritisation to avoid suffering permanent damage as a consequence of the ever-changing environmental climate. Although York has suffered historically at the hands of flooding since the early thirteenth century (Radley and Simms, 1971), studies have been carried out which outline that flooding has become significantly worse in York over the past century (Archer, 1999; Macdonald et al., 2003; Macdonald and Black, 2010); notably this occurred between the 1940s and 50s (Farrant, 1953), until significant flooding in the 1980s and 2000s.

4. Discussion: Living with floods or surviving floods?

As described in previous section, York and its heritage sites are regularly affected by flooding. Current flood mitigation measures deployed in York include a floodwall and the Foss Barrier. These mitigation measures however do not fully protect the heritage related built environment of the city. The York local authorities treat flooding as a natural process and thus emphasise that it is impossible to fully prevent such events and therefor the focus should be on risk management (City of York Council, 2015).

The majority of York's environmental issues have historically come in the form of flooding, usually as a direct result of the River Ouse bursting its banks after periods of heavy rainfall. The continued worsening of flooding in the York region has to some extent been related to the land usage of areas north (upstream of the Rover Ouse) of York; the removal of sufficient vegetation is seen as a key factor in increasing run off and thus causing increased flooding in York (Sansom, 1996); this could be exacerbated in the future by the effects of climate change (English Heritage, 2008). According to the analysis of epigraphic flood markings (inscribed markings) (Macdonald, 2007) inside the basement of the old Merchant Venturers' Hall in central York, the city had been built up over the original flood plain during the centuries. Although the ground level in York has been raised, there was no change in base river level during the historical period. Examination of historic and contemporary maps indicates that no significant changes to the channel form through York appear to have occurred in the past 250 years (Macdonald and Black, 2010).

4.1 Main challenges

Although relatively resistant to flood damage, historic-building materials can all suffer some degradation and may need appropriate treatment. The degradation is often triggered by a combination of flooding and weathering, which affect materials of the site structures. These materials include stone, solid brick and mortar walls, timber frames, wattle-and-daub panels, timber boarding and panelling, earthen walls and floors, lime-plaster walls and ceilings and many decorative finishes (English Heritage, 2008). Organic materials such as timbers swell and distort when wet and suffer fungal and insect infestations if left damp for too long; if dried too quickly and at temperatures that are too high, organic materials can shrink and split, or twist if they are restrained in panels (Historic England 2015). Inorganic porous materials do not generally suffer directly from biological attack. Significant damage can occur when inherent salt and water (frost) crystals carried through the substrate are released through inappropriate drying or very cold conditions; in addition to severe water damage, water contaminants and sediment concentration significantly increase during a flood period (Longfield and Macklin, 1999), which can result in heritage and historical sites suffering from erosion and contamination, as well as generic water damage.

As already mentioned in Section 2, physical damage requires structural interventions that would enhance protection, however the interviews have demonstrated that there are a number of flaws that make the existing protection system not as effective as it could be, despite the UK having a system in place that inspects heritage sites (as described in Section 2.1). The following challenges have been highlighted by the interviewees:

- *Ineffective communication*: There is a very little contact between English Heritage and the owners and managers of the heritage sites. This impacts the ability of the latter to identify possible hazards and address them in a timely manner. Whilst most of the site owners and managers are aware of the hazards based on their experience, they are not prepared to deal with other potential hazards. The communication with local authorities exists however it is mainly aimed at the emergency response. In addition, in the event of flooding local authorities team heritage building similar to any other building assets affected by flooding.

- *Lack of formal stakeholders' engagement*: Whilst some collaboration exists, it is often informal and depends on personal relationships, as there is no specific contact for heritage site protection.

- *Lack of competencies*: local stakeholders are mainly responsible for the identification of the damages and risks; they however are not appropriately trained to conduct such exercises. This leads to the rather *reactive nature* of strategies adopted by the site owners and managers. Whilst the inspections take place every five years, it is not sufficient for the levels of pre-emptive decision-making that are typically required for effective DRR.

- L*ack of funding for pre-emptive measures*; instead the funding can only be received once the site has been damaged (and the damage may be irreversible).

5. Conclusions

This paper has discussed that despite an increasing number of frameworks for addressing climate-induced hazards for heritage sites, there is still a need for change in the way these frameworks are implemented locally. The lack of practical enforcement results in sites remaining unprotected and exposed.

The remarkable robustness of many historical structures in York has already demonstrated their resilience and ability to adapt to changing environment, however with the increase in extreme weather events, there is a need to support and enhance such resilience.

This is the case not only in York but internationally. Although Sendai Framework on DRR establishes the recognition of culture as a key dimension of DRR, there is still a challenge of implementing the policies, which would build the capacities and set up institutional mechanisms at different levels and ensure that culture is given its due recognition.

Despite a large range of policies and tools, the actions aimed at the mitigation of climate change impacts for cultural heritage are dispersed. It is necessary to provide appropriate tools to proactively act in minimising (or indeed preventing) the impacts of climate change as well as in the case emergencies caused as a result of climate- induced hazards. In addition, there is a need for sharing knowledge and actions with stakeholders, through either close interaction with environmental and construction professionals, and through training and guidance at site level. It is also important to incorporate climate adaptation strategies and develop risk management plans for cultural heritage as a part of a larger pro-active planning and development strategies and risk mitigation plans, rather than in isolation. Risk management of cultural heritage sites should be seen as one of the important components of the urban space, with the impacts of new spaces on heritage spaces being considered. The most important aspect of ensuring the effective implementation of the prevention and mitigation measures to heritage sites is through empowering and engaging communities and encouraging full participation in the preservation of what is notably their cultural and heritage sites. It is often the case that local stakeholders are those who are most passionate in maintaining the cultural fabric of sites, and the most enthusiastic about site preservation.

The main question however remains: How can site managers and custodians be supported in finding adequate responses to increase the resilience of heritage from natural hazards and climate change related risks? There is a need for an integrated multi-sectorial disaster risk management framework that would address this issue focussing on pro-active strategies and formal multi-stakeholders' engagement.

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Heat Stress in the U.S. Construction Industry

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Abstract

Construction workers perform demanding physical tasks and can be exposed to excessive heat and environmental conditions resulting in heat related illness and injury. Few research studies have examined the heat related illness and injury issues in the construction sector, particularly in the United States. Our literature review revealed that most heat stress research in the construction sector occurred in Australia, Hong Kong, India, United Arab Emirates, Japan, and China. The US Occupational Safety and Health Administration Fatality and Catastrophe Investigation Summaries database was search for a five-year period (2009-2013) for heat related cases in the construction sector. The research detailed in this paper summarizes the fifty-eight OSHA fatality and inspection reports during that period and describes the risk factors associated with heat stress among construction workers. Best practices and strategies to mitigate exposure are discussed, and a path forward for future research is offered. The U.S. does not regulate heat specifically but uses the General Duty Clause for heat related enforcement.

Keywords: Heat stress, safety, health, construction

1. Introduction

Construction work requires workers to be exposed to the elements, and in the summer months that includes heat. Heat stress fatalities are a concern as observed from the OSHA fatality index (OSHA 2015a) where 30 fatalities were observed in 5 years in construction alone.

The purposes of this paper are threefold. Firstly, we will evaluate the extent and severity of the problem of construction fatalities related to heat, through OSHA reports, identify and describe the risk factors associated with heat exposure among construction workers. The paper will identify the best practices and strategies to mitigate exposure, and try to determine a path for future research in order to find the extent of heat protection measures practiced in the US, how much contractors understand what measures they need to take in order to protect their workers from heat.

2. Background

Heat stress occurs when the body is unable to lose heat after continuous physical labour. This causes body temperature to rise and the heart rate to increase. There are several ailments that arise on construction sites that are related to this excess heat. These are heat stroke, heat exhaustion, heat cramps, fainting (heat syncope), and heat rash (Lopez 1996; McKinnon et al. 2005).

Heat stroke, is the most serious of the ailments, and it is caused by the inability of the body to control its internal temperature, thus the body stops sweating, and excess heat is not dissipated. Signs of heat stroke include: mental confusion, delirium, loss of consciousness, convulsions, and even coma, body temperature of 106^{o}F and higher, and skin that is hot and dry. Heat exhaustion is the result of excessive loss of fluids through perspiration, caused by failure to drink adequate water and/or intake of salt. Workers suffering from heat exhaustion, are weak, and fatigued, and experience nausea and headaches, while at the same time they have clammy skin, and slightly elevated temperature (Lopez 1996). Fainting occurs to workers not acclimated to hot environments, in particular when they are just standing still in the heat. It is suggested that fainting victims lie down for a short time, away from direct heat. It is also suggested that in order to eliminate the chance of fainting workers should be moving around instead of standing still. Lastly, heat rash occurs in hot and humid areas, when sweat is not easily evaporated (Lopez 1996; McKinnon et al. 2005).

Construction workers perform demanding physical tasks and can be exposed to excessive heat and environmental conditions resulting in heat related illness and injury. As reported by McKinnon et al. (2005) from data provided by the Bureau of Labour Statistics, 40% of deaths in 2002 related to heat strain occurred in the construction industry. Few research studies have examined the heat related illness and injury issues in the construction sector, particularly in the United States. The literature review revealed that most heat stress research in the construction sector occurred in Australia, Hong Kong, India, United Arab Emirates, and China (McDonald et al. 2008; Chan et al. 2012; Farshad et al. 2014; Rowlinson et al. 2015; Jia et al. 2016; Li et al. 2016).

Some research in the US has produced industry suggestions and regulations, examples of which include informational pamphlets and material from National Institute of Occupational Safety and Health (NIOSH) that provide information for preventing heat stress, identifying the symptoms, and guidelines for acclimatization (NIOSH 2014). The Occupational Safety and Health Administration (OSHA) similarly has information and pamphlets available its website, but in addition regulations for heat stress prevention recommendations and employer obligations to preventing and protecting workers from heat stress (OSHA 2015c). It is clear to say that guidelines and recommendations are available to US contractors to implement in order to reduce the incidences relating to heat stress (fatalities and injuries) in the US, and yet these incidences occur and they seem to be happening in specific regions of the country, and more likely to small contractors.

3. Methodology and Collected Information

Fatality and Catastrophe Investigation Summaries are developed after the US Occupational Safety and Health Administration conducts an inspection in response to a fatality or catastrophe. These summaries and inspection details provide a description of the incident and are available online at https://www.osha.gov/pls/imis/accidentsearch.html. On August 9, 2015, a search was performed to build a database of construction heat-related fatalities and catastrophes. The search was limited to a five-year period from January 1, 2009 through December 31, 2013. OSHA's database for 2014 was incomplete. The cases are catalogued using keywords, and the ones used for this search were: heat exhaustion, heat stroke, and heat. The search was only limited to construction related industries, and that was achieved using OSHA's Standard Industrial Classification Codes for Construction. These are: Major Groups 15 (Building Construction General Contractors and Operative Builders), 16 (Heavy Construction Other than Building Construction Contractors), and 17 (Construction Special Trade Contractors). Some of the case summaries were duplicated and these cross-referenced in order to remove these duplicates (OSHA 2015a). Sixty-five cases matched the search criteria, and after reviewing each case seven were eliminated. The eliminated cases dealt with electrical burns, HVAC equipment, and were not related to heat exposure. This left 58 cases in the five-year period that met the criteria for heat related fatalities and catastrophes in the construction section (OSHA 2015a).

The cases listed in the OSHA (2015a) directory are mapped by state in Figure 1. As observed the majority of the cases took pace in southern states (California, Arizona, Texas, Louisiana, Georgia, South Carolina, North Carolina, and Arkansas), where temperatures are expected to be higher. Yet, there were incidences in northern states as well. One incidence took place in Wisconsin, a northern states, and that happened in May of 2010. This suggests that although the majority of the cases would happen in the south, contractors should be aware that even in northern states, cases involving heat stress can take place. Thirty (52%) of the cases involved a fatality, while the rest (48%) were non-fatal. Nine of these cases (16%) took place concrete work, eight (14%) in specialty trade work, while seven (12%) of these were in roofing, siding, and sheet metal work, and another seven (12%) in highway and street construction.

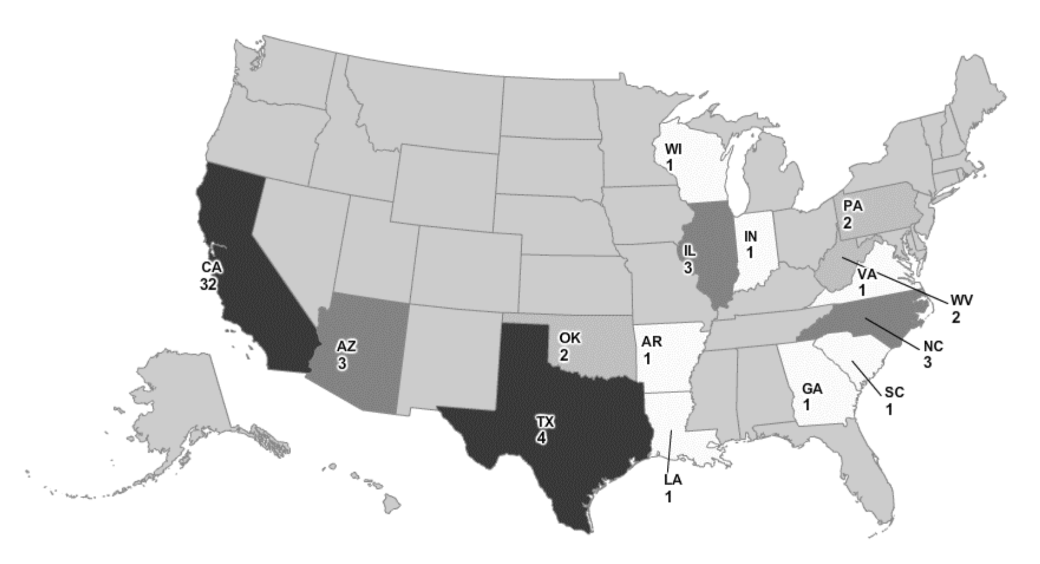

Figure 1: Heat stress case studies by state (OSHA 2015a)

As observed in Table 1, over half of the cases that experienced an incident involving heat stress took place in contracts under $50,000, while that percentage for contracts under $1,000,000 was 79%. This suggests that the majority of the incidences took place in contracts undertaken by small contractors.

Table 2 shows the heat stress incidences according to the month they took place. As expected, the majority of the incidences took place in the summer months (June, July, and August) with a percentage of 74%. It is clear though that incidences resulting in heat stress do not only occur in the summer. As observed there was one case in February, albeit that incident took place in California.

Table 1: Project costs with heat stress incidents (OSHA 2015a)

Project Cost	***Number of Cases***	***Percentage***
Under $50,000	*31*	*53%*
$50,000 to $250,000	*5*	*9%*
$250,000 to $500,000	*4*	*7%*
$500,000 to $1,000,000	*6*	*10%*
$1,000,000 to $5,000,000	*9*	*16%*
$5,000,000 to $20,000,000	*2*	*3%*

$20,000,000 and over	*1*	*2%*
Total	***58***	***100%***

Table 2: Month of heat stress incidence occurrence (OSHA 2015a)

Month of Incident	***Number of Cases***	***Percentage***
February	*1*	*2%*
May	*7*	*12%*
June	*15*	*26%*
July	*21*	*36%*
August	*7*	*12%*
September	*6*	*10%*
October	*1*	*2%*
Total	***58***	***100%***

4. US Heat Stress Regulations

The U.S. does not have specific regulations for occupational exposure to heat. According to the General Duty Clause of the Occupational Health and Safety Act (OSHA), Section 5(a)(1), it is up to the employers to provide their employees with a workplace that is "free from recognizable hazards" that might cause harm to the workers. This is a legal obligation from the part of the employer (OSHA 2015c). Under these regulations and obligations employers are required to provide all PPE, record any injuries and illnesses, provide potable water, first aid, and training. When a worker is experiencing heat stress and seeks medical attention the employer is required to report the incident. If the worker though merely rests and drinks water, without needing first aid or hospitalization, the n the employer does not require to report the incident. As a result, many instances of heat stress remain under reported. Furthermore, the penalties to the employer for allowing heat stress fatalities to take place are not severe, and of low monetary significance.

As a case study to highlight the regulatory and practice implications within the US construction industry, this fatality is provided. An employee on his first day of his new job was installing formwork for curbs. The temperature was 97 Fahrenheit with humidity of 74%. The heat index reached 130 degrees Fahrenheit according to the OSHA citation report number 313632184. OSHA found the new employee was not acclimatized and employees were not trained to recognize heat related illness. US OSHA does not have a specific heat stress standard in for nay industrial sector. To cite employers for violations involving heat stress, OSHA uses the General Duty Clause. The General Duty Cause requires that "each employer shall furnish to each of his employees employment and a place of employment which are free from recognized hazards that are causing or are likely to cause death or serious physical harm to his employees"(OSHA 2015b). In this case the citation for the fatality totalled a mere $3,500. The average monetary penalty for the 30 heat related fatalities in this dataset initially assigned by OSHA was $7,542.50. However, many penalties are negotiated lower. The 30 fatalities were as well for a final average fine of $5,643 per fatality. This is hardly a monetary deterrent for companies to understand and heat stress in the construction sector. The largest fine was $27,435, but most are a few thousand dollars with one as low as $300.

Awareness of heat related illness is seen as a key to prevention (Lopez 1996). In the US, many construction companies use OSHA's voluntary 10 and 30 hour training programs for enhanced training of their workforce. The 10-hour class is intended for entry level workers, while the 30-hour class is more appropriate for supervisors or workers with some safety responsibility. However, neither class requires any information about heat stress, nor is it mentioned in the list of electives. Including heat stress in this training would benefit workers and increase awareness in the industry, however small contractors do not require this training of their workers.

5. Heat stress prevention recommendations

Rowlinson and Jia (2015) proposed a methodology for developing tools for determining optimized work-rest regimens and work paces by applying the predicted heat strain (PHS) model to anchor heat stress management guidelines. They propose the development of regional guidelines developed by the presented protocol and the continual update of these guidelines can be compared to provide a global picture of occupational heat stress and advance knowledge of the effect global climate change on work-related stress.

More heat prevention recommendation come from McKinnon et al. (2005) where the authors suggest early recognition of the symptoms and prevention is key in limiting the progression of heat related issues to a more serious phase. They suggest that workers should use personal protection equipment (PPE) that allow for ventilation of the body, implementing engineering controls to remove workers from direct sunlight and heat, provide plenty of drinking water, acclimate the workers to extreme temperatures, and administer educational programs for workers to recognize heat stress symptoms.

Heat stress prevention measures have been successfully implemented in other parts of the world. One particular example comes from the Arabian Gulf, where McDonald et al. (2008) describe measures taken in Qatar in order to decrease the heat-stress-related medical treatments. Incidents were seen to be reduced from a value of 0.164 incidents per 200,000 workhours to 0.012 in a period of 3 years. This was achieved by applying engineering controls, for heat reduction in rest areas and by applying administrative controls in work areas. Such measures included umbrellas, insulated water bottles, evaporative bandanas, acclimatization of the workers, employee rotation, buddy system, work-rest period guidelines, and water consumption guidelines.

It seems that the communication of the hazards associated with heat exposure on the construction job site, in conjunction with administrative controls, is the best method to prevent heat stress incidences. Such a plan, similar to the one described by McDonald et al. (2008), is described in a conference paper by Chesson (2012). The author there describes successful measures that promote a comprehensive approach both for heat management and sun protection for workers employed at an oil field on Barrow Island in Australia. Such measures included engineering controls (reflective shields, mechanical ventilation, tents, etc.), administrative controls (tool-box meetings, work-rest schedules, self-pacing, education, etc.), and PPE (cool vests and bandanas, personal cooling equipment, loose fitting light coloured clothing, etc.)

6. Discussion

Some of these ailments discussed in this paper can be treated with basic first aid in order to eliminate the possibility of death. Heat stroke requires the prompts removal of the worker to a cool area, and at the same time attempt to cool them down by soaking their clothes in water, and vigorously fanning them, while waiting for medical help to arrive. First aid for heat exhaustion includes the removal of the worker from direct heat to a cool place for rest, and injection of electrolyte solution, while more severe cases would need medical treatment (Lopez 1996).

It is important though to prevent heat stress from happening, rather than dealing with its aftereffects. Lopez (1996) suggests the following: install ventilation and cooling fans; incorporate equipment that require less physical labour such as pneumatic tools; provide drinking water to all workers; acclimate workers to heat through gradual exposure; incorporate loose fitting clothing; educate workers on symptoms and treatment of heat stress.

In a study performed by Kenney (1985) showed that medical screening could be used to predict the performance of workers under heat stress conditions. These conditions were achieved my providing workers with a vapour barrier rubber suit that inhibited the dissipation of sweat, while pedalling on a stationary bike. Healthier workers were able to perform better in the physical test, and, and the author concluded that to increase worker's performance, it would be advisable to acclimate them in these adverse environments (Kenney 1985). The author continued by suggesting annual exams take place to evaluate the capability of workers to perform their tasks in extreme heat conditions.

Heat stress can be caught early by incorporating wearable devises and sensors that sound alarms when certain health parameters; such as heart rate and body temperature, exceed normal conditions. An example of an early study is described by Cohen et al. (1988) where employees wearing personal monitors that measured physiological strain and were able to monitor themselves and takes breaks as suggested. A more recent study (Gatti et al. 2013) looked at a modern monitor that measured heart rate and breathing rate under simulated construction activities, and the authors concluded that with advances in technology, it is possible to monitor workers' condition instantaneously.

Rowlinson et al. (2014) report that climatic heat stress is determined by six key factors. They are (1) air temperature, (2) humidity, (3) radiant heat, and (4) wind speed indicating the environment, (5) metabolic heat generated by physical activities, and (6) "clothing effect" that moderates the heat exchange between the body and the environment. Rowlinson et al. (2014) suggest that by making use of existing heat stress indices and heat stress management processes, heat stress risk on construction sites can be managed in three ways: (1) control of environmental heat stress exposure through use of an action-triggering threshold system, (2) control of continuous work time (CWT, referred by maximum allowable exposure duration) with mandatory work-rest regimens, and (3) enabling self-paced working through empowerment of employees.

7. Conclusions

Heat stress in US construction sites occurs in the southern states, but some of the northern states have had heat related incidences. In addition the majority of the cases took place in contracts that are below 1 million in value, suggesting that the majority of the incidences probably happen to projects undertaken by smaller contractors.

Administrative and engineering controls have been proven from research in other countries to reduce the number of incidences, and it seems that a good regiment of such measures would make a significant improvement to the US construction heat related incidence rates. What is still unknown is the identification of the best measures that need to be implemented that would be cost effective for small scale contractors who do not have the capability and flexibility to provide an array of prevention techniques. Further research is required to identify current US practices, with emphasis in practices employed by small contractors, and identify the effectiveness of such measures.

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Part II: Constructing Commitment and acknowledging human experiences

3. Health and Safety
4. Organisations, Knowledge and Communications
5. Projects, Procurement and Performance
6. Users, Clients and Stakeholder Engagement

TAMPERE UNIVERSITY OF TECHNOLOGY

What does ‘common sense’ really mean in health and safety?

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Abstract

Extensive literature search has revealed that construction workers refer to the use of ‘common sense’ in site safety. This was also discovered in a recently completed PhD project where workers openly discussed a common sense approach to health and safety on site. The use of this term can be problematic. Different workers labelled different behaviours under this generic term. Also, some used it to refer to positive experiences and application of knowledge based on experience. Others employed the term negatively, or dismissively: “*It’s just common sense…*” General use of the term puts emphasis on ‘basic knowledge’ required for attaining minimal or satisfactory achievement of a given task or activity. This is in conflict with some workers’ interpretation of skilled and experience based action. In academic language ideas in this field are more substantially and in depth explored under ‘communities of practice’ and ‘local knowledge’. These concepts offer an avenue for analysis not tied to specific wording employed by respondents but interpreting broader sets of data particularly for this study (i.e. observation material and text around specific extracts of text). This paper presents findings from five micro construction firms regarding the concept of common sense and site safety. Practical constraints, such as a researcher’s stage of development and skill in qualitative analysis, potentially hinder the development of argumentation. The interpretative school of thought accepts researchers’ influence on the processes; and we add depth and nuanced understanding to this discussion via practical examples of such issues. Interpretation of the data collected through ethnographic case studies indicates although workers interpret common sense differently, although it is essentially a means of working safely. However, common sense safety techniques tend to fall outside strict site rules which are often bureaucratic.

Keywords: common sense, communities of practice, interpretative research, site safety

1. Introduction

The notion of incorporating a 'common sense' approach to construction site safety is a fairly new concept. This concept has gradually gained momentum in the academic realm (see Ludhra, 2015; Oswald *et al*, 2015; Aboagye-Nimo *et al*, 2013) and in some policy making reports (see Lord Young of Graffham, 2010; Davis, 2009). Literature on common sense safety tends to considered common sense in a positive light, to mean '*the ability to behave in a sensible way and make practical decisions*' (Ludhra, 2015: 3). An individual's ability to behave in a sensible manner with regard to safety can be interpreted differently depending on context. Thus common sense can be studied as a practice-context related subject.

This paper seeks to generate an understanding of the meanings construction site workers attribute to the idea of common sense in construction site safety. The overall aim of this paper is to explore what workers of micro construction firms mean by the term common sense. As mentioned in the previous paragraph, the study considers the term in relation to settings of the participants of the study. In order to understand the contextual conditions that influence the way in which individuals may employ 'common sense'. The next section explores literature on communities of practice and situated knowledge.

2. Communities of practice in construction

The focus of this study is on the micro construction firm as a 'community'. Communities of practice are semi-formal, self-governing networks of people who share a common interest in a specific aspect of practice (Bartholomew 2008: 146). Another way of describing communities of practice is an activity system about which participants share understandings concerning what they are doing and what that means in their lives and for their lives and for their community (Edwards and Mercer, 2013). Thus, workers operating in such a community are united in both action and in the meaning that action has, both for themselves, and for the larger collective (Lave and Wenger 1991: 98). This paper investigates the common knowledge that is shared by micro construction firms in the form of local knowledge and common sense in relation to site safety.

Workers produce safe working practices and hence safe working environments by engineering heterogeneous elements including knowledge, materials, relations and communication within a community of practice (Gherardi *et al* 1998: 204). Such knowledge is known to exist outside formal organisation structures although recognized and empowered by the organisation (Bartholomew, 2008: 148-149). This type of safety practice and use of informal knowledge in construction is relatable to coalminers' 'pit sense' (Kamoche and Maguire, 2011). Pit sense is described as a tacit and situated form of knowledge constituted by tunnellers as a way to navigate and assess risk (ibid: 725). Similarly, the construction industry uses tacit and local knowledge extensively as it is important in raising performance at an organisational level (Addis 2014: 1245). This type knowledge which is often referred to as common sense due to its inexplicable nature is very instrumental in accident prevention and site safety (Aboagye-Nimo *et al*, 2015). Particularly, it helps workers to be able to choose between different physical approaches when confronted with risks (Forsythe 2014: 242).

2.1 Common sense and local knowledge

Previous studies into the use of common sense in construction site safety have defined common sense as the practical knowledge and judgement developed by workers after gaining years of experience on site (see Oswald *et al*, 2015; Aboagye-Nimo *et al*, 2013). Practical knowledge and judgement on site requires complex interaction of explicit and tacit knowledge gained through training, experience, guidance by leaders, experiential learning in new situations and from experts and experienced workers who have preceded us (Gherardi and Nicolini 2002: 192). People without extensive local knowledge may stand right next to danger and not notice it (Baart 2009: 953). Local knowledge is knowledge specific to a particular situation (Sole and Edmondson, 2002). It can be described as the knowledge that people in a given community have developed over time, and continue to develop (Tutt *et al*, 2013). Thus it can be argued that this type of knowledge is context-related. A lack of this local knowledge can result in unsafe conditions for workers and their colleagues (Koch, 2013). In terms of common sense and local knowledge, what is 'reasonable' in terms of safety must be shared knowledge i.e. workers must agree on it. In relation to the knowledge-sharing process on construction sites, there are four different influences namely; openness, motivation, trust and pressure of time (Fong 2007: 208).

Using this common sense and local knowledge may occasionally fall outside the scope of official safety procedures as implied by Lord Young of Graffham (2010) and confirmed by Oswald *et al* (2015). This will thus create some misunderstanding between workers using this type of knowledge (micro construction firm workers) and those implementing official safety procedures (e.g. principal contractors). Unfortunately, when misunderstandings occur between principal contractor and subcontractor, it can lead to the subcontractor can be put on a 'blacklist' (Taylor, 2013).

The key themes will be investigated through fieldwork. Explanation of the research methods adopted for the empirical investigation follows.

3. Research methodology

This research seeks to understand the subjective view of construction site workers in relation to common sense safety. For this reason, an interpretation of the views expressed by these workers is imperative; thus the philosophy of interpretivism is adopted. Since common sense can be argued to exist differently amongst different communities of practice (see section 2), the concept of common sense was stretched to cover phrases presenting similarities in meaning. These included phrases such as '*automatically knowing*', '*general knowledge*' and '*obvious knowledge*'. Great care was taken through methodological rigour and robustness to ensure that this did not result in 'concept misformation' (see Campbell *et al*, 1984). Some of the factors taken into consideration was the possibility of the researcher misinterpreting the data collected as they were still in the process of carrying out a PhD research project. This was minimalized by the inclusion of research supervisors of a variety of expertise including a linguistics expert.

Numerous researchers that have sought to understand practices of groups and teams operating on construction sites encourage the use of in-depth qualitative methods (see Fellows and Liu, 2015; Tutt *et al*, 2013). In order for a researcher to understand a context and appreciate a group's shared values and beliefs, it is important that the researcher gains insight into what, how and why their patterns of behaviour occur (Fellows and Liu 2015: 24). A researcher can thus become very effective at gaining such insight by immersing their self in the group being studied i.e. becoming part of it (Pink *et al*, 2010). Epistemologically, an ethnographic approach is one of the most effective methods by which a researcher can explore value structures and beliefs that influence the group behaviours especially during the construction phase of a project (Fellows and Liu, 2015). In this paper, the definition adopted for an ethnography is:

'*an iterative-inductive research (that evolves in design through the study), drawing on a family of methods, involving direct and sustained contact with human agents, within the context of their daily lives (and cultures), watching what happens, listening to what is said, asking questions, and producing a richly written account that respects the irreducibility of human experience, that acknowledges the role of theory as well as the researcher's own role and that views humans as part object/part subject.*' (adapted from O'Reilly, 2012: 3; Pink *et al*, 2010: 648).

Non-participant observations, semi-structured interviews and conversations were incorporated under the umbrella of the ethnography. Five micro construction firms operating on different sites were studied in this research (see table 1). They all operate in the East Midlands region of the United Kingdom (UK). In order to build trust between researcher and participants, gatekeepers were used to establish the contact. This was followed by an honest disclosure of the aim and nature of the study. These steps were crucial to the study because small and micro construction firms are known as 'hard-to-reach' due to their secluded nature in relation to their interaction with outsiders (Willbourn, 2009).

Analysis of the data was conducted starting with a thorough thematic coding of the information (transcribed interview data and field notes from observations) using QSR NVivo. Using this computer assisted approach helped in the better organisation of the collected data. In addition, patterns were able to be drawn from the data, especially inferences that could not be drawn from analysing interview data and observation data separately.

4. Findings and analysis

Participants from all the five sites (i.e. the five micro firms) were working at different stages of their various projects. Site activities included electrical wiring, plumbing works, brick laying, screeding, excavations, laying foundation, landscaping and roofing works. Ages of the participants and their years of experience in the construction industry also varied vastly amongst the research participants. The least experienced participant had been on site for only one year and the most experienced site worker had worked for 40 years. This ensured a good variation in workers' views particularly when discussing a topic as contextual as common sense. Table 1 below presents an overview of the five case studies.

Table 1: Profile of case studies

Details / *Case study*	*Type of work*	*Nature of the project/ work*	*Number of participants*
Case study 1	*General builders*	*Refurbishment of existing structure*	*5*
Case study 2	*Ground workers*	*Preparation for new builds*	*3*
Case study 3	*Ground workers and general builders*	*New building*	*3*
Case study 4	*General builders*	*Preparation and laying foundation for new housing community*	*3*
Case study 5	*General builders*	*Completing new building*	*4*

The owners of the micro firms were John (14 years' experience), Derek (20 years' experience), Scott (13 years' site experience), Tony (13 years' site experience) and Tom (12 years' site experience) respectively.

4.1 Initial impressions of common sense and site safety

One consistent finding from both observations and interviews was the fact that none of the newer employees (less than two years' of site experience) associated any of their safety practices to common sense or local knowledge. On the other hand, participants that had extensive experience in the industry seemed to attribute a significant amount of their safety practices to common sense and their extensive site experience. For instance, Andy (Case study 5) who had about 38 years of experience on site stated;

"*Safety is common sense, isn't it?"*

To him, common sense and safety are not mutually exclusive entities. He holds both concepts collectively. Tony shared a comparable view. He believed *"general health and safety"* could not flourish without common sense. Ludhra (2015) agrees with the points raised above as it was found that common sense is relevant in safety practices.

Another point that came across from most participants was how 'dynamic' common sense safety was. Andy clarified that "*common sense [safety]*" varied from site to site. He believed that common sense is demonstrated or used differently as a response to project and site conditions. Thus one needs to depend on their local or situational knowledge when implementing the common sense approach. Rick, having over 32 years of construction site experience also mentioned that common sense depends on what a worker was doing, citing scaffold use as an example. Thus there was a general view that common sense is indeed dependent on the situation at hand. In other words, common sense is not a planned approach to safety but more of a responsive technique. The workers highlighted how important it was to have context-related knowledge on risk management. This is in line with findings from Tutt *et al* (2013) and Baart (2009) that safety knowledge can be very specific to precise situations and thus outsiders or less experienced individuals would not comprehend the level of risk or dangers prevailing.

In trying to explain what he understood by the concept of common sense safety, Tom used a past situation to illustrate how his experience and local knowledge had saved him from a potential accident. He was asked to carry out an unsafe activity; *"…to jump into a trench without ladders"*. His response to that request was *"no"*, stating that "*normal people don't do that*". He thus insinuates that there are some basic standards of safety that the average workers must have. His common sense and local knowledge about working in such conditions or situations enabled him to analyse the situation at hand and subsequently decide it was not safe and hence he would not go through with the task.

In trying to improve the understanding of the meaning of common sense in safety from the participants' perspectives, the next sections look at different ways that common sense was found to implemented on site.

4.2 Common sense as a positive safety approach

Some workers believed common sense was a good way to approach safety. Even going to the lengths of likening good safety practices to common sense. As mentioned in the previous section, Andy rhetorically asked 'whether common sense was not safety'. Although he likened implied common sense and safety were one entity, he clarified that further training was always needed for all workers. It is worth noting that he did not assume a complacent stance or imply that workers knew it all and hence did not need further development. This corroborates findings from Reynolds *et al* (2008) as they identified that good workers admit that further safety training is always important as it helps improve upon safety awareness and helps workers to stay focused. Through observation, it was also witnessed that Andy was very communicative with his colleagues. Although Tom did not point to common sense directly, he and Andy both agreed that the best was to help workers practice safely was to continuously tell them what is safe.

Common sense as a term may be used casually by the participants when discussing safety but when one analyses the data from interviews and observations in its entirety, it is obvious that outsiders may have a different view of what the workers 'really' mean. Rick added that he had been on many different sites since he began his construction career and as such had seen a variety of risks. In reference to how common sense was applied to ensure safety, he described how and when he believed people on site should apply common sense:

"*it depends on what you're doing. You may be on a scaffold, make sure there's no hand rails missing. Yeah, you got easy access, safe access? If you're working on excavations, are they fenced off so you can't fall down? If there's traffic is it, is it all fenced off so that you can get around?*"

Although he attributes the above scenarios to common sense (which some claim to be basic knowledge) it may be difficult for new and less experienced workers to also identify these with such ease. A less experienced worker may assume missing handrails are part of the design and hence continue to work on it. Also, a worker new to excavations may not know the depth at which the digging may lead to serious dangers. In examining Rick's statement, it can be gathered that he is not proposing a laid-back attitude for safety. On the contrary, he is proposing that workers question or double check whatever activity they undertake. Managing knowledge in many situations including safety matters in the construction industry is difficult because site activities are fluid and dynamic (Dainty *et al,* 2007) and for this reason, Rick's idea of constantly reassessing situations is an effective way of maintaining site safety.

Tony discussed that using common sense and experience, he is able to manage and supervise his workers. It was through this knowledge that he is able to decide what "*PPE [personal protective equipment] to provide for all the workers [for their various tasks]*". He believed that as a leader, it was his duty to double-check and reassess situations and help come up with effective solutions that newer workers may not be able to comprehend. He added that even though there are stricter rules for health and safety in recent times, there can be different ways of carrying out a task safely and sometimes the common sense approach will be safer than the officially written procedures. A typical example of such a situation was described as workers being forced (by official site policies) to wear gloves for every task even though it may reduce their firm grip on certain tools hence causing 'riskier' situations for the workers and their workmates. Forsythe (2014) explains that experienced workers possess experiential and local knowledge that will enable them to choose a safe technique when faced with different situations. For his leadership style, Tony adopted an open communication system where workers can freely debate the safest approaches in working. This is because other workers may have a better common sense approach to a particular situation than others. The open discussion technique was also encouraged by John and Derek. On one occasion, Derek was observed having a serious dialogue with one of his newer workers. The topic of discussion was whether an area they were working could be considered as an enclosed area. This discussion was joined by all the other workers and was resolved agreeably. Derek's side of the argument won the most support from the colleagues on this particular issue. This further demonstrates the openness described by leaders. In comparing the construction industry to coalminers' pit sense, older and more experienced workers believe it is their responsibility to protect the younger workers not as a requirement of their job but as personal protective and altruistic role.

John states that he knows all his workers are '*bright'* and as such he can leave them to use their own discretion when working safely. He further adds that he still makes it a point to walk around site and have direct discussions with them in order to know that their discretionary ability is being utilized in a beneficial manner. This is also in line with Andy's response whereby he believes further training and teaching need to be conducted continuously as it helps in the formation and sharpening of ideas. Going beyond the formal risk assessment activities, John adds the following:

"*I'm a big believer in there's never just one way of doing something. Risks do differ*".

In such situations, he firmly believes that one's common sense and experience would be invaluable as far as identifying effective solutions for the prevailing risks. This is in line with his practice of encouraging other workers to voice out their opinions with regard to safe practices. In relation to allowing new workers to use their own discretion, workers from Case study 2 were observed discussing that it was only appropriate when the worker is known to work safely. One of them added that "*you only get to know each other when you've worked with them for some time*". This idea of getting to know one's colleagues was linked to trust because workers believed that one person's mistake or unsafe practice could easily lead to further safety problems for other site operatives. Andy's quote clarified this narrative precisely as he stated the following: "*I mean if you can't trust those you're working with, then you can't trust anyone*". Trust is one of the main indicators of effective knowledge-sharing on site (Fong, 2007). Even though common sense is meant to be an individual's basic knowledge on safety (therefore differing from one person to another); site workers feel they have to be able to evaluate and trust exactly how much safety knowledge their colleagues have.

To summarize, by using common sense in a positive manner workers are able to question situations that they believe could lead to dangerous outcomes. More importantly, people are able to use this common sense more effectively if they have gained a wealth of experience on site. Also, an important part of using common sense safely is by knowing that one's colleagues have a good understanding of safety and thus can be allowed to work to make decisions on their own. This section has presented a positive aspect of common sense and safety. The next section offers empirical findings of workers that did not perceive this concept in same light.

4.3 Using the notion of common sense to avoid bureaucracy

Out of all the five sites visited, workers from Case study 3 showed the least regard for official safety practices. This was also reflected in their responses concerning common sense safety. In trying to dismiss discussions about site safety, George (from Case study 3 with 8 years' of experience) casually responded by saying "*As you can see, it's all up and down. It's just common sense*". George associated health and safety to official site policies and regulations. This response was quite the opposite of what workers from the other four cases had been presenting. On the contrary, the other sites' participants had clarified how they believed workers needed to question situations and be open about how they perceived risks. Scott also revealed that he believes that safety should be about general knowledge and for that reason, it should be left to the workers on site. He stated that the bureaucrats sitting in site offices did not really know what was happening 'on the ground'. It is clear that his problem is not working safely but instead he had a problem with bureaucratic arrangements put in place by those in managerial positions. He states:

"*[They should] Leave it to us really. [We] know what we're doing anyway*".

He believes the individuals that set the site rules and regulations should appreciate workers have enough safety knowledge (i.e. common sense) when dealing with practices. Considering he is the owner of this small company, he could be in the position to encourage communication between his team and the openness and further discussion of the best safety methods. He based his feelings on situations he had encountered from previous projects whereby they had worked as subcontractors. Kamoche and Maguire (2011) found that managers in the coalmining industry may turn a blind eye to workers using pit sense. In other words, they know the practices may not be official but they understand that it is a safety technique that the experienced workers are adopting. Unfortunately, Scott and his team had not experienced this kind of attitude on construction sites.

In trying to further clarify his views on how feels about bureaucratic safety rules, Scott stated that: "*Obviously we've all got basic general knowledge of health and safety so we all know what's safe and what's not safe…*". Scott has strong views about what he believes the people higher up in the management chain ought to be doing but has failed to engage with them. This may be out of fear of his company being blacklisted. In one of the discussions observed during a lunch break in Case study 5, workers of the small company openly discussed the potential ramifications of pointing out impractical sections found in official rules and regulations. One worker described is as "commercial suicide" because he believed it was an act of killing one's own business opportunities; another indication of being placed on a blacklist. According to Taylor (2013), many prominent principal contractors in the UK were guilty of using this blacklist to exclude many firms from their projects.

Some of Scott's comments indicated that he was more concerned about finishing works than working safety, for example, "*[People] probably want to get their work done fast obviously because you need to get the work done as fast as possible*". To him, completing tasks was a necessary trade-off if safety was to be sacrificed. This was also associated with project manager and principal contractors having bureaucratic safety rules that slowed down productivity and still demanded workers to finish activities in an unattainable timeframe. When asked about working with teams (i.e. as fellow subcontractors), he insisted that his preference was to have site managers and other subcontractors out of their way. This could be resultant of the pressures of having to deliver projects in timeframes so tight that they would rather carry on with their work and not get distracted. Workers from this group were using the term common sense in two ways; the first was common sense as a safety approach i.e. a similar view to what others had expressed on other sites and second, was using the concept to avoid having to confront safety bureaucratic rules and regulations. With regard to the second point, coalminers trying to use their informal and local safety knowledge (pit sense) were forced to increase or maintain productivity in the face of increased bureaucratic measures increased in their industry (Kamoche and Maguire, 2010).

Steve was the most experienced worker in Case study 3 with 28 years of site experience. Although he shared some similar views to his colleagues', he showed some contrasting views as well. He believed bureaucracy was getting in the way of carrying out practical work. He expressed unhappiness at how bureaucratic health and safety issues in the construction industry had become. Specifically, he talked about how safety rules and procedures have become prescriptive: "*[People should] use common sense. They're too much by the book instead of common sense. You can't always do jobs like you can on paper*". This comment was in reference to risks being more practical and dynamic and hence standardizing safety approaches was not the way forward. This view was shared by all the other groups. Fong (2007) highlights one of the major factors to affect knowledge-sharing on site to be pressure of time. As indicated by Scott, he and his team would rather get on with their work, thus the pressure of time is clearly preventing the possibility of knowledge sharing that could have happened between their team and others.

4.3.1 The odd one out

Steve (the most experienced participant from Case study 3) shared some positive safety views with respect to the use of common sense and safety. Steve had assumed the role of safety representative of their team i.e. he was in charge of discussing safety matters with principal contractors and other teams on the site. He was observed telling George and Scott what was supposed to be done regarding certain safety issues. Considering Steve's views and behaviours in the context of findings from his colleagues, it can be interpreted that he acts as the 'moral compass' of their group. Alternatively, it can argued that he has more experience of working with different contractors and hence is more experienced in 'playing the game' of job satisfaction. His colleagues do not exhibit the same amount of restraint when having to deal with those they observed to be in rule-making positions. It may be possible that Steve is the one that has kept their company in business for so long as he has prevented the other team members from committing commercial suicide by using a different form of common sense i.e. knowing when and how to satisfy project requirements especially when dealing with safety matters. With the many hoops and hurdles that workers have to jump through on site, participants from Oswald *et al* (2015: 533) were quoted as stating that they '*couldn't finish their jobs without breaking rules*'.

5. Conclusions

Findings from five micro construction firms operating in the East Midlands of the UK have been presented in this paper. The methodological strengths of this study lied with the philosophical underpinnings. For the ontological aspect of this study, common sense was approached to be a subjective concept i.e. different people would interpret it differently. For this reason, it was crucial that the researcher got very close to participants being studied. Through multiple ethnographic case studies, the chosen micro firms were closely studied to gain understanding of how site workers perceive and use common sense safety.

Unless teams and individuals in decision-making positions accept the need for including the common sense and local knowledge approach in site safety, workers will feel pressured by what they consider to be overbearing bureaucratic measures. Unfortunately, if these conditions continue to prevail, workers of small and micro construction firms may be forced further underground. As mentioned earlier (see Willbourn, 2009) they are already known to be the hard to reach groups especially on safety matters. Workers may also carry out practices that may be prohibited even though they may be safer. Additionally, under the time pressures coupled with excessive site rules, workers may also end up cutting corners creating more unsafe environments an opposite of what the rules were supposed to accomplish. Common sense is not a laissez-faire attitude towards safety. In some instances, it challenges workers to double-check situations that would have not been critically evaluated under the bureaucratic safety measures. Workers may be afraid to discuss their views of using this informal type of safety approach with major contractors out of fear of being blacklisted. When construction common sense safety is compared to pit sense used by coalminers, it is evident that more can be done in the industry to accommodate this invaluable approach to safety as it is based upon experience and vital local knowledge.

This study was part of a larger PhD research project and future studies have been recommended to look into the safety practices of other micro construction firms in other regions of the country. Following the anticipated success of this next phase, the study can be extended to cover projects outside the UK.

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An Ethics Reasoning Approach To Health And Safety In Construction

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Abstract

The legal, business and moral cases for health and safety are promoted as the rationale for companies adopting good health and safety practices in construction. The legal and business cases are limited by compliance to laws that are extant and subject to change and to an equating of business success with profitability, thus subjecting safety investment to successful returns on investment. The moral case has strength in that it is derived from fundamental moral principles concerning what is good, a perspective on health and safety that has longevity. Despite strong and improving legislation in many jurisdictions, commissioned research demonstrating the positive nature of the business case and the good intentions of the industry and its professional advisors, health and safety in construction has not achieved a prevention culture and fatal accidents, serious injuries and illness continue to occur. Focussing on the moral case and how it relates to both compliance with legal duties and maintenance of good business practices, a project was initiated to explore the of foundations workplace ethics and to determine whether these foundations and the practice of ethical decision making was understood by all stakeholders and supported by the key decision makers. Research in the field of educational psychology and moral development indicated that conventional moral reasoning, exercised by a majority of adults, was based on compliance with legal requirements and prohibitions and on adherence to social group norms. Utilising a critical theory methodology to analyse workplace culture on construction sites a new perspective on the complexity of interrelationships on-site was developed that uncovered a range of reasoning processes behind health and safety decisions. An understanding of ethics reasoning addresses the limitations of conventional moral reasoning and underpins a new approach developed by the authors to health and safety education and autonomy in decision making. This paper describes the authors' module on ethics reasoning, developed for construction professionals and which is incorporated into two undergraduate degree programmes.

Keywords: Construction ethics, health and safety, safety decision making

1.Background

1.1.Regulatory measures and improvement

The history of the development of health and safety legislation in the United Kingdom (UK) often parallels the history of significant safety failures (HSE 2014b) which mirrors similar developments internationally, e.g. the Seveso directives in Europe following on from the 1971 Seveso disaster. The legislative approach to OSH proved effective with accidents and accident rates consistently falling since the 1970s (HSC 2003b). Davies and Jones (2005) examining the efficacy of the regulatory approach found a general downward trend in over 3-day injury rates for men and women and downward trend in major injuries until 2000, with an upward trend since. When correlated with the business cycle, it was noted that a 1% increase in the GDP above trend was associated with a 1.4% increase in the rate major accidents suggesting to Davies and Jones (2005) that accident rates increased with the hiring of new workers and with increased worker effort (as in overtime working). Schlagbauer and Heck (2014) have found that increased worker effort leads to an increase in accidents when workers have insufficient rest/recovery time which leads to tiredness and exhaustion, and thus to reduced concentration and physical capacity, and thus to accidents. The ISSA (2010) found an increase in psychosocial risk and ill-health as a consequence of the post 2008 economic downturn and Goh et al. (2015) estimated that there are 120,000 excess deaths per annum in the USA attributable to workplace stressors and how work is managed.

Between 1995 - 2015 the rate of fatal injuries to workers in Great Britain (GB) declined from 1.2 to 0.46 deaths per 100,000, though the Health and Safety Executive (HSE) acknowledge that that the trend since 2008 is less clear, (HSE 2015b). The decline in the rate of injuries has fallen from 2.9 to 0.5 per 100,000 between 1974 - 2014 and the fall in (reported) non-fatal injuries was from 336,701 to 77,310. Half of this reduction is due to changing employment patterns and occupations, (HSE 2014c). The increase in work-related stress and related conditions have been increasing since the 1990s and this may be as much due to an increasing awareness of the conditions as to actual increases due to increased psychosocial risk in the post-2008 period. The sharpest decrease in the fatality rate occurred after the introduction of the 1974 Health and Safety at Work Act and subsequent regulations until 1997, with the rate then reasonably level until 2008 when it dropped again over the two year period 2009/2010 and has again remained level since, (HSE 2014d).

As construction accounts for 5% of the British workforce but 31% of all fatal injuries and 10% of reported major injuries, it is therefore the highest risk industry in the UK (HSE 2014a, 2014e).

1.2.Alternative models for achieving Prevention

In parallel with the statutes a number of theories on occupational safety and health (OSH) and models of good practice were developed, most notably Risk Assessment and Risk Management, which are now internationally recognised approaches to OSH. Other theories, concerned with the failure of regulatory compliance to achieve a prevention culture, examined problems associated with management practice, worker behaviour (Geller 1998, 2000, Cooper 2000, 2010) and the contradictions between the demands of production and profits and workers' need for employment (McAleenan 2015). Behaviour Based Safety, the outworking of the works of Cooper (2000, 2010) and Geller (1998, 2000) have become internationally recognised and adopted by statutory safety bodies (HSA 2013, Fleming and Lardner 2002) and large corporations (Cooper 2015). In parallel with these developments, the International Social Security Association (ISSA) was advocating the reintegration of OSH competencies into vocational and professional education, (ISSA 2003).

The authors, had developed and were implementing Operation Analysis and Control, a holistic model which promoted a dynamic approach to the management of work activities that focuses on the elimination or control of hazards from the outset of project and activity planning,(McAleenan and McAleenan 2001, 2002).

The development of OAC commenced from the analysis of the limitation of the language of Risk Management and of the safety discourse. The central concept was control and what was necessary to the process of control of work activities on construction sites. The analysis went to the core of human awareness, understanding and perceptions of work and the management of work activities. The result was the negation of risk based approaches to work and project outcomes and its replacement by an approach that respected and utilised the competence of workers who are fully au fait with the requirements of the task, are, with the right resources, capable of achieving them and are in control of their own activities including the safety component.

1.3.Ethical failings in construction

The process of developing OAC entailed, amongst other things, an examination of a number of concepts associated with the moral case for OSH and in particular the assumptions underpinning the discourse of safety leadership and its impact on agency.

Corporate Social Responsibility (CSR), a central ethical and moral issue in the industry, is expected to be a driver for social and environmental sustainability while meeting the requirements of shareholders. Yet within the construction industry, the reputation for unethical practices is regarded as a major contributor to reduced quality and poor safety practices (Hamza et al. 2007 and 2010, Olufemi and Oyedeli 2014, CIOB 2013, Ameh and Odusani 2010), that contributes to accidents and the endangerment of human life (Zhou and Wu 2013). Additionally, the CIOB (2013) found that 49% of respondents believe that corruption is present and that 50% do not believe that the industry is doing enough to counteract it.

In the field of educational psychology and moral development, Kohlberg (1971) and Eckensberger (2007) stated that conventional moral reasoning, exercised by a majority of adults, is based on compliance with legal requirements and prohibitions, and on adherence to social group norms. Focussing on the moral case and how it relates to both compliance with legal duties and maintenance of good business practices, the authors initiated a project to explore the foundations of workplace ethics and to determine whether these foundations and the practice of ethical decision making was understood by all stakeholders and supported by the key decision makers.

Utilising a critical theory methodology to analyse workplace culture on construction sites a new perspective on the complexity of interrelationships on-site was developed that uncovered a range of reasoning processes behind health and safety decisions. An understanding of ethics reasoning addresses the limitations of conventional moral reasoning and underpins the case for a new approach to health and safety training and autonomy in decision making. The aim of this paper is to elucidate the case for an ethics reasoning approach to professional education and describe a project by the authors that led to the development of a module on ethics reasoning which has been incorporated into two undergraduate programmes.

2.Ethics, morals and reasoning

2.1.Definition of ethics and morals

It is useful at this point to clarify a distinction between the terms “ethics” and “morals” as both are often conflated, (Chismar 2004). Ethics is an internal process whereby the individual strives to attain authenticity as a human being, (Žižek 2012) and as such it is a function of Man as a social Being. Morals, specifically moral behaviour, is a function of agency and ethics reasoning and is directed outwards towards others, a manifestation of care for others, (Žižek 2012).

The project recognised the range of moral philosophies that exist and the fact that they sometimes do not sit comfortably with each other despite them being fundamentally concerned with doing good or doing no harm to others. Why this should be so informed the objective of the project; to determine the function and universality of ethics and how moral behaviour is decided, as well as the methodology for exploring this objective. The strength and stability of the moral case for OSH that elevates it above both the business and legal cases required an exploration of the fundamental level in order to explain and supplant the above described unethical behaviours with a rational ethic that permits of objectively and universally “good” moral behaviour.

2.2.Problems with agency in the real world

It can be difficult to reconcile the notion of Agency with real world situations. The competent worker, expected to make work-related decisions based on age, experience and level of skill (Dalton Vs Frendo, Irish Supreme Court 1977, in Garavan 1997), none-the-less finds him/herself engaged in work where what to do, when to do it, with what resources and even how to do it is often subject to the decisions of managers and supervisors who convey this information to the worker.

In unsafe situations, the legal right and duty not to undertake unsafe work is often also a fiction, known and understood by all but left unstated as this would negate its function as a "legal fiction". This reflects Hegel's (in Russell 1996) refection of Kant's notion of autonomy where-in the moral agent assumes responsibility for translating abstract injunctions into concrete moral obligations (Žižek 2012). For Hegel (1817) autonomy and the freedom to act stems not simply from following one's own will, but from there being real world structures that correspond to the structures of the will, i.e., a rational State that respects the freedom of the individual.

In the concrete reality there are many structures within which the moral agent exists but which are less appreciative of moral autonomy or tolerant of agency. The workplace culture described by Schein (2013), springs from the values and beliefs of its leaders is, with its hierarchical structures and heteronomous decision making, reflective of unequal social relations where-in decision making is bounded by production targets and operational necessities. Safety (vision) statements such as "Stop Work" or "Safety First" are bounded by the subliminal messages inherent in Geertz's (1973) alternative Thick description of workplace culture, which permeates a workplace and can contradict the overt messages that his Thin description describes as being an aspect of a superficial awareness of culture.

A deontological model of site safety has safety rules jostle for position amongst statutory duties, commercial contracts, contracts of employment and professional codes of conduct, creating disharmony and confusion. This model is the outworking of Kohlberg (1971) and Eckensberger's (2007) "conventional moral reasoning", a reasoning based on group interests and adherence to societal norms and laws where loyalty to the group or the influences of laws with the greatest sanctions are dominant. Yet construction professionals Codes of Ethics/Conduct conflict with this deontology, advocating a post conventional reasoning based on universal rights and exhorting the professional to exercise their judgments in the interests of wider society (IEA 2015).

OSH is not the sole consideration of professional ethical decision making, but when contextualised with the Universal Declaration of Human Rights (United Nations 1947) the professional has a duty to understand the human rights of the worker and to fully appreciate and implement this obligation to workers, the employer and the client.

2.3.Moral necessity

The moral injunction to do no harm to others is embodied in health and safety laws. Morality derives from culture and embodies those mechanisms that make culture a system of uniquely human controls (Geertz 1973). It is how Man relates to the world and others in it, and from it materialises his self-realisation (Freire 1973), his self-actualisation (Maslow 1943). It is also inherently human, arising from Man's awareness of himself as a species distinct from other species and within which he recognises others, and himself in others (Fromm 1961). This is the root of empathy in which is found the form of morality that echoes the symmetry between Self and Other (Žižek 2012). The process of ethical development and moral maturing is the process of humanisation (Freire 1973) and defines the practical relationships with others. In its mature form the symmetry of moral action acts to the benefit of all.

The awareness of ourselves and others of necessity entails an awareness of both that which is beneficial and that which is detrimental in human relationships; we either harm or we help, and this is codified in the Golden Rule of Moral Reciprocity, “treat others as we would want others to treat us”. This stands in contrast to the “zero level rule”, “do not do to me what you do not want me to do to you”, (Žižek’s 2012). With the publication of the Seoul Declaration (ILO 2008) a new series of paradigms were prescribed which shifted the focus from accident prevention, the “zero level rule”, to the creation of workplace cultures that actively contribute to the welfare and wellbeing of workers; the Golden Rule entering into health and safety practice.

In exploring Hegel’s dialectic, Žižek (2012) distinguishes ethics as care for the self, a striving towards authentic being. This concept of ethics parallels Freire’s (1973) concept of humanisation and is at the core of the human ontological project. Human behaviour is the synthesis of internal ethics and external morality and as such the moral case for health and safety stems from necessity, being, as it is, inherent in the relations that exist between people. Thus the ethical failures in the construction industry and the resultant harms are not simply detrimental to workers and organisations but are the antithesis of humanisation and social progress.

2.4.Ethics Reasoning approach to OSH

Codes of conduct and codes of ethics are integral to professionalism. The Engineering Council (EC, 2013) advocates that the professional bodies place a personal obligation on their members to act in accordance with the Royal Academy of Engineering (RAE, 2011) and EC standards and principles. The Joint Board of Moderators (JBM, 2009) has more specific guidelines for teaching ethics and the professionalism expected of students on construction degree courses in the UK.

A number of problems have been identified with the teaching of ethics. Warnick (2010) suggests that the dissatisfaction felt by some professionals in regard to current work ethics impacts negatively on quality, while Strahlendorf (2005 citing Logan 2001) lists economic pressures, differing national and cultural standards and the lack of legal standards as some of the reasons for unethical behaviours. Herkert (2000) suggests that the focus of engineering ethics on individual and micro-ethics is to the detriment of work on social or macro-ethics concerned with collective social responsibility which would have a bearing on Corporate Social Responsibility and the OECD (2004) principles of consideration of all stakeholders. Guenther (2000) argues for the need of professionals to have the ability to reason out ethic issues in any situation rather than be constrained by specific rules that may be in different professional codes. This is echoed by Strahlendorf (2005) who makes the case for professionals being able to question those codes and reason out appropriate ethical approaches to moral behaviour.

Ethics Reasoning is on the curricula of a number of universities (e.g. Univ. of Texas 2015 and Leeds Univ. 2015). Whitbeck (2011) has also conducted work on ethics reasoning in engineering and the RAE (2011) guidance contains case studies to facilitate reasoning skills.

This project commenced with the work of Piaget (1932) who pioneered the work on cognitive development and moral reasoning in children and this was substantially developed and tested widely by Kohlberg (1971) and Eckensberger (2007). Their findings of an invariant development of moral judgement are classified in three categories; pre-conventional, conventional and post-conventional (Table 1).

Table 1: Kohlberg's levels of moral reasoning

Level of moral development	*Stage of reasoning*	*approx ages*
Pre-conventional, "do's and don't's"	*Stage 1. Right is obedience to power and avoidance of punishment.*	*< 11*
	Stage2. Right is taking responsibility and leaving other to be responsible for themselves.	
Conventional	*Stage 3. Right is being considerate: "uphold the values of other adolescents and adults"' rules of society.*	*adolescence and adulthood*
	Stage 4. Right is being good, with the values and norms of family and society at large.	
Post-Conventional	*Stage 5. Right is finding inner "universal rights" balance between self-rights and societal rules - a social contract.*	*after 20*
	Stage 6. Right is based on a higher order of applying of applying principles to all human-kind; being non-judgemental and respecting all human life.	
	adapted from Kohlberg,1986	

Using these levels and stages as a foundation, the authors developed an industry specific undergraduate module within the Quantity Surveying degree course that included a problem solving component. As the semester progressed, students were presented with hypothetical and real-world scenarios of increasing complexity that included the use of case studies relating to contract acquisition, construction quality and ODH on construction projects. The students were asked to suggest individual and group solutions to the problems identified and to provide a rational explanation for their choices, which were then subject to challenge in open forum discussion.

These exercises were integrated with teaching and study on various theories of ethics, in particular utilitarianism, deontology and virtue ethics, and in the context of international and national codes relating to Human Rights and OSH obligations. The expectation was that the first year students who undertook this module would initially demonstrate stages 3-4 ethics reasoning and be moving towards stages 4-5 reasoning by the end of the module and with appropriate reinforcement, be demonstrably stage 5 by their graduation year. This would accord w with the general findings in Piaget (1932) and Kohlberg's (1971) work.

In the first iteration of the module the outcomes showed a higher than expected pre-conventional reasoning, however by the second semester, a number of students were demonstrating reasoning at one level higher, close to Kohlberg's (1971) prediction that 50% of students would reason at one level higher after twelve weeks. This is likely to have been due to the students having a period to time in which the module and learning was assimilated into their thinking.

The second iteration of the module introduced the moral philosophy and theories of ethics described above, and this cohort of students demonstrated more conventional stage 3 reasoning with some demonstrating stage 4. The stage 3 reasoning emerged strongly with problems with high construction and OSH context and with which the students were less familiar. This stage 3 reasoning was related to their perception of loyalty to their (fictional) future employer and acceptance of the authority of managers. However in more generalised problems where their awareness of the law was broader, stage 4 social conformity reasoning was more in evidence.

The module has evolved over 4 years and now comprises the following elements:

- Ethical problem solving exercises to develop skills
- Introduction to the prevalent theories of ethics
- Case studies, to be analysed on the basis of the various theories
- Stages of Ethics Reasoning
- Contextualisation, construction and international protocols and codes
- Agency and resolving conflicts

The project demonstrated that the context within which skills development occurs needs to be one that is familiar to students to allow them to exercise personal judgement rather than defer to an existing deontology. As such it is appropriate that the ethics reasoning skills development takes place continuously throughout their under-graduate studies, for example through regularly presenting case studies in other modules that allow the students to evaluate and address the moral issues in them. This will further allow for greater assimilation as there will be period between teaching/study when the ideas and skills can imbed. A new under-graduate Safety Engineering and Disaster Management degree course, co-developed by one of the authors, recognises this and has integrated ethics reasoning throughout the course with a clear focus on developing and demonstrating stage 5 reasoning and critical analytical thinking into Prevention through Design by their graduation year.

3.Conclusions

Ethics and moral behaviour are at the core of Man's relationships with others and with himself, and construction is the epitome of these relationships, contributing to Man's wellbeing, satisfying basic needs and meeting the higher emotional and intellectual needs of self-actualisation. They are at the heart of construction professionalism and transcends simple adherence to codes or compliance with statutes. Ethics Reasoning recognises these deontologies as milestones on the road to a mature ethic based on equality and respect for all humanity, and a morality that acts in the interests of and advances the wellbeing of all.

An Ethics Reasoning approach to the industry and, specifically, to OSH recognises that professional and vocational workers have the capacity within their competences to be aware of and act on the universal principles of social justice and human rights. This approach further recognises and takes account of the various ethical philosophies found in national cultures and through the reasoning process contextualises these perspectives with the fundamental principles of moral behaviour, i.e., the Golden Rule.

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Regulatory Factors Contributing to Building Collapse in South Africa: A Case Study

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Abstract

This paper presents the causes of building collapse linked to non-compliance to relevant regulations. A case study research that was conducted on the Tongaat mall building collapse in South Africa forms the basis for the highlighted factors. Through data collection that entails content analysis of official inquiry into the collapse and subsequent semi-structured face-to-face interviews of construction workers who took part in the ill-fated project, major regulatory failures were identified. Salient findings show that the regulatory functions on the building project were compromised, and the inability to ensure that the project fulfils all compliance requirements significantly enhances the existence of a work environment that led to two fatalities and twenty-nine injuries. This study corroborates findings that have highlighted implementation as the weak link in H&S practice in terms of construction regulations in South Africa. In other words, the benefits of adequate policies on paper can only emerge through proper applications on construction sites.

Keywords: Accident, Construction, Health and Safety, Regulation, South Africa

1. Introduction

The collapse of the Tongaat mall building that was under construction in November 2013 is a justification for optimum construction management practice in South Africa. The practice illustrated in the analysed reports shown in Emuze et al. (2015) is indicative of several deviations from acceptable H&S practice. The triggers for the collapse, a beam and two columns occurred due to poor supervision of construction work. This paper is a follow-up on the work presented in the 2015 CIB W099 conference held at Belfast, Northern Ireland. In the paper presented in Belfast, Emuze et al. (2015) used content analysis as a method to provide possible reasons for the accident that resulted in 2 fatalities and 29 injuries. Emuze et al. (2015) note that poor construction work, poor supervision of work, and non-compliance to H&S regulations constitute the major contributing factors that led to the Tongaat mall building collapse. These contributing factors were also reported when buildings collapsed in Malaysia (Aini et al., 2005) and the United States of America (USA) (Levy & Salvadori, 2002). However, this particular paper reports on the lived experiences of the participants in the ill-fated project. Base on the findings of the official inquiry into the accident, it was determined that the research would benefit from further exploration of the experience of project actors through face-to-face interviews that tend to yield rich data (Ritchie et al., 2014).

This approach is concerned with understanding particular situations, rather than generalizing findings. The method used is primarily for in-depth analyses of interviews, recorded observations and documented communication (Thomas, 2011). Thus, face-to-face interviews that were preceded by content analysis presented in Emuze et al. (2015) were used to collect the responses to the research questions. The research question that forms the nexus of this paper is "*how did regulatory factors contribute to the collapse of the Tongaat mall in South Africa*". The objective of this paper is to provide the answer to this question by presenting the implications of building collapse from the perspective of regulations in the next section. Thereafter, the methodology section concisely indicates the procedure that was followed to obtain additional primary data in the study. The methodology then leads to the results and a discussion on the implications of regulatory failures in construction accident causation. The conclusions tied the insights from the accident together. It is important to focus on accidents linked to collapse in construction as it seems to be an ending tragedy in South Africa where another major collapse occurred in October 2015 as shown in Figure 1 (http://www.news24.com/Multimedia/South-Africa/PICS-Deadly-Joburg-bridge-collapse-20151015#). A pictorial view of the Tongaat mall collapse shown in Emuze et al. (2015) speaks to the need to stop the circle of building collapse in South Africa.

Figure 1: Collapse of a bridge under construction in Johannesburg (Source: News24: online)

2. Synopsis of the Tongaat Mall Building Collapse

The regulatory failures experienced on the Tongaat mall collapse involve multiple parties to the project. Based on the analysed inquiry documents in Emuze et al. (2015), the notable failures pertain to structural design, quality of construction work and supervision and non-compliance to the requirements of construction regulations (Table 1). This paper focuses on the regulation aspects of the failures observed in the accidents. The developer / client of the project failed to comply with official orders to stop the project. For instance, the developer ignored court orders to stop construction six days prior to the collapse of the slab that led to fatalities. Before the court order, the host municipality had been expending efforts to stop construction for a range of contraventions. A major contravention is the refusal to heed the instruction not to proceed with construction work on site. The municipality reports that it did not grant 'permit to build' to the developer of the mall. This attitude to regulations by the developer, which is hereafter referred to as the client, impacts on construction H&S (Smallwood, 2008). As shown in this accident, it could contribute to injuries and fatalities. This is particularly crucial when compliance is not open to negotiation. As shown in the findings of this building collapse, the client may have averted the loss of lives if compliance was observed. The compliance issue is not new in South Africa. In a 2009 report by the construction industry development board (CIDB), the Department of Labour (DoL) flagged non-compliance in most of the construction sites that were visited by its inspectors. The client is not alone in terms of regulatory failure. The engineer and the contractor appear to follow the footsteps of the client in this regard. From the analysed documents, the engineer may be found wanting concerning full compliance to section 9 of the South Africa construction regulations, which states that "*the designer of a structure shall inform the contractor in writing of any known or anticipated dangers or hazards relating to the construction work, and make available all relevant information required for the safe execution of the work upon being designed or when the design is subsequently altered*". Compliance or non-compliance to this clause influences the triggers of the collapse, which is a slab that was supported by beams and columns that cracked.

Table 1: A summary of causal factors of the Tongaat mall collapse

Failure (s)	*Description*
Construction work / supervision	Slab sagged before collapse
Construction work / supervision	Scaffold / formwork / false work removed too soon
Construction work / supervision	Weak concrete used for construction on site
Construction work / supervision	Severe lapses in construction work and supervision
Construction work / supervision	Reasons for construction failure - beams
Structural design	Reasons for construction failure - design
Structural design / construction work	Steel bars are missing in the elements - slabs, beams, etc.
Construction work / supervision	Lack of H&S audit on project site
Regulatory control	Mall plans rejects / failed approval four times
Regulatory control	Demolition of the site was never approved
Regulatory control	Developers was consistently fined for failures
Regulatory control	Workers instructed to keep working despite official notice

Source: Emuze et al. (2015)

The link between design and accidents as well as the outcomes of accidents in the form of injuries and fatalities has been highlighted in the work of Cooke and Lingard (2011). For instance, the Australian study examined 258 construction fatalities and note that 40% were linked to the design of the work place. The compliance gaps were also notable when the workings of the general contractor (GC) on the project are x-rayed. This is not unconnected to the lack of relevant qualification by the general foreman (GF) of the GC. Qualification is relevant to knowledge of the regulatory environment. Given that the analysed inquiry document shows an unconcealed disregard to section 5 of the construction regulations, it is very likely that the GF do know the regulations, which is not an excuse in law. In particular, the section says that a principal contractor should "stop any contractor from executing construction work which is not in accordance with the principal contractor's and/or contractor's H&S plan for the site or which poses a threat to the health and safety of persons". The interpretation of this clause and its compliance is important and it requires the GF, assuming he is in the know, to take steps to mitigate possible failures on the project site.

These narratives from the analysed document provide impetus for the collection of data from the participants of the collapsed building project. The next section presents a concise version of the methodology utilised in the research.

3. Methodology

Similar building collapse studies at the construction stage in which fatalities and injuries were recorded have used a case study research design to interpret the events (Aini et al., 2005). The case study approach was also used for this study in order to gain analytical comprehension of the events (Thomas, 2011). Primary data collection in the study comprises context analysis (Emuze, 2015) and face-to-face interviews, which forms the basis for the findings presented in this paper. Before the commencement of the interviews, the official inquiry documents of the DoL were analysed to identify issues dominating the media coverage of the Tongaat mall accident. The media coverage refers to online and printed news materials that were evaluated in terms of text (words) and images that have been recorded without the interference of the researchers. Online materials were accessed through the press releases of the DoL in South Africa, and the printed materials were sourced from newspapers. The analysis of content was linked to the role of actors in the collapsed building.

The analysis utilised the textual data to elicit meaning, gain understanding, and develop empirical knowledge on the collapsed mall (Corbin and Strauss, 2008). After the content analysis that produce the discussion in section 2 of this paper, on site visits were made to the location of the accident several times to schedule interview appointments with participants of the project. The findings of the analysed document provide the basis for the compilation of the interview protocol, which was made up of 33 questions that interrogated the issues uncovered in the analysed documents. However, the questions related to regulations constitute the focus of this paper. These questions include:

- How did you experience on-site inspection of the Tongaat Mall project?
- What is your perception on the enforcement of compliance with Construction Regulations (2003) by the local authority / municipality during the Tongaat Mall design phase?
- What is your perception on compliance enforcement on the Tongaat Mall project?

Figure 2 shows that the developer did not adhere to the tenets and principles of the construction regulations of South Africa as amended in 2014. This assumption stems from the fact that construction of the mall continued unchanged although plans were unapproved by the municipal authority. On site visits and documents show that the construction is taking place close to a rail track where authorization for construction was not given at the time of the accident. In brief, the regulatory questions emerge from Figure 2. These questions were posed to the interviewees in the study. The interviews focused on the project participants that were directly involved with the construction of Tongaat mall so as to access information on actual events from primary sources. Although the client and GC of the collapsed building declined to be interviewed, members of the inquiry (including H&S specialists, community liaisons officer, and local municipality building inspectors, and subcontractors) talked to the research team off the record. The interaction with the members of the inquiry paved the way for the contact made with some workers on the project. Thus, actual interviews were conducted with nine construction workers that were active on the project at the time of the accident. The interviewees were all male workers.

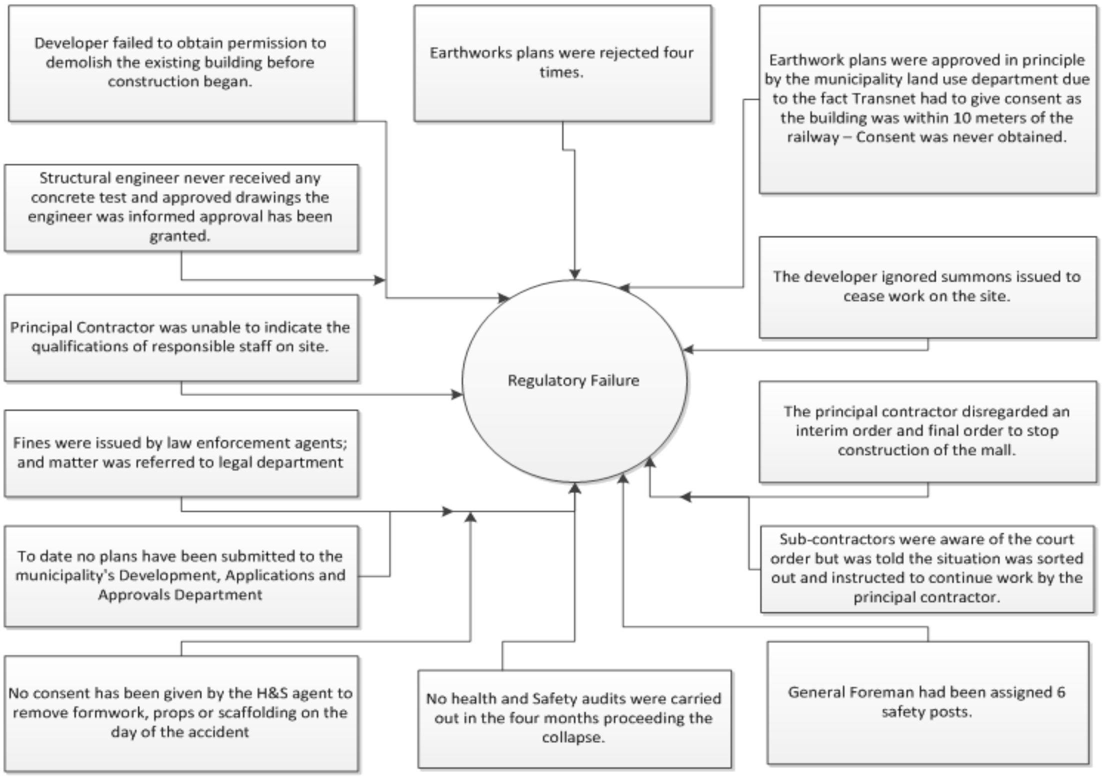

Figure 2 is a summary of the regulatory failures extracted from document analysis

4. Results

When the background information of the interviewees were analysed, it was apparent that the general workers perceive that the GF for the contractor is their employer, who assign them to various tasks on the project, although all of them see themselves as concrete workers. The interviewees confirm that they have extensive experience in the industry, though they are not specialized in a particular trade, although they work mostly on concrete work. More important to this paper is the revelation that these workers appears to have a superficial knowledge of the South African construction regulations as they were unable to engage in conversations that shows extensive understanding of either regulations or legislation related to construction.

The interviewees also report that there was high employee turnover on the project and often, workers were assigned to tasks that are beyond their capacity to accomplish. When asked why a worker would undertake a task that he is not qualified to accomplish, the interviewees point to issues surrounding job security. That is, if a worker does not agree to undertake an assigned task, he may be out of the site within a short time. Given that the unemployment rate in South Africa is estimated to be 25.1% in 2014 (Central Intelligence Agency (CIA), 2015), these workers were not willing to risk secured employee by objecting to instructions from the GF.

In particular, the responses of the workers to the aforementioned regulatory open ended questions presented in section 3 are illustrated in Figure 2. These questions investigated the involvement of the local governmental authority in the Tongaat mall project in terms of on-site inspections and the enforcement of relevant regulations.

Figure 3: Interviewee perceptions of regulatory environment in Tongaat project

It also assesses the enforcement of the regulations by the municipal authority where the project is located. The analysis of the data indicates that the interviewees were not really aware of inspections performed on the site. This suggests that either the interviewees were not notified when such persons arrived on site or that they did not recognized such persons on the site. The lack of clear responses to the municipal question signified that the local authority had limited presence on the site. The responses to the third question mean that the interviewees perceive a significant lack of leadership in terms of enforcing regulations on the project. For example, the interviewees could not identify the responsible personnel that represented the municipality on the project in terms of regular visits to the site.

Furthermore, the interviewees say that would decline ever working on a site where personal protective equipment (PPE) is not accessible contrary to legislation. They will also be hesitant to work on a site where the required supervision and where construction regulations are lacking.

The interviewees also note that the high rate of production was forced on them to the detriment of quality workmanship. They cited the fact that walls were constructed too fast without the necessary reinforcement or bracing whereas formwork and props were also removed too soon. The removal of formwork from a column triggered the collapse of the building on the 13th of November, 2013. The interviewees recognize that the procedures were incorrect, and when they attempt to object, they will be reprimanded. The interviewees pointed out that work is scare and that they are in dire need of employment so much so that this placed them in a position where compliance to the directives given to them must be obeyed without a challenge. In brief, most of the interviewees were unhappy about the lack of PPE on site. They were also saddened about the fact that their H&S and wellbeing were compromised on the project.

The analysed data show that the rate of unemployment among the interviewees was high and that they needed the remuneration – hence their inability to challenge poor work processes. The interviewees again reiterated that if they did not comply with the directives given to them their employment would be terminated. Some of the interviewees indicated that they do not want to be associated with the construction of the mall to guard their own safety and wellbeing. As shown in Table 2, a cross analysis of the content analysis and interview findings establish the fact that the accident occurred on a site where clear deviations from construction regulations and the requirement of the H&S Act of 1993 of South Africa existed side-by-side.

Table 2: A summarised cross analysis of regulatory factors of the Tongaat mall collapse

Content analysis + Interview findings
Lack of inspection by regulatory bodies and professional team
Construction procedures were questionable in order to meet deadlines and to avoid penalties.
Formwork was removed to soon
Control and regulation of concrete mixing questionable
Construction flaws were rectified in dubious ways
Construction workers had little or no knowledge of the Construction Regulations
Supervisors were substandard and lacked leadership
Lack of inspection by regulatory bodies and professional team
Appointed safety officer was unknown to construction workers
Inadequate induction / work training

Source: Authors

5. Discussion

This aspect of the research confirms the regulatory contributors to the Tongaat mall building collapse accident. Given that incident investigations are normally used for origins of failure in a system (Manuele, 2014), it is vital to understand various contributory factors to the Tongaat mall accident. The Tongaat mall collapse could be seen from a multifactorial aspect of incident causation. The study that began in 2014 and was first reported in Emuze et al. (2015) shows that there was an initiating event, which was followed by many contributing factors that evolved in sequence. Such sequence could be likened to the illustrations of the loss causation model (LCM) of Bird and Germain (1985). This model recognises that management should prevent and control accidents. It would appear that for management to prevent accidents, the first step would be to adhere to all the requirements in a regulatory environment. Causal factors in accidents may start from decisions made by management when policies, standards, procedures, provision of resources and accountability system are constrained (Manuele, 2014). Again, the observation by Manuele (2014) resonates with the events of the Tongaat mall accident. In specific terms, the striking of formwork when it is rather too early is evident of inadequate accountability system in which the GC through the actions of the GF continued to work sub optimally on the project. Flagrant disregard of even a stop order from the municipality is evidence of the use of a GF that do not appreciate the definition of an accident, which is aptly defined as "… unexpected event or occurrence that results in an unwanted and undesirable outcome… (Hollnagel, 2004: 5)".

Researchers have recognised the importance of the client in the management of H&S, especially their influence on contractors (Smallwood, 2008; Suraji et al, 2001). To emphasise the crucial role of clients in H&S management, Suraji et al. (2001) argue that construction accidents are caused by inappropriate responses to certain constraints in the environment. They observed, for example, that the client responses are the actions or failure to act in response to constraints that emerge during the development of a project. According to them, these include reducing the project budget, adding new project criteria, changing project objectives and accelerating the design or construction efforts of the project. These perceptions are reinforced by clients who abdicate their roles and put on H&S responsibilities on contractors. In the case of the Tongaat mall accident, the client appear to be in haste to complete the project so much so that the permit to build was not obtained and the H&S component of the project was subservient to time and cost considerations. The client appears to be fixed on occupation date / opening day of the mall.

In a socio-technical system (such as in construction) where the relations between human and machines are intertwined, compliance to regulations should be the minimum in terms of good H&S practice. The system shapes the technical and social conditions of work in a way that both the system's outputs and the needs of workers are accommodated (Manuele, 2014). Regulation is a key part of the system in construction and when accidents eventuate, abnormal outputs are within the system. The lack of control in managing loss is always due to deficiencies in management programmes, standards identified and the degree of compliance with such standards (Amyotte, and Oehmen, 2002). Whereas, high-level governmental and regulatory factors tended to be similar for accidents that occur in socio-technical systems, the physical and human factors differ across different projects (Woo and Vicente, 2003). Thus the risk posed in an environment where compliance to regulations and the legislation is either low or limited can be high. This is the case in South Africa as attested by the CIDB (2009). For example, this particular accident killed 2 people and injured 29 while another recent bridge collapse in October 2015 also recorded fatalities and injuries (Figure 1). A lack of effective mechanisms to implement legislation and regulations for improved H&S performance in a developing country such as South Africa is a major issue (Alkilani et al., 2013).

This next step of the study is to make use of the context analysis and interview data in the compilation of graphic representations of the events / causal flow of the accident. With the use of causal trees, event trees, and causal-effect charts, this step would entail the management of the complex flow of recorded events so as to create an overview of complex happenings in the Tongaat mall accident. Such representation would focus on the propagation of the effects of undesirable actions inherent in technical faults and human errors through the project system of Tongaat mall building construction (Svedung and Rasmussen, 2002).

6. Conclusions

The narrative in this paper shows that regulatory failures were rampant in the collapsed building in South Africa. Some of these failures provide fertile grounds for the propagation of multiple causal accident factors. A socio-technical accident causation model that highlights the influence of organisational culture of both clients and GC involved in Tongaat mall project is needed to show all the shortcomings that were in existence when H&S policies, standards, procedures and accountability took the back seat in the ill-fated project. The model would relate to inadequacies in controls, especially from the regulatory environment, which appears to allow construction to continue on the site despite several stop orders from the concerned authorities. In relation to this paper, the answer to the question posed in section one is that regulatory factors significantly contributed to the collapse of the building in terms of clear disregard for important sections of construction regulations, and H&S legislation in South Africa. Evidence of deviations can be seen in Table 2 and the interview findings. This realisation unfortunately confirms the long held perceptions that while South African construction is not lacking in legislation, compliance is a major hurdle to be scaled in the industry.

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Construction Permit to Work Requirement in South Africa: Closing Commencement Gaps

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Abstract

The Construction Regulations enacted in 2003 realised a range of roles and practices that have impacted the status of health and safety (H&S) in South Africa. In 2014, the regulations were revised with the introduction of new sections that are aimed at reinforcing the regulatory environment. One of such section is the 'permit to work' requirement, which inter-alia, seeks to stop the award of work to non H&S complaint contractors. To assess implementation readiness, a sequential mixed method study was conducted in 2015. The collected survey and interview data shows that there are practice gaps that would lead to the inability of clients to obtain the work permits as envisaged by the revised regulations. The multi prong implications for clients, designers, and contractors means procurement delays will occur in the interim and such events would impact on project planning. The delays may occur due to capacity constrains at the Department of Labour (DoL) who is mandated by law to issue the permit. More important is the need for the DoL in South Africa to remove all implementation road blocks so that the permit to work system that is met to engender injury and accident free construction work environment would be successful.

Keywords: Construction, Health and Safety, Regulation, South Africa

1. Introduction

The implementation of optimum H&S practice is a prerequisite for a reduction in injuries and accidents in the construction industry (Hallowell, 2010). Among other various interventions, legislation and regulations are used to promote good H&S practice in the construction industry. The use of legislation is relevant in an industry in which non-compliance is prevalent due to its structure. In terms of structure, the construction industry in South Africa is dominated by a large number of small and medium size (SME) contractors (Emuze and Smallwood, 2011). These SMEs are unable imbibe the zero-accident culture (Othman, 2012). The expansion of the zero-accident or zero-harm culture in the industry has increased the need to know, and implement, relevant H&S regulations in the industry (Wilkins, 2011). Price Water House Coopers (PwC) (2013) reports that while there have been insinuations that fatalities are linked to the high price environment – chasing profits causes accidents that result in injuries and fatalities – the reality is that improving H&S is a profit motivation (Smallwood, 2004). Most construction workers employed by SMEs and even large contractors in South Africa are either semi-skilled or unskilled with little education and this poses a great challenge in managing H&S since risks to H&S increases with a low level of awareness and lack of training (Lingard and Rowlinson, 2005). In an attempt to promote workers' compliance to H&S regulations in the industry, the need to convey the implications of dangerous conditions and effects of non-compliances through appropriate training and education cannot be over emphasised (Wilkins, 2011).

Windapo and Oladapo (2012) note that construction H&S has long been the focus of attention of many industry stakeholders in South Africa. PwC (2013) reports that leading construction companies, the government and unions are showing increased concern with respect to H&S, which is essential if the industry is to remain progressive. The poor H&S performance in South African construction is therefore motivating stakeholders (Agumba and Haupt, 2011) and the government is not left behind in this motivation in terms of interventions. One of such intervention is the enactment of Construction Regulations. However, there is a gap in the implementation of the Construction Regulations that was promulgated in 2003. The gap is apparent as clients lack consistent and uniform standards of compliance with H&S because they often appoint contractors without verifying their H&S compliance capability. According to Windapo and Oladapo (2012), contractors perceive regulations as an additional burden, which they have to conform with and which gives rise to unnecessary costs. In an attempt to avoid these perceived additional costs, contractors tend not to comply fully with H&S regulations. For instance, contractors are not compelled by the client to notify the DoL before commencing with projects where required. This reported action of contractors is the basis for the overall study, which is done in partial fulfilment of the requirement for an MSc qualification.

One of the research questions of the study that forms the tie for this paper is "*How should public sector client implement the newly introduced construction works permit in South Africa*? The objective of this question is to determine the public sector's readiness in terms of the fulfilment of section 3 of Construction Regulations (2014), which states that a client who intends to have construction work carried out, must at least 30 days before that work is carried out apply to the provincial director for a construction work permit to perform work which exceeds 180 days, or will involve more than 1800 person days of construction work or works contract is of a value equal to or exceeding thirteen million rand or CIDB (Construction Industry Development Board) grading level 6 (Republic of South Africa (RSA), 2014). The Construction Regulations of South Africa is applicable to all persons involved in construction work and its application impact directly on construction H&S. This paper start with a synopsis of the newly introduced permit to work requirement of the regulations and its implications for construction projects in the next section. Thereafter, the methodology section concisely indicates the procedure that was used in the research. The methodology discourse leads to the findings and a discussion, which informs the conclusions of the paper.

2. Scope of Construction Regulations (2014): A Synopsis

Construction regulations (2014), which was promulgated on the 7th of February 2014 (RSA, 2014) apply to all persons involved in construction work – section 2(1) of the regulations. At the launch of the regulations, the South African labour minister states that:

"*For any legislation to be effective it must be enforced and our inspectors will not tolerate non-compliance. These regulations should serve as a deterrent to all those who have not yet grasped the value add of creating and maintaining healthy and safe workplaces. As we are well aware, construction workers build our roads, houses and workplaces and repair and maintain our nation's physical infrastructure. This work includes many hazardous tasks and conditions such as work at height, excavations, noise, dust, power tools and equipment, confined spaces and electricity. Therefore worker involvement is a key factor in improving safety performance on a construction site. Organised labour, as well as employers, must ensure that H&S of workers on construction sites is not compromised. We cannot be callous with the lives of workers. We must always remember that behind the statistics of people who are killed in our industry, there are real human beings, children who lose parents, wives or husbands who lose their loved ones who are in most cases breadwinners. This industry should not be thought of as a killer industry but rather take its place as a major player in our economy" (SACPCMP, 2014)*".

As shown in Table 1, the regulations were issued in terms of the Occupational Health and Safety Act 85 of 1993 (RSA, 1993). Among other clauses, section 3 of the regulations introduced a new requirement to the construction industry in South Africa. The permit to work requirement place compliance obligations on stakeholders – clients, contractors, DoL and construction H&S professionals. The section states that a client must ensure that the principal contractor keeps a copy of the construction work permit contemplated in sub regulation (1) in the Occupational H&S file for inspection by an inspector, the client, the clients authorized agent, or an employee. Obtaining the permit and keeping it for inspection are grey areas for the implementation that began in August 2015.

In order for the public sector to fulfil the requirements of Construction Regulations (2014), there is need for it to accommodate regulatory changes and make the necessary improvements that will afford required compliance. Section 5(5) of Construction Regulations (2014) states that where a construction work permit is required as contemplated in regulation 3(1), the client must appoint a competent agent to assist him in undertaking the measures he needs to take to comply with the requirements and duties imposed upon him by or under Construction Regulations (2014) provisions and the Occupational Health and Safety Act (OHSA) 85 of 1993, and that the duties which are to be carried out by the agent must be done with integrity. This requirement brings up a range of issues. One is the competency and capacity of DoL to accommodate the permit to work applications; and two, is the available of competent construction H&S professionals that can be appointed by the client in order to fulfil the purpose of the regulations. These two issues are significant in South African construction that suffers from many incidents of injuries and accidents (CIDB, 2009) and chronic non-compliance cases on construction site as evident in major accidents (Emuze et al., 2015).

Table 1: A summarised application scope of construction regulations 2014

CONSTRUCTION REGULATIONS 2014
OCCUPATIONAL HEALTH AND SAFETY ACT, 85 of 1993
Scope of application
2. (1) These Regulations are applicable to all persons involved in construction work. (2) Regulations 3 and 5 are not applicable where the construction work carried out is in relation to a single storey dwelling for a client who intends to reside in such dwelling upon completion thereof.
3. Application for construction work permit.
3. (1) a client who intends to have construction work carried out, must at least 30 days before that work is to be carried out apply to the provincial director in writing for a construction work permit to perform construction work if the intended construction work will: (a) exceed 180 days; (b) will involve more than 1800 person days of construction work; or (c) the works contract is of a value equal to or exceeding thirteen million rand or Construction Industry Development Board (CIDB) grading level 6. (2) An application contemplated in sub-regulation (1) must be done in a form similar to Annexure 1. (3) The provincial director must issue a construction work permit in writing to perform construction work contemplated in sub-regulation (1) within 30 days of receiving the construction work permit application and must assign a site specific number for each construction site. (4) A site specific number contemplated in sub-regulation (3) must be conspicuously displayed at the main entrance to the site for which that number is assigned. (5) A construction work permit contemplated in this regulation may be granted only if: a) the fully completed documents contemplated in regulation 5(1)(a) and b) proof in writing has been submitted—
(i) that the client complies with regulation 5(5) (ii) with regard to the registration and good standing of the principal contractor as contemplated in regulation 5(1)(j); and (iii) that regulation 5(1)(c), (d), (e), (f), (g) and (h) has been complied with. (6) A client must ensure that the principal contractor keeps a copy of the construction work permit contemplated in sub-regulation (1) in the H&S file for inspection by an inspector, the client, the client's authorised agent, or an employee. (7) No construction work contemplated in sub-regulation (1) may be commenced or carried out before the construction work permit and number contemplated in sub-regulation (3) have been issued and assigned. (8) A site specific number contemplated in sub-regulation (3) is not transferrable.

Source: RSA (2014)

3. Methodology

In this research, the implications of the Construction Regulations (2014) for the public sector was explored as past research and present anecdotal evidences show that the DoL and by extension, construction clients, may not be able to cope with the requirements of the implementation of the permit to work system. The study began with a review of the regulations and associated literature to get a sense of the direction and intent of the new clauses. Thereafter, the findings of the literature were used to compile a semi-structure questionnaire distributed among general contractors (GCs) in a metropolitan area in South Africa. The questionnaires were administered on construction sites so that the targeted sample was reached. The questionnaire was distributed to a sample of 28 GCs actively registered with the CIDB in grades 6-9. The grade of the contractors is in conformance with section 3 of Construction Regulations (2014). The questionnaire consisted of ten questions each, with several sub questions. The questionnaire referred to the implications of the regulations for the Department of Public Works (DPW) procurement system. The survey yields 79% response as only 22 questionnaires were validly completed and processed. Primary data collection in the study thus comprises survey research and face-to-face interviews, which forms the basis for the findings presented in this paper (Creswell and Plano Clark, 2011).

Before the commencement of the interviews, the survey data were analysed to identify the main perceptions of the respondents. The data also influenced the collection of the textual data in that the interview protocol focus on getting the opinions from the regulatory authority and other construction professions, especially in relation to the permit to work requirement. The interview field work began by identifying built environment professionals that have managed construction projects on behalf of the DPW in the province, director of procurement in DPW, chief director infrastructure in DPW, and an official of DoL in the province. A letter, which explained the purpose of the interviews, was delivered by hand to some of the participants, while emails were sent to participants whom upon being called on the phone asked for the letters to be emailed. Face-to-face interviews were successfully secured with eight out of nine potential interviewees. Interviews were conducted between the month of March and April 2015. Semi-structured face-to-face open ended interviews were conducted by taking notes while audio recording of the interviews was in progress. In brief, purposive sampling was deemed useful for the study because it is important to collect the perceptions of people in construction with requisite work experience and contact with DPW procurement system.

4. Results

When the survey respondents were asked to indicate the number of years that they have been involved in construction, all of them have been working in the industry for more than six years and three of them even have more than 20 years construction industry experience. As shown in the tables in this section, the respondents were asked to rate their perceptions on a five point Likert scale, which range from 1 (strongly disagree) to 5 (strongly agree). An 'unsure' option was provided on the scale to cater for questions in which the respondents were either not able to comprehend or provide an answer. The computation of the responses was done with descriptive statistics, which produce the percentage responses for each sub question and the associated mean scores (MS). The statements in the tables have been ranked based on the MSs and where there is a tie, the standard deviation score was used to break it (Salkind, 2015).

In Table 2, it can be observed that when asked whether Construction Regulations should promote compliance to H&S in the industry, majority of the respondents were generally in agreement. The ranking suggests a significant agreement with the perception that the regulations should promote compliance to H&S in the industry. The statement is relative to the need for everyone involved in construction to be familiar with the regulations. However, the respondents concur that compliance with Construction Regulations (2014) requires specific competences because it has realised a number of revisions that differentiates it from Construction Regulations (2003). One of such revisions is the permit to work requirement that is enforced by the DoL. To this end, the respondents suggest that sensitisation of stakeholders is required in the industry as most of them are not familiar with the revisions in Construction Regulations (2014).

Table 2: Contractors' perception of Construction Regulations of South Africa

Statement	*MS*	*Rank*
Construction Regulations should promote compliance to H&S in the industry	4.63	1
Industry role players are relatively familiar with construction regulations 2003	4.17	2
Compliance with construction regulations 2014 requires specific competences	3.89	3
Construction regulation 2014 realised notable revisions and requirements	3.77	4
Industry role players are relatively familiar with construction regulations 2003	3.75	5
Permit to work system to be enforced by DoL in August 2015 is based on construction regulation 2014	3.63	6
Industry role players are relatively familiar with construction regulations 2014	2.93	7

Source: Authors

In Table 3, the respondents strongly indicate that delayed project initiation has economic and social impacts on the community. This perceived delay could be made worse if the view that the DoL has not engaged project actors on the modus operandi for the implementation of the permit to work system is a reality. The table confirms the media perception that the permit to work requirement could delay project initiation and planning because of the required documentation and the capacity of DPW to function properly in this context. Another reason for this perception could be the paucity in the number of construction H&S professionals that can be engaged for the implementation of the system. It is also notable that awareness related to the permit to work system enforced by the DoL in August 2015 is deemed to be low as opposed to high by the contractors that took part in the survey. On the average, the respondents were also of the opinion that clients' deliverables are vulnerable to the requirements of the permit to work system.

Table 3: Contractors' perception of permit to work requirement

Statement	*MS*	*Rank*
Delayed project initiation has economic and social impacts on the community	4.50	1
DoL has engaged project actors on the implementation of the permit to work system	3.62	2
Permit to work could delay project initiation and planning	3.55	3
Awareness relative to the permit to work system to be enforced by DoL in August 2015 is high	2.94	4
Clients deliverables are vulnerable to the requirements of the permit to work system	2.33	5

Source: Authors

The survey findings become clearer with the interviews that were conducted with the DoL and other professionals that would be directly involved in the implementation of the permit to work system. When asked to indicate whether they are aware of the permit to work system that came into effect in August 2015, six out of eight interviewees responded in the affirmative. The six interviewees indicated that they are aware of the permit to work system, although how it will be implemented is not clear to most of them. One of the interviewee claim total ignorance about the regulations, and another interview is uncertain about the time of its application.

In addition, the interviewees were requested to indicate if they are familiar with Construction Regulations (2014) in terms of key points of departure from Construction Regulations (2003). The question was used to determine whether the interviewees are familiar with Construction Regulations (2014). This can be deduced if they can identify the differences between Construction Regulations (2014) and the previous regulations. Given that the interviewees flag issues of 'delays in processing documentation for verifications, and cost and time implications', it can be assumed that their level of familiarity is acceptable. It is realized that the interviewees are familiar with Construction Regulations (2014), and also that interviewees could distinguish between the two Construction Regulations, this is since issues such as delays, permit to work system, processing and verification of documentation were some of the highlighted concerns among the respondents. Regarding the point of departure from Construction Regulations (2003), the respondents' mentioned that there is clear departure in which the permit to work system is the highlight. There is an indication that interviewees were aware of Construction Regulations (2014) and the point of departure from Construction Regulations (2003).

This question leads to that of compliance, which says "*Relying on your familiarity with Construction Regulations (2014), please discuss compliance issues in the industry*?" In response, the interviewees were of the opinion that lack of compliance to the new requirements will ensue, mostly SME contractors and thus, enforcement will have to be promoted by the DoL.

In addition, the DoL official interviewed was asked to comment on the enforcement aspect of the permit to work requirement. To quote the interviewee directly in response to this question, the official says *"No construction shall be permitted to commence without the site-specific official number allocated to it. Prohibition notice shall be served to the contractor to stop immediately. And if not displayed then we will issue a contravention notice, for the contractor to comply within specified time".*

In an elaboration, the official says that the DoL will issue a letter of acknowledgement for the permit request and issue the required number within 30 days. The interviewee further says that contractors must insist on the 1st page copy of their permit be stamped as proof of submission. When the permit to work requirement is operational, the official note that information advocacy sessions shall be conducted with all possible clients and principal contractors. The DoL will also engage all voluntary associations and statutory councils in the awareness drive. In the case of backlogs in application processing due to capacity constraints, the official says that "*There might be backlogs likely to be caused by unavailability of personnel, there might also be some minor backlogs since department still have to decide on personnel to be appointed for processing permits*". Given that this interview was conducted less than 3 months to the implementation start date, this sentence is not comforting to contractors.

In particular, the official was asked to briefly explain how permit application backlogs will be addressed if they manifest. The question was asked to assess if the DoL prepared for possible backlogs to be encountered at the commencement of the system. The official responded when he says "*The proposed plan is to have a principal inspector per province who shall assess the H&S specifications, baseline risk assessment and costs, and make recommendations to specialist inspector for granting the permit*".

5. Discussion

A concise cross analysis of the survey and interview findings is presented in Table 4, which shows that the survey respondents and the interviewee agreed on some of the issues. The survey reveals that stakeholders in the industry are familiar with Construction Regulations (2003). This finding is aligned to the findings by the CIDB (2009), which emphasise that Construction Regulations are perceived to have had a wide spread impact, and in particular increased H&S awareness and increased consideration by GCs. The survey also suggests that Construction Regulations should promote compliance to H&S in the industry, and that compliance with Construction Regulations (2014) requires specific competences. The study reveals that professionals who are responsible for the implementation of permit to work requirement of Construction Regulations (2014) need specific learning related to implementation. Relevant H&S education and training at all levels in the industry will empower people to make the requisite H&S contributions, which include the tertiary education of all built environment disciplines. More importantly, H&S enforcement agencies such as the DoL and the client such as the DPW should have the requisite construction expertise.

Table 4: Cross analysis of the survey and interview data

	Survey questionnaire	*Interviews*	*Survey questionnaire*	*Interviews*
	Differences		*Consensus*	
Construction Regulations 2003 & 2014			Construction regulations should promote compliance to H&S in the industry.	Clients must be informed on how to comply, principal contractors should be trained about H&S and appoint registered H&S professionals and designers' sets of documents must incorporate H&S.
Familiarity with Construction Regulations 2014	Industry role players are relatively familiar with construction regulations 2003. Industry role players are not relatively familiar with construction regulations 2014.	Industry role players are relatively familiar with construction regulations 2014.		
Permit to work System	Awareness of the permit to work system is low.	Awareness of the permit to work system is moderate.	Permit to work could delay project initiation and planning.	There would be implications to service delivery due to permit to work system. Possible impact on project initiation and planning will be in terms of the client as they need to get a permit before he/she starts a project.
Competency	H&S competency level required for compliance with construction regulations 2014 will influence procurement method choice and implementation.	Selection criteria that would establish the H&S competency level required is knowledge, skills, training, qualifications certification, necessary documentation, quality and experience.	Construction regulations 2014 requires specific competencies.	Consultants, clients and contractors need competency for construction regulations to work.

Source: Authors

According to Hughes and Ferrett (2008), clients must make sure that designers, contractors and others whom they propose to engage are competent or work under the supervision of competent people, and are adequately resourced and appointed early enough to fulfil their duties. The study suggests that competency level required for compliance with Construction Regulations (2014) will influence procurement method choice and implementation. The study suggests that permit to work could delay project initiation and planning, while it also suggests that delayed project initiation has economic and social impacts on the community. These issues affect the DPW as a public sector client and the DoL. While the DPW and the DoL are both governmental agencies in South Africa, their roles in the implementation of the regulations clearly differ. For the DPW, it is a client that must fulfil certain requirements in terms of the regulations. Key requirements include:

- Appoint a competent designer, CHSA, and principal contractor;
- Prepare a baseline risk assessment and H&S specifications by a competent SACPCMP registered CHSA;
- Apply and obtain a permit within time frames set out in Legislation (30 days) in order to roll out infrastructure projects.

These above mentioned obligations will serve and be verified by the DoL, who must assign duties of processing of permit to work application to competent officials who shall act within principles set out by the regulations; ensure permits are granted within time frames set out in regulations (30 days); and also educate the public about permit to work requirements in order to get optimum compliance. In order to enhance compliance, agencies such as the DoL need to be sensitive to the context within which they undertake their activities, their target audience and to the varying competencies and resources of those being regulated and have some awareness of those external resources (e.g. third party actors) that may be involved (Health and Safety Executive (HSE), 2008). The interviewees agreed that implementation of Construction Regulations (2014) needs stringent measures and DoL must closely police non-conformance. The CIDB (2009) highlights that the primary objective of any H&S legislation is the prevention of accidents with their consequences in terms of injury, disablement and fatality, and ill health within the work environment. The achievement of this objective depends on good legislation supported by effective, sensible and accountable enforcement. The attainment of the objectives also depends on proper H&S training, which has the capacity to improve compliance with the new permit to work requirements (Wilkins, 2011). According to the DoL, the purpose of the Construction Regulations (2014) is as follows: (1) cultural change by among others, the permit system; (2); involving client, agent / designers, principal contractor, contractor, and H&S officers at the initial stage and through the life span of a project regarding all matters of H&S (Maphaha, 2015).

6. Conclusions

The study reveals that Construction Regulations have strengthened inclusive H&S roles and responsibilities in South Africa. This is particularly true for principal actors in a construction project. For instance, sections 5(1) (a-d) of the Construction Regulations (2014) states that a client must prepare a baseline risk assessment and prepare a suitable, sufficiently documented and coherent site specific H&S specification based on the baseline risk assessment. The client must then provide the specifications to the designer and ensure that the designer takes the prepared H&S specification into consideration during the design stage; while 6(1) (b-c (i) states that designer of a structure must take into consideration the H&S specification submitted by the client before the contract is put out to tender, 7(1) (a) states that a principal contractor must provide and demonstrate to the client a suitable, sufficiently documented and coherent site specific H&S plan.

The study also found out that permit to work will have impact on project initiation and planning. The DoL is likely to experience backlogs because of unavailability of personnel required for processing permits. To ensure compliance, the DoL must have all internal arrangement for implementation in place – this will assist in closing all commencement gaps. Among other intentions, the permit to work system would ensure that suitably qualified personnel are involved in a project in terms of providing the required H&S cover for each project. However, the survey and the interview data of this paper shows that the DoL is not fully prepared for the roll out of the permit to work system given the fact that none of the interview and the survey respondents know how the system will unfold or is presently unfolding. Even the DoL official that was interviewed could not provide a clear implementation plan for the system. Taken together, it can be argued that the implementation of the permit to work system may not be smooth sailing and the compliance issues that have always hinder complete implementation of regulations may yet again become a stumbling block to the realisation of the intentions of the permit to work system.

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Using institutional theory to understand occupational safety and health practices in smaller construction firms in the UK

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Abstract

Despite the fact that small and medium-sized enterprises (SMEs) and micro enterprises play a key role in the construction industry and experience higher rates of work-related accidents than their larger counterparts, comparatively little is known about the factors that influence how such enterprises approach occupational safety and health (OSH) in the workplace. In this paper we use institutional theory to understand the factors that promote the survival and legitimacy of particular OSH practices amongst SMEs and micro enterprises in the construction sector in the UK. Our research involved analysing qualitative data from 44 interviews with participants from a range of construction firms, of different sizes and specialisms. The findings from our analysis suggest that the practices of smaller construction enterprises are influenced by a range of coercive, mimetic and normative pressures, however two factors were seen to be particularly influential: the coercive pressures exerted by principal contractors in larger supply chains, which serve to filter subcontractors; and on the job socialisation, a process that reinforces and ensures the survival of both desirable and undesirable OSH practices in smaller organisations.

Keywords: SMEs, micro enterprises, institutional theory, template analysis, interviews

1. Introduction

Despite the fact that small and medium-sized enterprises (SMEs) and micro enterprises play a key role in the construction industry and experience higher rates of work-related accidents than their larger counterparts, comparatively little is known about the factors that influence how such enterprises approach occupational safety and health (OSH) in the workplace. Developing a better understanding of these influences could help policy makers, OSH practitioners and larger contractors to design more appropriate interventions for encouraging and supporting smaller construction firms to work more healthily and safely.

In this paper we use institutional theory as a framework, or theoretical lens, through which to understand the factors that promote the survival and legitimacy of particular OSH practices amongst SMEs and micro construction firms. These factors are explored using data from a recently completed two-year study of OSH practices in SMEs and micro enterprises in the United Kingdom (UK), which was funded by the Institution of Occupational Safety and Health (IOSH). The study covered a wide range of industry sectors including logistics, healthcare and construction; however for the purpose of this paper we focus on the findings from 40 interviews with owners and employees in SME and micro construction firms.

We begin by exploring what is currently known about the influences on OSH practices in smaller organisations, both generally and specifically in the construction sector. We then describe the methods underpinning our research into OSH and smaller organisations and explain the reasons for using institutional theory as our analytical framework. The findings from our analysis are presented in section 4 and discussed in further depth in the conclusions in section 5.

2. Background

SMEs and micro enterprises comprise the vast majority of organisations in most countries. For instance, in 2014 smaller organisations *"... accounted for 99.3 per cent of all private sector businesses in the UK, 47.8 per cent of private sector employment and 33.2 per cent of private sector turnover"* (FSB, 2014). However, there is no universal definition of what constitutes an SME or micro enterprise, with categorisations varying from country to country. In the European Union (EU), micro, small and medium sized enterprises are classified as organisations employing less than 10, 50 and 250 people, respectively (Table 1). Although the EU also uses financial criteria sheet to categorise organisations, employee headcount is the most widely used criterion and is therefore used to classify enterprises in this study.

National and supranational statistics suggest that that accident rates are higher in SMEs and micro enterprises than in larger companies, with one study (WHP in Europe, 2001; p.21) finding that fatal accident rates were twice as high in small and micro companies than those in large companies. Similar differences in accident rates have also been evident in specific countries and sectors. For instance, Walters and Bolt (2009) found that firms with fewer than 14 people employed 40% of the construction workforce in Britain but, for the period 2003-08, two-thirds of fatalities were self-employed or employed by firms of 15 people or less. In other words, workers in such companies had a greater risk of fatal injury.

Table 1: Classifications of medium, small and micro enterprises (EC, 2003, p.14)

Enterprise category	**Headcount**	**Annual turnover**	**Annual balance sheet total**
Medium	<250	≤€50 million	≤€43 million
Small	<50	≤€10 million	≤€10 million
Micro	<10	≤€2 million	≤€2 million

However, despite the fact that smaller organisations are far more prevalent and experience a greater risk of accidents, traditionally researchers have tended to focus on OSH practices in larger organisations (Eakin, 1992). This discrepancy may be explained by the fact that SMEs and micro enterprises are less visible and harder to reach than larger organisations. It may also be that researchers have viewed SMEs and micro enterprises as smaller versions of larger organisations, thereby overlooking their distinctive characteristics and the different contexts in which smaller organisations operate (Eakin and MacEachen, 1998). Nevertheless, over the last two decades there has been a growing body of literature on the subject of OSH in smaller enterprises, covering a wide range of sectors and geographical settings, and involving a variety of methodologies and stakeholders[1].

Generally speaking, the literature paints a negative picture of OSH practices in smaller organisations, with previous studies finding, amongst other things, a lack of management commitment (e.g. Eakin and MacEachen, 1998; Holmes and Gifford, 1997; Parker et al., 2012), a lack of employee engagement (e.g. Barbeau et al., 2004; Champoux and Brun, 2003) and confusion about employee and management responsibilities (e.g. Bradshaw et al., 2001; Fairman and Yapp, 2004). Smaller organisations have also been found to have lower levels of awareness and knowledge of legislative requirements and regulations (e.g. Antonsson et al., 2002; Bradshaw et al., 2001) and have a tendency to underestimate or discount risks (e.g. Hasle et al., 2011; Fonteyn et al., 1997).

Of particular interest to us in this paper are studies that have shed light on the factors that influence OSH practices in smaller organisations. Such studies are important because they tell us *why* individuals and organisations act in particular ways, not just *how* they act. Vickers et al. (2005, p.152) argued that *"... more widely based studies that have sought to locate the development of policy in the context of a detailed and more holistic understanding of the factors that influence how small firms approach the management of health and safety have been much less in evidence."* In a related paper, Vickers et al. (2004) suggested that OSH practices in

[1] See Gibb et al. (forthcoming) for a more comprehensive review of this literature

smaller firms are influenced by a combination of internal characteristics (such as management style) and external pressures (for instance, from customers and regulators).

Smaller enterprises tend to be dominated internally by the interests and goals of owner-managers (Marlow, 2005), who often have a preference for informal and individualised practices (Hoque and Noon, 2004). For many owner-managers, the business is an extension of themselves - their ego, personality, motives and desires (Banfield et al., 1996). A number of studies have highlighted the impact of these interests and goals on the OSH practices of smaller firms. For instance, Eakin (1992) found that owner-managers in smaller enterprises wanted to avoid being paternalistic and, in some cases, felt that they lacked the authority to intervene to improve OSH practices. Similar issues were identified by Parker et al. (2012, p.474) who found that *"employers were conflicted about allowing employees a certain level of independence while also maintaining a safe workplace."*

However, whilst the insights from such studies are certainly valuable, contributors to the broader business and management literature have argued that *"...if we are to understand industrial relations in the small firms, then we need an approach that goes beyond simply looking inside the small firm and describing the (paternalistic) management styles used to control the labour process… it is necessary to consider both the environment within which small firms operate as well as the impact of this on, and the effect of, managerial choice."* (Barrett and Rainnie, 2002, p.427). Such arguments are based on the premise that smaller organisations are particular sensitive to the environment, or context, in which they operate (Baldock et al., 2006; Barrett and Rainnie, 2002).

For the purpose of this paper we used institutional theory as a framework, or theoretical lens, for understanding the external influences on smaller enterprises' OSH practices. Institutional theory has its roots in the work of Meyer and Rowan (1977), who suggested that *"... organizations are driven to incorporate the practices and procedures defined by prevailing rationalized concepts of organizational work and institutionalized in society. Organizations that do so increase their legitimacy and their survival prospects, independent of the immediate efficacy of the acquired practices and procedures"* (p.340). These institutional rules mean that, over time, organisations become homogenous or *isomorphic* – that is to say, their practices and procedures become more similar. Developing this idea further, DiMaggio and Powell (1983, p.150) argued that there are *"... three mechanisms through which institutional isomorphic change occurs"*, these being:

- Coercive – pressures exerted on organisations by other organisations upon which they are dependent or by society (e.g. through government regulations)
- Normative – in which organisations conform to the practices that are deemed legitimate in their field, in order for themselves be acknowledged as reputable.
- Mimetic – whereby organisations model themselves on other organisations that they perceive to be more legitimate or successful in their field

DiMaggio and Powell suggested that while there may be an interplay between the three mechanisms, "... *they tend to derive from different conditions and may lead to different outcomes.*" (p.150).

Institutional theory has been used in a diverse range of contexts in order to understand and explain why practices in particular sectors or professions become legitimised and dominant. Glover et al., (2014, p.103) argued that the *"... strength of institutional theory is that it offers explanations of why certain practices are chosen without an obvious economic return."* Ju and Rowlinson (2014) used institutional theory in their case study of safety management strategies of construction contractors in Hong Kong. Using data from 62 unstructured interviews with site personnel on a large-scale railway project, they found that *"Multiple stakeholders exert incompatible safety pressures on contractors through a variety of mechanisms, such as regulatory constraints, enforcement activities, normative force and cultural influence."* (p.734). These incompatible pressures were seen to result in a disconnect between the rhetoric of the safety management system and the reality of site practices.

Acknowledging the value of institutional theory for studying the influences behind OSH practices, our aim in this paper was to use this theory to understand the factors that promote the survival and legitimacy of particular OSH practices amongst SMEs and micro enterprises in the construction sector in the UK.

3. Research methods

David and Bitektine (2009, p.168) contend that *"... institutional theory represents a very large tent that houses a great variety of theoretical agendas and methodological approaches."* In this study, our approach to applying institutional theory involved coding interview data (transcripts and notes) using template analysis (see King, 1998) – a method that entails both deductive and inductive reasoning (Saunders et al., 2009). The deductive part of the template analysis involved coding the textual data in Nvivo 10 software using a pre-prepared list of themes – the themes in this case being the three isomorphic mechanisms identified by DiMaggio and Powell (1983). Inductive reasoning was then used to identify sub-themes within each of the main themes. Where appropriate, the template was amended by adding new themes. The final template is summarised in Table 2 and discussed in further detail below.

The data used in our analysis were collected as part of a cross-sector study of OSH practices in SMEs and micro enterprises in the UK (see Gibb et al., forthcoming). The study involved a mixed-method, qualitative approach comprising 149 structured interviews, nine short-term ethnographies and 21 semi-structured interviews with 179 owners and employees in smaller organisations from a range of industry sectors, including logistics, agricultural, healthcare and construction. Participants were selected purposively for maximum variation, that is to say they were chosen because they were likely to provide useful insights into a range of different work settings. For the purpose of this paper, our analysis focused on the 44 interviews with participants from the construction sector, including representatives from a large contractor and an industry body.

Adopting a qualitative approach in our research allowed us to tell the story of OSH practices in smaller organisations from the perspective of the actors concerned, and to understand how and why they came to have a particular perspective on OSH. Unlike Ju and Rowlinson's (2014) study – which focused on a single case study– our research focused on multiple organisations and work settings, in order to determine if institutional pressures vary across contexts within the same sector. Where possible, multiple interviews were held within the same organisation in order to access different perspectives (e.g. those of owners and employees) on the same issues. The interviews tended to be conducted in participants' place of work, enabling us to discuss their OSH knowledge and practices in context. In most cases, interviewees needed very little prompting and talked extensively about their experiences and understanding of OSH in their data-to-day work, providing us with a rich narrative for analysis.

4. Findings

Analysis of the interview data revealed a range of positive and negative institutional influences on OSH practices in smaller enterprises, as summarised in Table 2. **Coercive** pressures were mentioned most frequently by interviewees; however, such pressures took a variety of different forms. Many interviewees cited government regulations as a reason for adopting particular working practices, although individuals' responses to regulations were often mediated by other factors, such as an individual's attitude or work setting. For instance, one plumbing and heating engineer (sole trader) stated that:

> *"Obviously there are a lot of regulations and legal requirements and obligations which you have to fulfil… obviously it depends on your own personality. My personality is, if I do something, I wouldn't do anything different than what I'd do for my mother. So it's personally affected, if you like, but obviously you have the constraints of all the regulations and legal requirements."*

There was a perception amongst some interviewees that, in practical terms, OSH regulations were not always easy to implement in construction because of the varying conditions and that some degree of tolerance or flexibility was required.

Some principal or main contractors (usually medium-sized or large enterprises) were also seen to exert a positive coercive influence on the OSH practices of smaller organisations, both specifically through the strict enforcement of site rules and the use of method statements, and more generally through their contractor management and training systems. One subcontractor explained how he and his colleagues were required to tidy up after themselves when working on site, a behaviour that was enforced by the site manager. For smaller businesses, failure to comply with such requirements would mean that they would not be able work on larger projects with larger contractors. This coercive pressure was summed up succinctly by an apprentice electrician with a medium-sized contractor, describing how

> *"You're expected to follow the site rules and if you don't you're red and yellow carded so you could be off site. If it's someone working for a small company for*

themselves then it's in their best interest to follow the site rules and if they get removed off site they're losing money themselves."

Elsewhere, the owner of a micro mechanical engineering business explained how:

> *"We know we can't break any rules. We're like robots really in a certain way. We just don't anything that's wrong really, you know you can't get away with it. You've got to wear your hat, you've got to wear all your PPE, that's got to be worn, you know you can't go out there not wearing it. You know you can't surf on the scaffolds. You just can't do anything that's wrong. You know you're not allowed to just build scaffolds. You know what's dangerous and what's not. It's common sense more than anything else."*

Interestingly, some interviewees described how they would work differently when not under the influence of a large contractor, for instance when working in a domestic setting or on smaller construction sites. In other words, these smaller businesses would adapt their approach to OSH, depending on who they were working for. One sole trader working in the construction industry explained that he uses 110v power tools on larger building sites, because that is what the main contractors require, but when working for domestic clients he uses 240v power tools instead because he feels that he can work safely with them and that 110v tools are unnecessary.

Not all SMEs and micro enterprises choose to work with larger organisations. For instance, two sole traders explained how they did not like to work on larger sites as they found it to be too much about rules and regulations and constrained their ways of working. Instead, they worked for a small collection of clients they had built up over the years said that they had been offered jobs on larger sites but turned down the work because after years of experience they preferred to work on their own terms. In particular, they did not like the idea of anyone talking down to them or telling them what to do.

On the whole, the principal contractors were seen to have had a positive influence on OSH practices amongst smaller enterprises in the construction industry, raising the overall standard in the industry. A representative from a construction industry body observed that *"... the people that are within that supply chain of those big influential principal contractors and clients are – they're not there yet but they are – they're certainly on the road to getting there. And they're a country mile away from where they were, you know five, 10 years ago, something like that."*

An OSH manager in a larger construction company described how his company had begun working with a smaller subcontractor that had a very low standard of OSH, however within a year the subcontractor had won a *"best at health and safety award."* The OSH manager explained how the subcontractor had been given access to training and assistance in developing their OSH programme. Any guidance they needed they knew who to ask - this process was facilitated by being approachable and by using standardised forms and procedures that allowed the subcontractor to understand what was needed without fundamentally changing the way they ran their company.

Table 2: Summary of interviews themes and issues

Theme	Positive	Negative
Coercive pressures	Government regulations Enforcement of site rules Principal contractor requirements Monitoring of subcontractors	Time pressures from larger client/contractors
Mimetic pressures	Adopting good practices Seeking competitive advantage	Avoiding bad practices
Normative pressures	Protect reputation On the job socialisation Pride in the job	On the job socialisation
Economic pressures	Cost of potential accidents	Cost of implementing OSH management systems Under-pricing of jobs

It was also apparent that not all principal contractors have the same OSH standards and some micro businesses explained how they would avoid working with those that had lower standards, and actively choose to work with *"good"* larger companies within networks because they felt safer doing so. For example, one construction sole trader described how sometimes, when subcontracting for another company, he might not be provided with the proper scaffolding or platforms to work on. Another interviewee told us that working with bad contractors was like *"stepping back in time"* as you do not learn anything and you know you are going to get hurt - "*working with a good contractor can bring up your overall standard of safety"*. There were also instances of smaller subcontractors (usually highly-skilled specialists) influencing the practices of main contractors, for instance by refusing to operate on sites that were deemed unsafe, unless their OSH requirements were met.

Interviewees also made reference to **normative** influences on OSH practices in smaller businesses. It is clear that OSH practices are shaped by individuals carrying knowledge with them from previous jobs and projects. In some cases, on the job socialisation was seen to have a negative influence of OSH, with longer-serving members of the workforce continuing to use practices that are no longer considered to be safe because such practices were still deemed to be legitimate by their contemporaries. However, there was a perception that the same processes of on the job socialisation were also having a positive influence on newer members of the workforce

> *"Certainly helping has been the changes in college courses and education of people coming into the industry at the bottom level. That's been a big – 'cause there is an expectation now, with an awful lot people coming – well with the majority of people coming into the industry, that there is a way of doing things and that can influence how a company works quite a lot."*

This finding suggests that there might be a progressive improvement in OSH practices over time, as longer-serving workers leave the workforce and new members enter it.

Normative pressures also acted upon larger contractors, in the form of reputational risk, who in turn then placed requirements on their subcontractors, as discussed earlier in this section. A representative from one larger contractor explained how

> *"… you are only as good as your supply chain is. It's all very well making sure that your staff know what they're doing, especially in construction you work with an awful lot of subcontractors on site as well and if they're not singing from the same hymn sheet that you are then obviously they're - to a certain extent they're still representing your company. Because obviously we work for the main contractors, we may employ different subcontractors on site. But if the subcontractors do something wrong then it obviously still comes back to it's our responsibility because we're the people that employ them… "So I think it was just deemed that how important it is nowadays that everybody does need to be doing things in the correct way and we try to put it across very firmly that we expect the companies that work for us to have the same important - place the same importance on health and safety as we do."*

Larger contractors are more visible and there is an expectation in the industry that they act responsibly and lead by example, however many smaller contractors were also keen to be seen to working in a healthy and safe manner. In some cases, attitudes to OSH were intrinsically linked with people taking pride in their work and their desire to operate professionally and responsibly – not just a legal duty of care, but a moral responsibility to do the right thing.

Mimetic pressures were less evident in our interview data, but nonetheless seemed have an influence on OSH practices in some of the organisations in our study. For instance, one sole trader explained how he picked up OSH knowledge when working as a subcontractor on larger building sites, knowledge that he then used when working on smaller domestic projects. He described how he had learnt (informally) through word of mouth not to use leaded solder, information that he then verified by consulting the (formal) water bylaws. Larger contactors also described how they would adopt the good OSH practices of their peers, which they may experience when working on a project with them, and saw this as a means of maintaining their competitive advantage

> *"Yeah, I think initially you think it's not broke then don't try and fix it, don't you? And then you see another way and you're well, actually yeah, our way was broken and there is a way of fixing it."*

Principal contractors with higher OSH standards also actively encouraged feedback and suggestions from subcontractors. There were also examples of where experiences of bad practice had influenced the behaviour of smaller enterprises. For instance, owner of a micro enterprise explained that one of the reasons he had set up his own business was because he had experienced bad practices and corners being cut when working for other construction companies.

Our analysis has thus far focused on discussing the coercive, mimetic and normative influences on OSH in smaller organisations. However, economics also played a significant role in shaping OSH practices, both positively and negatively. For smaller organisations, keeping on top of the OSH requirements of larger clients and contractors can be expensive, especially in a competitive market where it is difficult to pass costs on to clients. One owner-manager of a micro enterprise suggested that some contractors price jobs too low and then subsequently cut corners in order to reduce the amount of time required to undertake the job. Another interviewee explained that

> *"Cost is still a big influence there, so an awful lot of the people on site, and probably the majority of people on site, are working piece rate. You know, they are paid by the amount of wall they lay, they're paid by the amount of hole dig, by the roof that they, you know, that they install, the plumbing that they install. So it's always about speed, it's always about how quickly can I get the cabling into this house, how quickly can I lay this wall. And anything that provides a delay to that is viewed negatively. You will get a huge negative reaction on a lot of sites to wanting to do a toolbox talk. It might only be 15 minutes long, but that 15 minutes is worth cash in hand to the people on that site. You know, it has a very clear monetary value to them, that 15 minutes, and therefore they look at it and think well toolbox talk or another £25 or whatever it might be."*

Although the cost of potential accidents was cited by some interviewees as a driver behind safer working practices, these tended to be representatives from larger contractors with responsibility for managing sites and subcontractors.

5. Conclusions

Our aim in this paper was to use institutional theory to develop a better understanding of the factors that promote the survival and legitimacy of particular OSH practices amongst SMEs and micro enterprises in the UK construction sector. Although based on a relatively small purposively selected data set, our analysis suggests that the practices of smaller construction enterprises are influenced by a range of coercive, mimetic and normative pressures, however two factors were seen to be particularly influential.

The first was the coercive pressures exerted by principal or main contractors in larger supply chains, who seek to positively influence the behaviour of smaller firms by strictly enforcing rules on construction sites, providing training to subcontractors and assessing them to ensure that they have the required skills and qualifications. Smaller enterprises that want to continue working as part of these larger supply chains are obliged to the comply with the rules – this approach could be interpreted as an example of what DiMaggio and Powell (1983) called 'filtering'. However, smaller enterprises choosing not to work with larger organisations is clearly a significant barrier to these coercive pressures and evidence from our interviews suggests that some subcontractors behave differently when working outside of a supply chain, an issue that warrants further research.

The second major influence was the process of on the job socialisation described by DiMaggio and Powell (1983), which seen to have both a positive and negative impact on OSH practices. For some longer-serving workers, on the job socialisation with colleagues can serve to sanction unsafe practices – they become the norm and are therefore seen as legitimate. However, on the job socialisation was also found to have a positive influence for newer entrants to the industry, particularly those that receive formal training and work on sites with higher standards of OSH. For such workers, working healthy and safely becomes the norm. This implies the existence of feedback loops that reinforce and ensure the survival of positive or negative OSH practices.

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Potential Strategies to Improving Safety in Small Construction Organisations

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Abstract

Efforts to improving safety in the construction industry have mainly been adopted by large organisations. As a result, these organisations have managed to substantially improve their safety performance. The construction industry, however, is dominated by small organisations. These organisations are facing difficulties to implement safety and, as a result, their safety performance is worse than their larger counterparts. Due to their large proportion in the construction industry, a small improvement among small organisations should have considerable impacts on the overall safety performance of the industry. This research aims to identify potential strategies to improve safety in small organisations in the context of the Australian construction industry. A questionnaire was developed based on a list of barriers and strategies identified from the existing literature. The questionnaire was then distributed to construction practitioners in Australia, particularly those working in small construction organisations, to obtain the perceived importance of each barrier and strategy. Open-ended questions were also included allowing the respondents to add additional barriers and strategies. Many perceived that external environmental factors are the key barriers that hinder safety implementation in small organisations. Improving safety, therefore, requires the support from influential stakeholders in the industry. Clients should consider safety as one of the key project objectives and include safety as one of the criteria in tendering. The government and regulatory bodies need to enforce safety regulations effectively and subsidise safety training for qualified small organisations. Safety performance should also be linked to insurance premium and licencing system in the construction industry. Finally, existing mandatory safety training needs to be evaluated and revised, while safety compliance for small organisations should be simplified and made practical.

Keywords: construction industry, improvement strategies, safety compliance, safety training, small organisations

1. Introduction

The majority of organisations in the construction industry are small businesses. For example, more than 98% of construction organisations in Australia can be considered as small businesses, employing fewer than 20 people (Australian Bureau of Statistics, 2013). These organisations are viewed as engines of job creation and economic growth (Hasle and Limborg, 2006; Sinclair and Cunningham, 2014). Arewa and Farrell (2012) found that small organisations constitute more than 90% of all businesses and account for 83.7% of employment and 67.4% of turnover generation in the construction industry.

Despite their significant economic and social contributions, small construction organisations have poorer safety performance than their larger counterparts (Hammersley and Sunindijo, 2015; Sinclair and Cunningham, 2014; Stiles et al., 2012). As a result, political and scientific interests in safety in small organisations have grown considerably since mid-90s. Many countries have launched programs and guidelines to support safety implementation in small organisations (Hasle and Limborg, 2006).

Despite efforts to improve safety in small organisations, research on this area is still relatively limited (Legg et al., 2015) and scattered among different disciplines and institutions (Hasle and Limborg, 2006). The research presented on this paper, therefore, is an initial step to systematically observe safety conditions among small organisations in the Australian construction industry. In particular, this research aims to identify key barriers that constrain these organisations from improving their safety performance and to identify strategies or interventions that can overcome the barriers and bring about improvements.

2. Literature Review

A number of search engines, including Google Scholar, American Society of Civil Engineers, Science Direct, Emerald Insight, and Taylor & Francis, were used to find relevant research publications on safety in small organisations published from 1991 to 2014. The search found 125 research papers and three books, which represent a wide range of industries, including agriculture, chemical, construction, manufacturing, mining, and transportation. Many of the publications also discuss small organisations in general instead of focusing on a specific industry.

It is interesting to see that the number of publications increases over the years, indicating that this topic is gaining popularity. There were 16 publications on safety in small organisations published from 1991 to 2000. The number increases to 53 in 2001-10 and increases further to 59 in 2011-14. More than 40% of the publications came from Europe, followed by Asia (20%), Australasia (16%), North America (12.5%), and Africa (8%).

Each publication identifies and, into a certain extent, discusses the barriers and challenges to implementing safety in small organisations. Economic consideration due to pressures to reducing price is a barrier put forward frequently. The fierce nature of competition in the construction industry makes economic survival through getting new works from clients the number one priority for many small organisations (Mayhew et al., 1997). As a result, the clients have high bargaining power and are able to use competitive tendering to compel small organisations to getting the job done with the lowest possible cost. Facing this industrial culture, small organisations are forced to opt for the only logical choice, making the clients happy no matter what, including neglecting safety to reduce costs (Torres et al., 2013; Wadick, 2010).

Many suggest that this barrier is the underlying factor that promotes the occurrence of other barriers. Due to economic pressures, owners of small organisations consider safety regulations and demands to improving safety as a heavy and unrealistic financial burden (Legg et al., 2015). Although large organisations spend more on safety than small organisations, but when the spending is calculated per employee, small organisations spend seven times more than large organisations (Health and Safety Executive, 2003). Therefore, the costs of compliance with certain aspects of safety regulations are considered too high in comparison to the perceived benefits and considered detrimental to the survival of their businesses (Walters and Lamm, 2013).

This negative perception towards safety results in poor safety culture. Owners and managers of small organisations do not consider safety as a priority because they are being inundated by other 'urgent' issues imposed by their clients. They do the minimum in terms of safety and even cut corners in order to reduce costs (Cagno et al., 2013). This condition is made worse by the lack of safety training because it is seen as expensive and unnecessary. Compulsory safety training is considered as inadequate or ineffective to gain the required safety knowledge and to develop positive safety attitudes (Hasle et al., 2010; Wadick, 2010). Business owners perceive that safety issues are bureaucratic concerns and are not their responsibility, but the personal responsibility of their employees (Kelloway and Cooper, 2011). This matter of responsibility becomes even more obscured due to subcontracting practices endemic among small organisations. Within these employment relationships, the responsibility for establishing and maintaining work health and safety becomes unclear (Mayhew et al., 1997). This work environment promotes a strong culture of autonomy and meeting the demands of contracts supersedes safety issue considerations (Kelloway and Cooper, 2011).

Essentially, small organisations have no knowledge, no time, and no resources to focus on safety. The absence of a professionalised human resource function limits the safety knowledge in small organisations. In most cases, the business owner is the human resource department and every other department of the organisation, thus it is unlikely for the owner to have specialised knowledge in work health and safety. The various roles that business owners have to perform and their small workforce mean that they have no time to participate and focus on educational, training, and workshop activities that require substantial commitments. The lack of resources prevents small organisations to hire consultants to solve problems and they will never have the resources (and time) to solve safety issues through experimentation and pilot studies (Kelloway and Cooper, 2011).

Besides discussing the barriers, intervention strategies have also been proposed in the existing publications. As economic reason is the underlying barrier, clients, who make key decisions on budget and other project performance criteria, are influential in supporting or constraining safety implementation (Lingard and Blismas, 2013). It is important for clients to allow for costs to implementing safety measures when selecting contractors, i.e., safety should be one of the criteria in the procurement process.

The government also plays important roles in improving safety performance of small organisations. The government should find a way to effectively monitor and enforce safety regulations. Without proper enforcement, small organisations that try to implement safety will be disadvantaged over those that cut corners (Mayhew and Quinlan, 1997). Linking safety performance with insurance premium, taxes, and licencing systems in the industry are potential incentive programs that can be used to encourage small organisations to focusing on safety (Hasle and Limborg, 2006). At the same time, the government should be aware of the fact that small organisations do not seem to have the ability or motivation to implement high levels of safety systems. Safety performance improvement, therefore, cannot be achieved by simply raising government safety regulations (Lin and Mills, 2001).

The existing safety training courses should also be evaluated. The costs of safety training and compliance are a barrier for small organisations because of their limited financial capacity and pressures to reduce costs. Free or subsidised safety training should be made available to small organisations. Furthermore, the effectiveness of existing safety training program, e.g., White Card, should be assessed. Although there is evidence to suggest that mandatory safety training programs have positive effect on safety culture in the construction industry, more robust training and refresher courses may be needed to further improve safety (Bahn and Barratt-Pugh, 2012).

3. Research Methodology

Quantitative research methodology was adopted for this research. Quantitative research emphasises quantification in the collection and analysis of data and entails a deductive approach to the relationship between theory and research, i.e., testing theories in the research context (Bryman, 2012). Aligning itself with quantitative research methodology, this research aims to test the relevance of the barriers and intervention strategies suggested in the existing literature in the context of small organisations in the Australian construction industry.

A questionnaire survey was the research method used in this research. The questionnaire consists of three sections. The first section enquiries the profile of the respondents. The second section consists of 13 barriers to safety improvement among small organisations, while the third section consists of 13 items representing strategies to improve safety performance among small organisations. The second and third sections use a five-point Likert scale format ranging from ‘strongly disagree’ to ‘strongly agree’. Some open-ended questions were also included so that the respondents can recommend additional barriers and strategies, which have not been covered in the questionnaire.

The questionnaire was distributed online and through mails to 838 construction organisations in New South Wales (NSW). Convenience sampling was used because of the large number of construction organisations in NSW. One hundred and eleven responses were received, representing a response rate of 13%. Sixty per cent of the respondents were business owners or self-employed and nearly 70% worked in small organisations employing fewer than 20 people. The respondents' average work experience in the construction industry was 24 years.

4. Barriers to Implementing Safety

Table 1 presents the barriers to implementing safety in small organisations, which have been ranked from the highest to the lowest. A one-sample t-test was also conducted to determine which barriers were deemed relevant and which ones were not. The test value was 3, meaning neutral. When the significance value is lower than 0.05, it means the mean score is significantly different from 3. As shown in Table 1, the top four barriers were perceived as important by the respondents, while the lowest two barriers should not be considered as barriers.

Table 1: Barriers to implementing safety in small organisations

No	*Barrier*	*Mean*	*Significance*
1	*Subcontracting practice especially the use of best price to win projects*	*3.74*	*.000*
2	*Clients focus on other objectives, e.g., time and cost, rather than safety*	*3.60*	*.000*
3	*Safety is expensive to be implemented*	*3.50*	*.000*
4	*Fierce competition in the industry*	*3.46*	*.000*
5	*Poor safety culture in the industry, especially among small companies*	*3.16*	*.145*
6	*Safety law and regulations are not adequately enforced; thus disadvantaging those trying to implement them*	*3.08*	*.489*
7	*Safety law and regulations are impractical for small companies*	*3.00*	*1.000*
8	*Lack of management commitment*	*2.91*	*.390*
9	*Owners and employees of small companies have other urgent and more relevant issues than safety*	*2.87*	*.261*
10	*Lack of safety knowledge to implement proper safety measures as required*	*2.84*	*.083*
11	*Small companies are not able to translate and adapt safety laws and regulations into their safety management system*	*2.79*	*.070*
12	*Mandatory safety training is inadequate to give basic safety knowledge for construction practitioners*	*2.77*	*.024*
13	*Mandatory safety training is impractical*	*2.44*	*.000*

Path analysis was conducted using AMOS (Analysis of Moment Structures) to determine the interrelationship among the four important barriers and the result is presented in Figure 1. The probability value of the chi-square test is higher than 0.05 ($p = 0.397$) indicating that the model fits the data. Other fit indices are less than 0.001 for the root mean square error of approximation (RMSEA), 1.000 for the comparative fit index (CFI), and 1.004 for the non-normed fit index (NNFI). All indices indicate good fit (Hooper et al., 2008). The numbers on the arrows are the path coefficients, which represent the amount of change in the dependent variables per single unit change in the predictor variables (University of Texas, 2002). All path coefficients are statistically significant providing strong support for the hypothesised model.

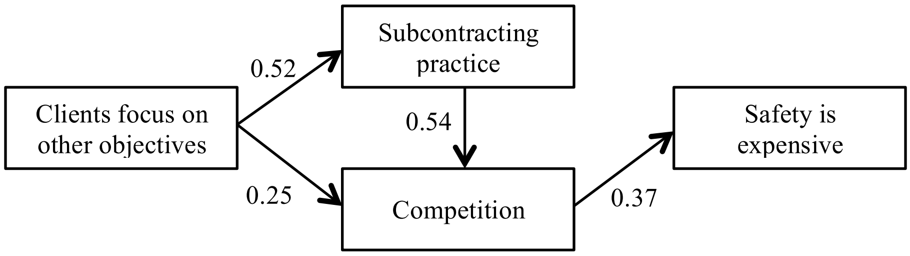

Figure 1: Interrelationship among barriers to implementing safety in small organisations

Figure 1 shows that the source of all the barriers is that clients focus on other objectives rather than safety. Clients of small organisations tend to focus on getting the job done as quickly and as cheap as possible. This characteristic affects the subcontracting practice in the industry, in which the lowest price becomes the main criterion to win projects. The demand for cheap construction services and the practice of bidding for jobs force smaller subcontractors to cut corners whenever they can (Torres et al., 2013).

This client-dominated industry together with the large number of small organisations worsen the competition in the industry, compelling small organisations to reduce their operational costs by any means necessary, including neglecting safety, to remain competitive. It is, therefore, not surprising to discover that safety was perceived as too expensive to be implemented by small organisations. Although they understand that poor safety has negative impacts on the financial performance of their organisations, they perceive that the costs of implementing safety are simply too high and are detrimental to their business survival (Walters and Lamm, 2013).

The responses to the open-ended question on key safety issues faced by small organisations reveal that many respondents felt that safety is expensive and impractical. Small organisations with their limited resources are subjected to the same safety obligations as their larger counterparts. They consider that the amount of paperwork is impractical because it leads to paper compliance, which does not translate into safer workplaces. At the same time, they are pressured by their clients to reduce costs and to complete the job quickly. All this causes small organisations to have negative perceptions towards safety. Safety is considered as a waste of time, which jeopardises their ability to compete.

5. Strategies to Improving Safety

Table 2 presents the potential strategies to improving safety performance among small organisations. As in the previous section, a one-sample t-test was conducted to determine strategies deemed important by the respondents. There are eight strategies that have potential to improve safety among small organisations, while the two bottom strategies should be excluded from the list.

Table 2: Potential strategies to improving safety in small organisations

No	*Barrier*	*Mean*	*Significance*
1	*Clients should consider safety as one of the project success factors*	*4.15*	*.000*
2	*Safety should be one of the criteria in tendering*	*4.03*	*.000*
3	*Government should subsidise safety training for small companies that meet requirements*	*4.02*	*.000*
4	*Safety performance and compliance should be linked to insurance premium*	*3.67*	*.000*
5	*Safety performance and compliance should be linked to the licencing system of construction companies*	*3.59*	*.000*
6	*Government should enforce safety law and regulations effectively*	*3.57*	*.000*
7	*Mandatory safety training should be more thorough and harder to pass*	*3.24*	*.023*
8	*Small companies should form a "safety responsible group" to share safety resources and to ensure that the each group member meets safety requirements*	*3.22*	*.026*
9	*Safety law and regulations should be less prescriptive to allow small companies to self-regulate safety*	*3.05*	*.612*
10	*Government should explicitly tell small companies what to do to implement safety*	*3.04*	*.735*
11	*Obtaining and renewing builder's and construction-related licences should be made tougher*	*2.98*	*.891*
12	*Harsher punishments or consequences to small companies that violate safety regulations*	*2.75*	*.023*
13	*Worker unions should pressure small companies to focus on safety*	*1.81*	*.000*

The top seven strategies require the support from the clients and the government or regulatory bodies in their implementation. This is understandable because the top barriers are external barriers in which small organisations have limited to no control over them. Therefore, strategies to remove the barriers should not only focus on activities that can and should be done by small organisations, but also on influential stakeholders who can change the norms and culture of the industry.

The first group of the influential stakeholders is the clients, which include typical home owners, government agencies, and also larger contractors. They are in the best position to drive the cultural change needed to bring about safety improvements as they are the initiators of project development. They make key decisions concerning budget, project objectives, timelines, and performance criteria, which can support or constrain safety implementation (Lingard and

Blismas, 2013). Votano and Sunindijo (2014) identify six safety activities that clients of small construction organisations can do to promote safety: (1) participate in site-based safety program; (2) review and analyse safety data; (3) appoint safety team; (4) select safe contractors; (5) specify how safety is to be addressed in tenders; and (6) perform regular checks on plant/equipment.

Looking at the responses to the open-ended question on what clients should do to promote safety among small organisations reveals one overwhelming response, i.e., clients should not use the lowest-price method when evaluating tenders. On a similar note, the respondents suggested that safety should become one of the criteria in tendering. During the construction stage, clients should also be realistic in setting project goals, particularly in terms of time and cost. Pressures to finish a project cheaply and quickly will encourage people to cut corners and neglect safety.

The second influential stakeholder group is the government and regulatory bodies. There must be stronger enforcement of safety implementation in practice. Without proper enforcement, there is no incentive for small organisations to focus on safety because safety is detrimental to their business survival. As shown in the questionnaire, the respondents also believed that linking the licencing system and insurance premium with safety performance is a feasible way to monitor safety implementation. The premium costs, however, should be comparable to the improvement costs to motivate small organisations to improve their safety performance. Furthermore, implementing this initiative requires effective enforcement and monitoring. Without it, these systems tend to lead to under- or non-reporting where injured workers are kept at work or discouraged to report their injuries (Probst and Estrada, 2010).

Training is another factor that falls under the responsibility of the government. The costs of safety training and compliance are a major barrier for small organisations. Therefore, the government should subsidise safety training for small organisations that qualify to get this benefit. The existing mandatory safety training is also seen to be too easy and inadequate to equip people who intend to enter the industry. The open-ended question on what the government should do to promote safety performance improvement among small organisations shows that some respondents consider this training as “a waste of time” and “a joke”. This shows that effectiveness of this training program should be evaluated, something which has often been neglected.

Besides suggesting for a more rigorous training and education system, the responses to the open-ended questions again sound a stronger call to simplify safety compliance. Safety regulations should be made more practical, particularly for small organisations that have limited resources and are currently facing external pressures, which force them to relegate safety as unimportant.

One thing that small organisations themselves can do is to collaborate and form a “safety responsible group” where the members can share resources related to safety. The group also serves as a control mechanism to ensure that each member meets safety requirements. By sharing their resources, the disadvantage faced by small organisations in terms of the economy of scale can be lessened.

An argument worth noting is that this research and past research indicate that small organisations tend to place the blame of their poor safety performance on other players and external factors. Although these factors are influential, there may be other initiatives that small organisations can do to improve their performance. Future research can investigate feasible methods and strategies that small organisations themselves can do to improve their safety. Perspectives from the government agencies and larger organisations can be useful to uncover more barriers and success factors improve safety among small organisations.

6. Conclusions

Improving safety among small organisations is essential to improve safety in the construction industry. Applying the same approach used in medium and large organisations is not practical for small organisations due to their unique barriers and constraints. This research found that the source of the barriers is the lack of interest from the clients towards safety. The use of lowest price method to award contracts worsens the situation because this approach compels small organisations to lower their prices by any means necessary, including neglecting safety. Due to this fierce competition, small organisations perceive safety as a burden, which is detrimental to the survival of their business.

External factors, in which small organisations have limited or no control over, are the main sources of these barriers. Therefore, strategies intending to address them require the involvement of leading stakeholders who are able to influence the norms and practices in the industry. Clients should see the value of safety and should actively participate in implementing safety. They also need to stay away from lowest-price mentalism when awarding contracts and include safety as one of the criteria in tendering. The government and regulatory bodies should find better ways to enforce safety regulations. Linking the licencing system and insurance premium with safety performance has a potential to promote safety into the foreground. Existing mandatory safety training programs should also be evaluated and amended. They are perceived as outdated and insufficient to equip construction practitioners with essential safety knowledge.

The respondents also strongly asserted the need to simplify safety compliance. Currently small organisations are expected to follow the same level of compliance as their larger counterparts. This approach was perceived as impractical because of the environment and industry norms where small organisations operate. The tendency to cut corners is the result of small organisations trying to work around impractical safety regulations imposed on them.

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Challenges for the FIFO/DIDO Workforce in the Australian Construction Industry: Impacts on Health, Safety and Relationships

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Abstract

Since 2000, Australia has seen a large growth in the mineral, resource and infrastructure sectors, with operations expanding to rural and remote locations, leading to an increase in demand for personnel to work fly-in, fly-out (FIFO) or drive-in, drive out (DIDO) rosters. Such models of work have become increasingly popular as it takes into account the relatively short lifespan of sites, and is considered more economical than building permanent accommodation or paying for rent, helping organisations remain economically competitive. While there are many organisational benefits to employing FIFO/DIDO rosters, there are frequently cited adverse effects on the workers themselves. The issues in employing these workforces are becoming more apparent, and include a range of physical, mental, psychosocial, safety and community challenges. The aims of this study were to: 1. Understand more clearly how employee family relationships are affected by the FIFO/DIDO working environment and investigating solutions. 2. Investigate the psychosocial health implications for employees in a FIFO/DIDO working environment and seeking recommendations for change. 3. Assess the impact of FIFO/DIDO travel on workplace health and safety incidents, and 4. Examine rosters, shifts, work hours, job design and productivity demands as to how best to design a safe, healthy and productive work environment for FIFO/DIDO employees. In conjunction with Australian government and industry partners, the projects agreed methodology consisted of four major phases. First, a desktop review was undertaken of the key documents including research literature and reports. Second, the information was used to help formulate a brief survey designed to examine psychosocial and organisational safety climate, rosters and shifts and integration of the frequently-used Copenhagen Psychosocial Questionnaire. Third, the review of literature also assisted in the development of semi-structured interview questions for the focus groups. The final phase was the analysis of the data and formulation of key recommendations. This paper addresses the research concerns and provides data and respondent commentary to more fully understand the impacts on workplace health and safety and the personal and social relationships of this workforce, and to explore strategies and actions that better meet the needs of employers, employees and their families.

Keywords: Construction health and safety; physical and mental health; social supports; work site communications; relationship maintenance.

1. Introduction

Since 2000, Australia has seen a large growth in the mineral, resource and infrastructure sectors, with operations expanding to rural and remote locations, leading to an increase in demand for personnel to work fly-in, fly-out (FIFO) or drive-in, drive out (DIDO) rosters. Such models of work have become increasingly popular as it takes into account the relatively short lifespan of sites, and is considered more economical than building permanent accommodation or paying for rent (Lifeline WA, 2013), helping organisations remain economically competitive.

While there are many organisational benefits to employing FIFO/DIDO rosters, there are oft cited adverse effects on the workers themselves. The issues in employing these workforces are becoming more apparent, and include a range of physical, mental, psychosocial, safety and community challenges. Research evaluating the impacts of fly-in, fly-out operations in Australia has been limited, and in February 2013 the Australian House of Representatives Standing Committee on Regional Australia made 21 recommendations aimed at improving these operations (Parliament of Australia, 2013). These are discussed in the desk top analysis. To date, none of the recommendations have been implemented.

Recent research into FIFO employees revealed that between 24 and 36 percent of personnel experience severe levels of psychological distress in the forms of anxiety, depression and stress symptomology (Tuck, Temple, & Sipek, 2013). Further, it was also found that 71.5% of these FIFO participants had planned to exit FIFO employment within five years. Based on the limited literature, potential impacts include loneliness, depression, satisfaction levels with onsite facilities and home contact, fatigue leading to safety concerns and strain on marital relationships. Construction workers, according to Doran, Ling and Milner (2015), are six times more likely to die from suicide then from an accident at work.

The concerns associated with FIFO/DIDO operations cover a range of variables, some of which are also prevalent in other industries (for example, manufacturing and nursing) and can broadly be described as having workforce and social and community impacts. The workforce areas of concern include roster schedules, shift work and work hours, sleep disruption, fatigue, safety performance, wellbeing both physical and mental, and workforce turnover. The social and community areas of concern include psychosocial wellbeing in personal and family relationships, and social and resource impacts on home and host communities. There is an early understanding emerging of the symbiosis of the workforce and social and community concerns but, as yet, very little evidence of how to translate the best aspects of this relationship into next practice.

The construction and infrastructure FIFO/DIDO workforce is facing challenges on several fronts with impacts on the individual worker (e.g. work productivity, safety, psychosocial resilience), the families of the workers (e.g. personal relationship challenges, remote parenting, health and wellbeing concerns) and companies themselves (e.g. difficulties attracting the right employees, increasingly unacceptable turnover rates).

Operations in regional communities utilising a FIFO/DIDO workforce are exposed to a myriad of concerns which are not only limited to their economic prosperity and survival, but also include the welfare of their contractors, employees, their families, and the home and host communities in which they operate. At the workplace these challenges include an understanding of the management of optimal roster designs for performance and employee satisfaction, the at-risk days and times to best manage tasks, hours of work including start and finish times to minimise sleep debt and fatigue, and the need for data on fatigue related work incidents and road accidents. There are challenges in relation to health and wellbeing for FIFO employees in ensuring the FIFO lifestyle is properly communicated and understood before engaging in FIFO work. No research to date has examined the linkages and relationships between workplace and personal relationships challenges in a FIFO/DIDO environment in the construction industry. In this regard, this research seeks to be aptly innovative.

2. Key Objectives

The objectives of the current study were to:

1. Understand more clearly how employee family relationships are affected by the FIFO/DIDO working environment and investigate solutions
2. Investigate the psychosocial health implications for employees in a FIFO/DIDO working environment and seek recommendations for change
3. Assess the impact of FIFO/DIDO travel on workplace health and safety incidents
4. Examine rosters, shifts, work hours, job design and productivity demands as to how best design a safe, healthy and productive work environment for FIFO/DIDO employees

This project sought to address in part some of these concerns and in particular to understand more fully the mutual impacts on workplace health and safety and personal and social relationships, and to explore strategies and actions that better meet the needs of employers, employees and their families.

3. Research Methodology

The project's methodology consisted of four major phases. First, a desktop review was undertaken of the key documents including research literature and reports. Second, the information was used to help formulate a brief survey designed to examine psychosocial and organisational safety climate, rosters and shifts and integration of the frequently used Copenhagen Psychosocial Questionnaire. Third, the review of literature also assisted in the development of semi-structured interview questions for the focus groups. The final phase was the analysis of the data and formulation of key recommendations.

4. Key Results

4.1 Desktop Review- Some of the key reports and research

Research evaluating the impacts of fly-in, fly-out operations in Australia's construction industry has not been conducted to date. In February 2013 the Australian House of Representatives Standing Committee on Regional Australia made 21 recommendations aimed at improving these operations. It points out that the remote construction industry workforce is primarily a short-term temporary workforce and many workers are employed on a fly-in, fly-out basis. This is supported by evidence from Mineral Council of Australia. Of these 21 recommendations, two (8 and 10) were particularly related to this research. Firstly, that the Commonwealth Government commission research to assess the health impact of fly-in, fly-out and drive in-drive out work on the workers and their lifestyles. And from this develop a comprehensive policy to respond to their particular needs. Secondly, that the Commonwealth Government commission research to assess the impact on children and family relationships of a long-term fly-in, fly-out/drive-in, drive-out parent.

Also, a discussion paper released by the WA Government's Education and Health Standing Committee into the mental health impacts of fly-in, fly out work in 2014 highlighted the lack of quality research on the mental health of FIFO workers. They felt research was needed into whether FIFO work practices were safe and how organisations managed psychological health risks. They noted that informal information indicated that there were 9 suspected suicides and that it was the organisation's responsibility to address issues related to mental health concerns. For example, the unaccompanied travel of at risk employees to their home base.

A research report in 2013 by Lifeline WA investigated the stressors and coping mechanisms of FIFO/DIDO workers. They found that 1 in 5 workers did not have on-site mental health or on-site counselling facilities in their industry and 1 in 10 did not have an Employment Assistance Program (EAP). It was also found that stress increased during rotation and was particularly high just before leaving work. The key stress of FIFO/DIDO work was family/home separation. Long rosters impacted significantly on this stress and increased when families with young children were involved. In addition, adjusting to long day/shifts disrupted sleep and led to fatigue. As a majority of the workforce are male there was the perception of 'suck it up princess, you just do it' approach to their FIFO role and coping. However, communication with family and friends was highly regarded as a coping tool. While there were clearly some negative effects, it was noted that there was also some benefits. According to FIFO/DIDO workers, the high financial return and the ability to have quality time with family at home was an advantage.

4.2 Survey Results

The survey data was collected across John Holland, RMS NSW and QTMR sites in Western Australia, New South Wales and Queensland. It covered a number of key areas and included the Copenhagen Psychosocial Questionnaire. These key areas included: Management's commitment to safety, Training and Procedures, Organisational Priorities, Rosters and Shifts, Psycho-social Factors, Health, Job Satisfaction and Work-Family Conflict. A total of 306 participants completed the survey. The table below highlights the key demographic information of participants who completed the survey. Typical of the workforce, a majority of respondents were male (94.8%), aged between 25 and 44 years, with an average age of 39 years. Approximately 61.2% of respondents said they were in a long-term relationship. The main survey results are presented below in Table 1.

Table 1: A summary of key results from the quantitative survey

Top 5 Highest Rated Questions

Management regard safety as an important part of operations	86.9% agree or strongly agree
Is you work meaningful	85.4% thought their work was meaningful
Do you know exactly what is expected of you at work?	66.3% agreed to a large extent or greater
Do you feel that the work you do is important?	65.7% agreed to a large extent or greater
Employees are able to openly discuss problems with supervisors or managers	61.2% agree or strongly agree

Bottom 5 Rated Questions

My work shifts interfere with my family or social life	66.7% agree
Can you trust the information coming from management	70.5% disagree
At your place of work, are you informed well in advance concerning, for example, important decisions, changes or plans for the future?	77.7% disagree
Do you feel that your work takes so much of your time that it has a negative effect on your private life?	83% or respondents say yes
Do you feel that your work drains so much of your energy that it has a negative effect on your private life?	85.8% of respondents say yes

4.2.1 *Copenhagen Psychosocial Questionnaire (COPSOQ)*

The shortened version of the COPSOQ is a tool for workplace assessment of psychosocial work environment. Lower scores (min 1 – max 5) identify areas where improvements can be made to the work environment. The results from the COPOQ are presented in Table 2.

Table 2: The results from the COPSOQ

Sub-Scale	Average
Quantitative Demands	4.01
Emotional Demands	2.66
Influence at Work	2.85

Social Support from Supervisors	3.34
Burnout	2.94
Stress	2.86
Tempo, Work Pace	3.24
Possibilities for Development	3.36
Meaning of Work	3.63
Commitment to the Workplace	3.45
Predictability	2.90
Rewards (Recognition)	3.19
Role Clarity	3.69
Quality of Leadership	3.41
Vertical Trust (Between Management and Employees)	3.34
Justice and Respect	3.12
Self-Rated Health	3.42
Job Satisfaction	2.97
Work-Family Conflict	2.69

4.3 Focus Group Results

The focus group data was collected using a semi-structured format. It addressed a number of key questions with prompts. These were:

- How do you feel employee family relationships are affected by the FIFO/DIDO working environment? In terms of partner relationships, relationships with children and parenting.

- (If negative) What are the solutions to this? In terms of communication while on-site, flexible workplace policies, professional support services for both the FIFO worker and their family, supportive groups for families at home and roster cycle.

- What do you feel are the psychosocial health implications (such as isolation, loneliness) for employees FIFO/DIDO working environment? Positive or Negative? In terms of work-life balance, management support, work pressure and family pressure, job satisfaction, personal and physical health, roster and work demands, sleep. The negative psycho-social health implications could be: family problems, mental health issues, divorce/separation, being overweight, tiredness, sickness or boredom. The positive psycho-social health implications could be: freedom from family pressure, financially secure.

- What do you recommend are the best ways to alleviate these implications? Including career development, professional support services (e.g. counsellors), links to family back home, broad band services, fitness equipment, private rooms, healthy food options, better rosters, links to host community and better work hours.

- What is the impact of FIFO/DIDO travel on workplace health and safety? In terms of fatigue, job performance and non-work time.

- What do you feel is the best design (in terms of rosters, shifts, work hours, job design and productivity demands) to ensure a safe, healthy and productive work environment for FIFO/DIDO workers? (In terms of rosters being symmetrical/asymmetrical, short/long; on either night/day shifts)

The focus group data was digitally recorded and transcribed. It was analysed using thematic analysis accompanied by relevant quotes. 15 focus groups of 5-6 participants were completed with employees across the mentioned partner organisations sites in Western Australia, New South Wales and Queensland. Results from the focus groups highlighted differences between temporary and permanent sites, as well as between FIFO and DIDO workers. Many of these differences can be considered due to the availability of different facilities and opportunities for social interaction. Five consistent themes to have emerged from the data are presented below in Table 3, with actual quotes from participants.

Table 3: A summary of themes from the qualitative focus groups

Theme	Employee Commentary
Isolation (from both family and co-workers)	• I think one of the biggest issues where we are based is communication. We are obviously based on a number of real camps and we know when you go back to real camp to you won't have reception. So you can stand outside on the phone and maybe if you are lucky you might get internet in your room and your landline might work if you're lucky so I guess that's the biggest thing. If you trying to communicate to your kids or anything like that you can really struggle. You might go nights and nights without contact with them because you don't get any reception.
Work related stress	• You know it's really worse, I've been doing my job for more than forty years and I've seen a trend, these days it's getting harder because these days because they are trying to save money and they seem to stretch the roster even further because there use to be a lot of projects with two and one moving to three and one.
Lack of management support	• It's an awesome program (Mates in Construction). It helped me out heaps up here but trying to put it between workforce and senior management stuff is stupid. I'm trying to get bloke in home because they're not well but management want to know what's wrong with them, who it is and it's got to remain anonymous, you know.

5. Discussion

This research found that workers psycho-social isolation in remote sites within the construction industry was a significant issue. Evidence from the quantitative data indicates that while formal communication from supervisors and management was good, workers level of trust in informal support from management was impacting on worker mental health. This isolation factor occurred across a number of levels, between the worker and their peers; between the worker and their direct supervisors and between the worker and their families. A comparison of FIFO and DIDO remote construction workers found that psycho-social isolation for FIFO workers was higher, this research found greater problems of worker mental health.

A common theme from the quantitative and qualitative data across all sites, regardless of whether the workforce was FIFO or DIDO, was a strong need for more training. In particular, this training was identified specifically around issues of financial planning/financial aid and realistic issues the workforce will face in regards to their health and well-being. As many of the current training and education methods were ad hoc, or learnt through experience whilst on the job, or discussions with their colleagues, there was a strong suggestion that the workforce needed more education and training on these key issues whilst employed as a FIFO/DIDO worker. Further, there was a growing need for more re-integration training for workers to return to the 'real world' such as mental health awareness training and family-work adjustment training.

Qualitative data also revealed that rosters were another area requiring change. Many of the FIFO workers for instance were unanimous in their support for having a 10 day off roster. This included having two consecutive weekends, as part of the 10 days. This was to allow for greater opportunity to have downtime and spend with their families away from work. While this was a common suggestion, many of the workers also said if this were possible, they had no qualms working the 3 or 4 weeks, as they understood they were paid to do a job. Of greater importance to them, was having the sense they had the opportunity to have genuine time off away from their work.

Data from qualitative component also indicated that organisations like Mates in Construction were seen as important to worker mental health. A number of workers recognised these supports as important and wished for their work to continue on-site. This recommendation is consistent with outcomes from the WA inquiry.

These researchers proposed four recommendations:

1. The improvement of communication between workers and management.
2. For the organisation to offer training to workers and in some cases their direct supervisors addressing finance, mental health and worker/family relationships.
3. For the organisation to offer rosters based on the worker's specific need.
4. For the organisation to continue support and promote external organisations such as Mates in Construction.

The four key recommendations presented in this paper are based exclusively on data from the focus groups and surveys of FIFO/DIDO workers. Several additional recommendations could be elaborated from the data, but the Authors felt that the main areas of expressed concern from the workers which they deemed as priorities, are those articulated in the four recommendations.

6. Conclusion

The results and subsequent recommendations indicate that mental health issues are an increasing problem for FIFO/DIDO workers in the Construction Industry. From this research we can conclude that for FIFO/DIDO workers in remote construction sites psycho-social isolation is of real concern. Higher levels of social capital (including communication, social networks and psycho-social trust) are required to combat the psycho-social isolation. If psycho-social isolation is not controlled, evidence indicates that this can lead to increased fatigue and stress upon the remote worker and a greater likelihood of human error.

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Health and Safety Management Practices in the Nigerian Construction Industry: A Survey of Construction Firms in South Western Nigeria

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Abstract

Despite the relevance of the construction sector in developing countries, the industry continues to record unacceptable levels of accidents and fatalities. The situation is no different in Nigeria where health and safety (H&S) management has been cited as a major contributor to poor H&S performance. Despite the need for improvement, there remains a dearth of research on the specific H&S management practices and elements of H&S management that need attention. This study thus provides insight into the H&S management practices of contractors in the South West of Nigeria. A questionnaire survey was used to investigate the H&S practices implemented by 115 construction firms. Results from the survey indicate that only a few H&S management practices are commonly implemented by contractors in South Western Nigeria. These practices include: informing employees about hazards on site before work starts; and communicating H&S information to workers through newsletters, leaflets and posters. H&S management practices that are less implemented include: providing H&S supervisors on site; site inductions for workers; rewarding workers for safe work behaviour; assessing the competence of workers and subcontractors; keeping incident records; investigating the causes of incidents, accidents and near misses; providing training programmes for H&S manager(s); and undertaking risk assessment for work packages or operations before they start. Overall, the research shows a gloomy outlook of the implementation of practices in key elements of H&S management (i.e. policy, planning, organising, risk assessment, implementing, performance measurement, and auditing). Contractors, relevant state authorities and industry bodies therefore ought to take collective action to improve H&S management by contractors.

Keywords: health and safety, health and safety management, survey, Nigeria

1. Introduction

Construction continues to be one of the main contributors to occupational related accidents, injuries and ill health. This is attributed to unsuitable working environments, unsafe worker behaviour, exposure to the harsh weather and other factors (Griffith and Howarth, 2001; Haslam et al., 2005; Manu et al., 2014). Particularly, in Sub-Saharan Africa, the occurrence of construction related injuries and fatalities persist in spite of Government sanctioned H&S standards (Idoro, 2008). Poor H&S performance remains at high levels as evidenced by a high number of injuries and work related illnesses. As a result there has been increased acknowledgment of the need for adopting H&S management practices that could help improve the situation. Despite improvements realised through the adoption of these H&S management practices in developed countries, it remains unclear the extent to which such practices are implemented by Nigerian construction firms. This study thus sought to address the research question of, "*what is the extent to which H&S management practices are implemented by contractors in Nigeria*". The study commences with an overview of the status of H&S in Nigeria's construction industry as well as a review of H&S management. This provides the foundation for the empirical phase of the study which is followed by the research findings and concluding remarks.

2. Health and Safety in Nigerian Construction Industry

Nigeria, being the most populous country in Africa and also the largest economy in Africa (World Bank, 2016), its construction industry plays an important role in the nation's economy. In 2012 the sector's contribution to national gross domestic product stood at 3.05% and in that same year the sector employed circa 6.9 million workers (National Bureau of Statistics, 2015). In spite of the socio-economic significance of the construction sector, it has an enviable reputation in terms of occupational health and safety. Accident and injury rates in developing countries like Nigeria are generally considered to be higher than in the developed countries (see Hämäläinen et al., 2009). This has been attributed to a lack of appropriate consideration of H&S management measures or practices in construction project delivery process (Belel and Mahmud, 2012). Despite being a party to the Geneva Occupational Safety and Health Convention 1981, Nigeria continues to lag behind in the implementation occupational H&S practices (Adeogun and Okafor, 2013). According to Idoro (2011) contractors with the best safety records in Nigeria still record substantially high numbers of injuries on their sites. A survey of 42 Nigerian contractors revealed such poor performance with rates such as 5 injuries per worker and 2 accidents per 100 workers even among some of the best performing firms (Idoro, 2011). According to Ezenwa (2001) these figures are often even worse in practice as a result of a culture of under-reporting and concealment. Other studies have further highlighted a high prevalence of non-compliance with safety regulations that require organisations to report accidents (Diugwu et al. 2012).

Whilst there have been occupational health and safety legislations governing work and work environments in Nigeria (e.g. Factories Act of 1990 and Employee's Compensation Act of 2011), some have attributed the poor safety performance to dysfunctional H&S laws and regulations (Diugwu et al. 2012). Compliance to and enforcement of occupational health and safety legislations have generally been described as poor (Idubor and Oisamoje, 2013; Okojie, 2010). Idoro (2004) also linked the country's poor H&S status to lack of concern, lack of accurate records and poor statutory regulations. Furthermore, these studies have generally highlighted the limited scope of H&S management by organisations which could be contributing to the poor H&S performance.

3. Health and Safety Management

Effective H&S management has been identified to have direct impact on H&S performance and resultant reductions in the number of incidents (Lingard and Rowlingson, 2005). According to Fewings (2013), good H&S performance in the construction industries of developed countries can largely be attributed to systematic implementation of H&S management practices stipulated in H&S management systems (Fewings, 2013). Gallagher (1997) further identifies the need for the adoption of the following practices in order to improve H&S performance: high level of senior management commitment; occupational health and safety (OHS) responsibilities known; encouragement of supervisor involvement; active involvement of a H&S representative who has a broad role; effective OHS committees; planned hazard identification, risk assessment and hazard elimination control; and comprehensive approach in inspections. In order to effectively implement H&S management practices there is a need for the adoption of an appropriate H&S management framework/system. One of the most commonly cited frameworks is the UK Health and Safety Executive's (HSE) framework for managing H&S (HSE, 1997). The key elements in this framework are H&S policy, planning, organising, risk assessment, implementation, measuring performance and review (see Table 1). This framework is similar to the BS OHSAS 18001: 2007 (BSI, 2007) and it has recently been revised to follow Deming's plan-do-check-act model (HSE, 2013) as shown by Table 1. Similar elements to the HSE's (1997, 2013) frameworks have also been shown by other H&S management models including the International Labour Organisation guidance (i.e. ILO OSH 2001) (ILO, 2001).

Table 1: Key H&S Management Elements

Management Practice Area/Element	***Management Practice sub-area/element ****	***Description and examples of practices****
Plan	*Policy*	*Written in-house H&S policy statement reflecting management's concern for H&S and detailing principles of actions to achieve H&S objectives e.g. policy document*
	Planning	*Planning for effective resource allocation e.g. pre-project H&S plans.*
Do	*Organising*	*The structural system to manage health and safety e.g. human resources, financial resources and equipment.*
	Risk Assessment	*Evaluation of risks and establishing necessary H&S measures to*

		avoid accidents e.g. risk assessments.
	Implementation	*Actual implementation of programmes e.g. training.*
Check	*Measuring Performance*	*Verification of the extent to which goals are achieved e.g. performance measurements metrics to include H&S targets such as number of accidents.*
Act	*Management review/Auditing*	*Reviewing in order to improve entire system e.g. External consultant reviews.*

**Sources: (HSE, 1997; Griffith and Howarth, 2001; Lingard and Rowlinson, 2005; BSI, 2007; Kheni et al., 2008; Cheng et al., 2012; Fewings 2013; Hinze et al., 2013, HSE, 2013)*

Several studies have highlighted the importance of the above elements to H&S (e.g. Kheni et al., 2008; Cheng et al., 2012; Manu et al., 2013; Agumba et al., 2013; Hinze et al., 2013). With regards H&S in the Nigerian construction industry, studies have mainly focused on other aspects of H&S such as regulations or performance (e.g. Ezenwa, 2001; Idoro, 2004; Umeokafor et al., 2014). It is therefore unclear the extent to which the elements of H&S management and their associated practices are implemented by contractors in Nigeria. This study therefore investigates the H&S management practices implemented by contractors in Nigeria.

4. Research Method

This research adopts a positivist paradigm by relating with facts, observations and figures via mathematical descriptive analysis. The positivist philosophical world view is known to be adopted for studies of this nature. This world view asserts that “knowledge of a social phenomenon is based on what can be observed and recorded rather than subjective understanding” (Matthew and Ross, 2010, p.27). Resultantly, quantitative approach was adopted for this study through the use of a questionnaire survey (Fellows and Liu, 2008). This approach was deemed appropriate for this study since the main answer to the research question pertained to "what" health and safety management practices are implemented by Nigerian contractors. According to Fellows and Lui (2008) questions relating to 'what' are most appropriately dealt with through quantitative approaches. In order to investigate the H&S management practices of Nigerian contractors, contractors' personnel in management roles were targeted for administration of a questionnaire. These professionals were specifically targeted as they are most likely to possess the requisite knowledge and experience relating to the management of H&S within their organisations. The questionnaire solicited these practitioners responses about the implementation of the H&S management practices associated with the above elements by their organisations. The structure of the questionnaire was in three parts: A, B and C. Part A was designed to collect general respondent and company information. Part B inquired about the health and safety management practices of the responding organizations. Both parts were designed to collect structured data to be analysed quantitatively. In part C responded were allowed to provide their opinions about challenges to implementing the H&S practices through opened ended questions. This was designed to allow respondents to elaborate on responses as well as their views about potential solutions. As it was impracticable to cover the entire Nigeria (due to its size - 36 states in 6 geopolitical regions), the study focussed on the South Western region which comprises 6 states. Due to difficulty in accessing an organised database/record of contractors in Nigeria, the participation of contractors was obtained via multiple channels including the Yellow Pages business directory and the lead researcher's contacts in the construction industry.

5. Findings

A total of 280 questionnaires were distributed to construction businesses within the target environment via electronic mail and hand delivery. A total of 129 questionnaires were returned. Out of the returned questionnaires, 14 were judged to be invalid (due to excessive missing data) leaving 115 useable questionnaires for the analysis. A sizeable number of respondents were construction managers, representing 42.60% of the total respondents. Others that responded were site managers (29.57%) and health and safety supervisors/managers (9.57%). Table 2 below gives a breakdown of the respondents' designated roles.

Table 2: Background of Respondents

Respondents role	***No.***	***%***
Company director	*17*	*14.78*
Construction manager	*49*	*42.60*
H & S supervisor/manager	*11*	*9.57*
Project manager	*4*	*3.48*
Site manager	*34*	*29.57*

40% of respondents had between five to ten years' experience working within the industry while 6.96% had over 15 years working experience. All the firms undertake private sectors works and 20% undertake public sector workers. A majority of the companies (i.e. 94.78%) undertake general building works and 42.61% undertake civil engineering works. Similar to the characteristics of construction firms in developed countries (e.g. UK, see ONS (2011)), most firms are small, having less than 50 direct employees (60.09%). While 24.35% employed between 51 to 100 direct workers, only 9.57% were large firms employing over 100 direct workers. A majority of the companies are relatively new with 66.09% of them operating for a maximum of 5 years. Only 2.61% of the companies have existed for over 15 years. Over 90% of construction firms do not have BS OHASA 18001 certification with only 7.83% possessing this certification.

5.1 H&S Management Practices by Contractors in South West Nigeria

The findings and discussion presented are based on the key areas or elements of H&S management as summarised in Table 1 above. In order to help identify the most widely implemented practices, the concept of academic degree performance is adapted to grade the survey results (e.g. UK masters, ≤ 49% = weak; 50-69% = pass to merit; 70% + = very good/ distinction). The level of implementation of the H&S management practices in Figure 1 and 2 were therefore categorised as: low (i.e. 0 - 49%); moderate (i.e. 50 - 69%); and high (70% +).

From this classification it was identified that the only elements of H&S management that have at least one practice being moderately or highly implemented are H&S policy, organising and risk assessment. This is presented in Figure 1 below.

Figure 1: Level of Implementation of H&S Management Practices within Policy, Organising, and Risk Assessment

5.1.1 H&S Policy

The survey revealed that half of firms have a formal company H&S policy statement. Top management involvement in H&S was observed to be low with only 18% of firms having a director with overall responsibility for H&S.

5.1.2 Organising for H&S

While some practices were performed by an appreciable number of construction firms (e.g. provision of health and safety communications to workers (62%) and displaying regulatory health and safety posters (60%) this was not reflected in other practices within this element of H&S management. Figure 1 above gives more details on the practices that have a low level of implementation.

5.1.3 Risk Management

The level of implementation of risk assessment practices amongst the companies was high or moderate for two practices and low for the others. For instance, whilst 90% of the companies inform employees about hazard before commencement of work, as low as only 13% review and update risk assessment during construction.

The results revealed very low levels of implementation of practices within the elements of planning and implementing, performance measurement, and review/auditing as summarised in Figure 2.

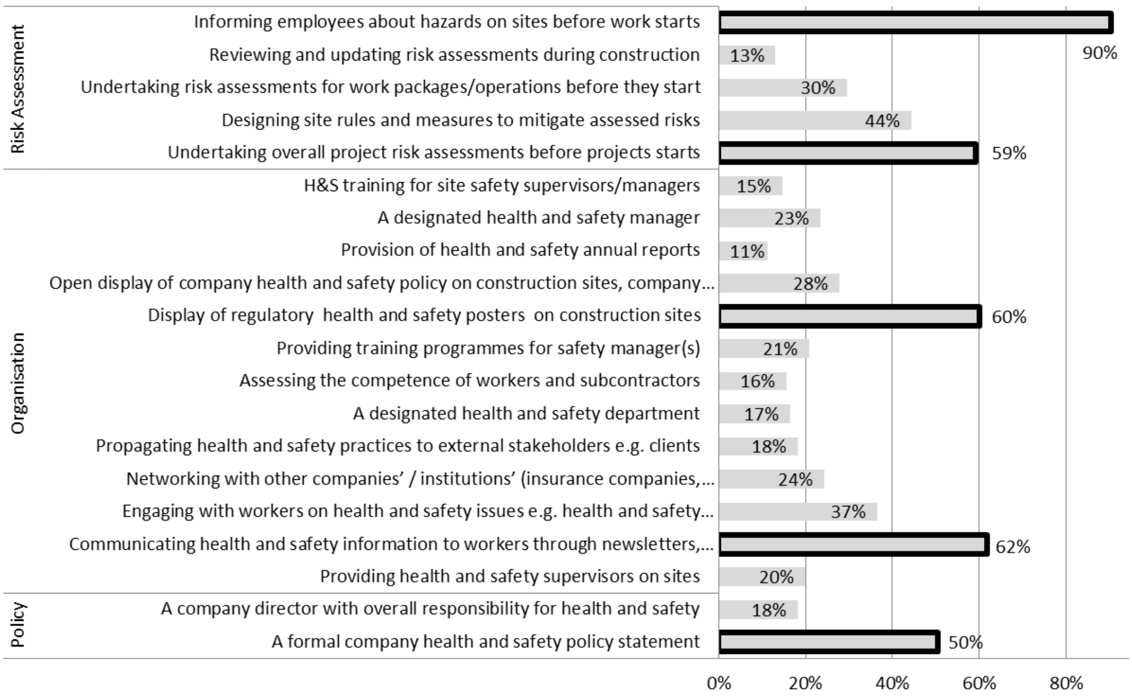

Figure 2: Level of Implementation of H&S Management Practices within Planning and Implementing, Measuring Performance, and Auditing

5.1.4 Planning and Implementing

None of the practices recorded over 40% with provision of sanitation and welfare facilities recording the highest level of implementation (i.e. 39%). Amendment and correction of health and safety plans during construction and rewarding of workers for safety behaviour however scored very low with 8% and 5% respectively.

5.1.5 Performance Measurement and Review

Similar to planning and implementing, none of the practices within this element recorded over 40% with publicising/sharing lessons learned from incident investigation recording the highest level of implementation (i.e. 18%). Keeping incident records on every project showed the lowest level of implementation (i.e. 10%).

5.1.6 Auditing

Similar to the above two elements, practices within this element of H&S management showed low levels of implementation with the highest being 20% for undertaking periodic safety management audits, and the use of in-house personnel for undertaking the audits.

5.2 Open Ended Responses - H&S Management Challenges

Challenges to construction H & S management was collated from the open responses. The challenges could be categorised under four main themes as given by Table 3.

Table 3: H&S Management Challenges

Challenge	***Sample Quote***
Cost	*"Only the bigger firms that land the plum contracts can afford it (certification and training). It's a luxury for small time contractors…" [Project manager].* *"We do our best with what we have and implement 'common sense' safety requirements" [H&S supervisor].* *"The cost and logistics of running onsite clinic facilities is out of the reach of most of us" [H&S supervisor].*
Bureaucracy	*"Reporting accidents to the authorities will often tie you down in red tape. The police and safety agencies just complicate things further" [Project manager].* *"Getting approval and accreditation for new safety standards takes a lot of time and money" [Project manager].*
Poor public health infrastructure	*"The government hospitals are poorly equipped and mostly on strike" [Site manager]*
Poor enforcement and awareness	*"I think it is unfair because while some of us put these requirements in place those that don't are not punished. Regulation that is not enforced is pointless" [Company director].* *"Many labourers do not wear protective clothing or know that they are supposed to. Even when these things are made available, they are not used properly" [H&S supervisor].*

6. Discussion

A cursory look at the results above reveals an overall poor H&S management amongst the participating companies. The structure of the participating companies mirrors the structure of construction companies in the construction industry of other countries as observed in the large number of the small and medium sized firms (about 84%) relative to their larger counterparts. Small-medium sized construction companies are described in Kheni et al. (2008) to be resource poor and barely able to survive in a capital intensive sector like construction. This is supported by the following comment regarding the cost of H&S management being a challenge for small companies: "*Only the bigger firms that land the plum contracts can afford it (i.e. certification and training). It's a luxury for small time contractors…*" [Project manager].

The BS OHSAS certification status of participating firms is also indicative of a sector where a large number of contractors lack the necessary policies, procedures and controls to effectively manage H&S. This correlates with research accounts in Idoro (2008; 2011), Kheni et al. (2008) and Umeokafor et al. (2014). The rather low involvement of top management in H&S is symptomatic of a low commitment of company management to protecting the H&S of workers. The importance of leadership support in management decisions and more specifically H&S

management is highlighted in Clarke (2013). Weak management commitment could undermine the other elements of H&S management and it is therefore not surprising that practices under planning and implementing, measuring and reviewing performance, and auditing recorded low levels of implementation (i.e. from 4% - 39%) amongst the surveyed contractors. The implementation of practices within the organising element range from low to moderate. Whilst there is moderate implementation of two practices (i.e. communicating health and safety information to workers through leaflets, newsletter and posters; and displaying regulatory H&S posters on site), there is low implementation of eleven practices indicating a generally poor outlook for the implementation of practices within this element of H&S management. This shows weak H&S management capacity with regards to organising for H&S which can lead to increased work related accidents. The poor outlook for practices within the organising element is out of sync with the situation in a similar developing country like Vietnam where Phung et al. (2015) and Nguyen et al. (2015) reported a moderate to high implementation for more practices within this element of H&S management. Whilst there appears not to be similar studies on the extent of H&S management practices implementation by contractors in a developed country context to aid comparison with the results from this research, it is expected that the situation in developed countries (e.g. UK and USA) would be relatively better given the better injuries record and health and safety regulation in these countries (see Hämäläinen et al., 2009; Abubakar, 2015). The implementation of the practices within the risk assessment element range from low to high. While there is moderate to high implementation of two practices, there is low implementation for three of the practices. That a low percentage of the companies undertake risk assessments prior to operations (i.e. 30%) and also review/update risk assessment during construction (i.e. 13%) shows that few companies take a proactive approach to dealing with H&S risks on projects. This could also have adverse consequences in terms of the occurrence of accidents, injuries and illnesses.

7. Conclusions

This research gives an insight into the H&S management practices of Nigerian construction firms, particularly those operating in the South Western Region. Results from the survey, although not generalisable to the entire Nigerian construction sector given the study's focus on a specific region, they suggest that very few H&S management practices are commonly implemented by contractors, particularly in the South Western Region. Generally, implementation of practices in all the key elements of H&S management appears to lagging. Elements that have a particularly gloomy outlook are planning and implementing, measuring performance and auditing. Action is needed by contractors to enhance H&S management in all the elements of H&S management. The support of state institutions and other relevant professional bodies (e.g. through provision of training programmes and awareness raising initiatives, and tightening of health and safety regulation) would be helpful. Public and private sector client organisations also have a key role in stimulating improvement in H&S management by including H&S requirements in procurement processes e.g. giving consideration to the health and safety competence/performance of contractors during contractor selection.

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An Investigation into Post-Accident Disputes Involving Migrant Workers in Singapore

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Abstract

One of the most vulnerable groups, in terms of workplace safety and health, are migrant workers who work temporarily in different countries and may not have the same level of protection as permanent residents. Their vulnerability can result in injured migrant workers being stranded in a foreign country without proper post-accident care and compensation.
Countries such as the Middle-Eastern countries, South Korea, Australia and China had reported vulnerability of migrant workers and different countries have different approaches to protect them. In the context of the construction industry in Singapore, employers of migrant workers are expected to take care of injured migrant workers, but there had been reports of migrant workers separating with their employers after an accident due to disputes on injury compensation. Many a times these migrant workers experience severe financial woes.

This study seeks to explore the injury compensation disputes that migrant workers face after an accident and the possible causes of the disputes. Sixty structured interviews were conducted with injured migrant workers at a NGO food programme in 2012-2013. These workers are generally construction workers (77%) or shipyard workers (33%). Most of the workers (93%) are from Bangladesh and some (7%) are from India. In addition, interviews with 2 employers and a lawyer were conducted. News articles were also studied to understand the issues involved.

The study provided insights on the different perspectives of the disputes. It was found that the main reason for migrant workers leaving their employer after their accidents was the fear of being repatriated by their employer without proper injury compensation. By leaving their employers, these migrant workers frequently end up with significant financial problems and mental stress. The possible underlying issues for these disputes were frequently lack of awareness of injury compensation processes and available assistance, unsound advice from lawyers that sought to represent the injured workers, and lack of trust between the workers, employers and regulators.

Keywords: injury compensation, labour dispute, labour relations, migrant worker, workplace safety and health.

1. Introduction

According to ILO (2015), there are about 232 million international migrants globally. The trend of increasing number of migrant workers will continue due to globalisation (Hämäläinen, 2009), economic inequalities, and other mega trends. Accordingly, migrant workers are an integral part of the Singapore industries since the 1970s (Piper, 2005). Similarly, the Singapore construction industry is heavily dependent on migrant workers. According to official statistics (Department of Statistics Singapore, 2015, Ministry of Manpower, 2015), the Singapore construction industry employs 98,200 residents and 322,400 migrant workers (work permit holders). That means migrant workers make up at least 77% of the workforce in the Singapore construction industry. It is noted that the work permit holders do not include higher skilled foreign workforce ("employment pass" and "S pass"). Besides Singapore, there are many countries with significant proportion of migrant workers and there are concerns that migrant workers are a vulnerable group in terms of workplace safety and health (e.g. Guldenmund et al., 2013).

Migrant workers are a vulnerable group in terms of workplace safety and health because they are in an unfamiliar foreign land, usually with language problems and they may not enjoy the same level of labour rights as permanent residents. Furthermore, many migrant workers moved to another country to earn money and they may be less interested in their own safety and health (Guldenmund et al., 2013). When a migrant worker gets injured, he or she may not receive the necessary level of protection and compensation (Harrigan and Koh, 2015). In addition, the construction industry is known for its poor safety performance. For instance, in 2014, 45% of the workplace fatal injuries in Singapore were from the construction industry. Such poor safety performance had also been observed in countries such as Taiwan (Cheng et al., 2010), the UK (Meliá et al., 2008), the US and Spain (Camino López et al., 2008). Having vulnerable migrant workers in the hazardous construction industry means that there is a need for more attention on post-accident protection of migrant construction workers to prevent abuse and assure that the rights of the workers are protected. However, there had been a lack of research on the how migrant workers cope with post-accident disputes and what are the reasons for the disputes.

As such, this study seeks to explore the factors influencing the occurrence of post-accident disputes between injured migrant workers and their employers. The issues highlighted provide basis for improvement of policies to better manage post-accident care of migrant workers.

2. Background

The terms 'migrant worker', 'transient worker' and 'foreign worker' have been used interchangeably in the literature. As defined by the Office of the United Nations High Commissioner for Human Rights (2011), a migrant worker is 'a person who is engaged or has been engaged in remunerated activity in a State of which he or she is not a national'. The term 'migrant worker' is used in this paper to align with United Nations' terminology.

2.1 Legal Framework

In Singapore, there are several regulations regulating the employment and management of migrant workers. The key labour relations legislations include the Employment Act and the Employment of Foreign Manpower Act (Attorney General's Chambers, 2015). In terms of workplace safety and health and work injury compensation, the main legislations are Workplace Safety and Health Act (WSHA) and Work Injury Compensation Act (WICA). The Employment Act governs the basic rights of the employees (e.g. minimum number of rest day and maximum number of workdays) and helps to ensure safety at work. The Employment of Foreign Manpower Act regulates the employment of all foreign employees with valid work passes and protects their well-being by specifying employers' requirement and obligations. For instance, the Employment of Foreign Manpower (Work Passes) Regulations (enacted under the Employment of Foreign Manpower Act) states that employer shall be responsible for and bear the costs of the foreign employee's upkeep and maintenance in Singapore. This includes the provision of medical treatment unless the medical costs forms less than 10% of the employee's fixed monthly salary and if the foreign employee's agreement to pay part of any medical costs is stated explicitly in the foreign employee's employment contract or collective agreement.

The Workplace Safety and Health (Incident Reporting) Regulations (enacted under the WSHA) requires the employer of an injured employee to submit a report to the Ministry of Manpower when the injured employee is granted more than 3 days of sick leave (consecutive or otherwise) by a registered medical practitioner on account of that accident or when the employee is admitted in a hospital for at least 24 hours for observation or treatment on account of that accident. On the other hand, the WICA provides an expedient, low-cost compensation system that is an alternative to claiming for damages under the common law. Employees can receive compensation as long as they were injured in a work accident or suffered a disease due to their work, and employers' liability can be capped. In general, the WICA assures payment for medical expenses and medical leave wages and compensation for permanent incapacity and death without the need to prove that the cause of accident is due to the fault of the employer.

2.2 Post-accident Disputes

Despite the legal framework to protect injured workers and to ensure that they are being taken care of after accidents, there had been reports of post-accident disputes that led to the injured workers being separated from their employers leading to hardship for the injured workers. According to Harrigan and Koh (2015), "Serious Mental Illness (SMI) is, in all likelihood, endemic" amongst their sample of 344 workers who had injury or salary claim workers lodged with the Ministry of Manpower (MOM). Even though the employers are required by law to provide accommodation and upkeep of the workers, 90% of the 344 workers were not living in the accommodation provided by their employers. These workers are mostly "runaway" injured workers, who had post-accident disputes with their employers. These workers do not want to leave Singapore because they are assisting with the MOM investigation on their injury compensation, but due to the regulation framework, the injured workers are not allowed to work for other employers. Harrigan and Koh (2015) found that the main causes of the mental stress among these workers (aside from the injuries) were due to lack of accommodation and threats of repatriation from employers. The findings by Harrigan and Koh (2015) were not surprising, because there had been numerous newspaper articles on the vulnerability of migrant workers. For example, Basu (2009) reported many injured migrant workers have to “fight to get compensation” and “some of them end up living on the streets while their cases are investigated - a process that can take anything from a few weeks to well over a year”. Similar problems were also highlighted by Phua et al. (n.d.).

However, it appears that employers are not the sole cause of the problems. Migrant workers had been jailed for making false injury claims (Teh, 2007) and many false claims were hard to detect. Basu (2009) reported that some workers were suspected of faking work accidents to obtain a “special pass” to continue to stay in Singapore and earn more through moonlighting as “freelance workers”. A special pass is issued by the Ministry of Manpower (MOM) to workers assisting in investigation or other relevant reasons. Special pass holders are not allowed to work, unless otherwise granted by MOM. Nevertheless, many injured workers still take up jobs while on special pass because their employers no longer pay for their upkeep. These workers were also suspected for abusing the special pass as an opportunity to extend their stay in Singapore to earn more money (Tan, 2013). Illegal work usually pay better because the illegal employers do not have to pay government levy for each migrant worker and mandatory insurance.

Similar disputes were also observed in other countries. For example, according to China Labour Bulletin (2007), migrant workers are known to “work in extremely hazardous conditions but when they get injured or contract a work-related illness, employers will often deny any liability and seek to avoid paying anything but token compensation”. Kim (2011) also reported that migrant workers in South Korea, “some employers refused to pay for compensation, or in the cases where they paid for the compensation, the migrant workers were forced to sign an agreement stating that there would be no further compensation, and that the employer held no responsibility regarding the industrial accident”. Furthermore, migrant workers in Middle-East (Hassan and Houdmont, 2014) and Australia (Reid et al., 2014) are also identified as vulnerable workers due to factors such as national culture, insecure job and payment to local recruiter. However, despite the severity of the issue, there was a lack of study on the post-accident care of migrant workers and disputes arising after an accident.

3. Research Method

This exploratory study consists of 3 main parts: (1) review of newspaper articles and online sources, (2) unstructured interview with 2 employers and a lawyer, and (3) structured interviews with 60 injured migrant workers.

The review of newspaper articles was focused on the main English newspaper in Singapore, The Straits Times (2015). Other online sources include online reports and webpages of NGOs, e.g. Transient Worker Count Too (TWC2), and the Ministry of Manpower (MOM). These articles and online sources were imported into NVivo, a qualitative data analysis software (QSR International, 2014), for systematic evaluation. More specifically, 11 newspaper articles, 4 online reports and a webpage were imported into NVivo. The coding was conducted inductively where text data were coded based on possible factors influencing the occurrence of post-accident dispute.

Telephone and email interviews were conducted with 2 employers and a lawyer to explore the causes of post-accident disputes. The interviewees were identified through the contacts of one of the authors. An unstructured interview approach was adopted to allow the researchers to explore the issues freely. This suits the exploratory nature of this study.

The structured interviews, conducted in 2012 and 2013, with the 60 migrant workers were conducted at two eateries where TWC2 was running their food programme for migrant workers. Each interview was conducted by one of the researchers based on a structured questionnaire. The questionnaire consists of 5 sections. Section 1 and 2 of the survey comprises the migrant worker's personal details. These sections provide the demographic of the foreign worker participated in the survey. Section 3 of the survey seeks to understand the nature of work the employer was engaged and aims at finding the relation between type of employer and dispute. Section 4 records the nature of the accident foreign worker involved and the medical care provided to them. Section 5 records the details of dispute and aims at finding the cause of post-accident dispute. The data and information collected from the 3 separated sources were input into NVivo and qualitative coding (Silverman, 2010) was conducted on them to derive useful insights and guide future research.

4. Data and Findings

4.1 Structured survey of injured workers

4.1.1 Profile of respondents

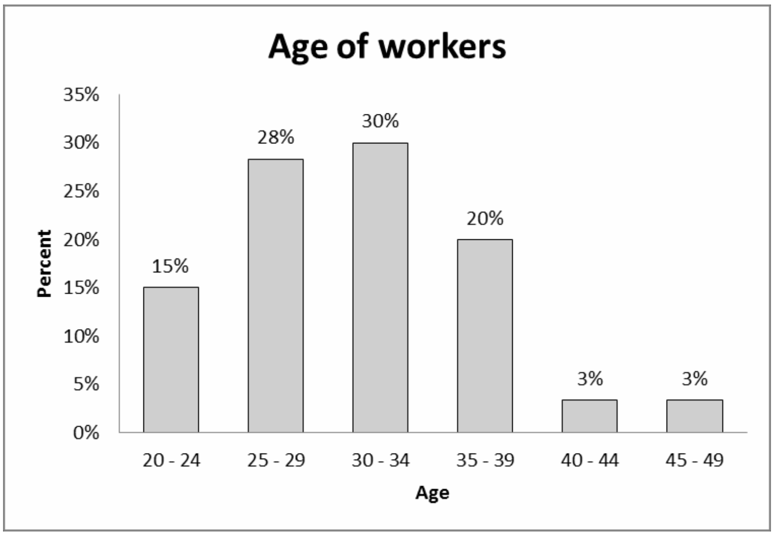

Figure 1 Distribution of age of surveyed workers

The following will present some of the key findings from the survey. Out of the 60 injured workers interviewed, 56 (93.3%) were from Bangladesh and 4 (6.7%) were from India. Forty-six (76.7%) of the workers were working in the construction industry and 14 (23.3%) were working in shipyards. Figure 1 shows the distribution of the age of the workers interviewed. As can be seen, most of the workers were relatively young at an age below 35.

4.1.2 Types of Employer

With reference to Figure 2, most of the respondents working in the construction industry were working for sub-contractors (45.7%), which is the most common type of employers in the construction industry. However, it is noted that 26.1% of the respondents were working for labour suppliers (26.1%), who provide short term labour to construction companies.

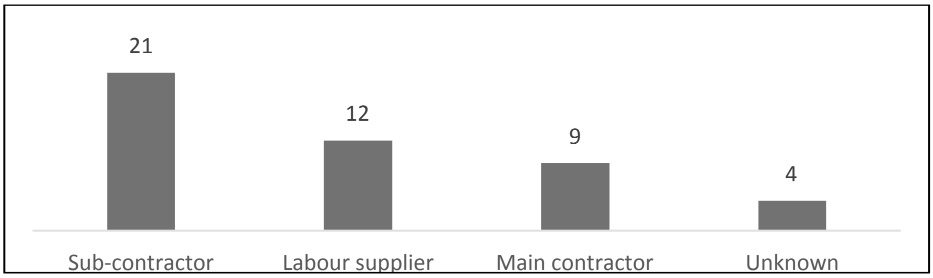

Figure 2 Types of employer

4.1.3 Factors causing runaway

Table 1 shows the ranked factors causing the post-accident disputes. Among the 7 factors, employer's threat to repatriate the worker was ranked as the most important factor in determining whether a migrant worker decides to leave his employer after an accident. Other concerns include the failure to pay salary during the injured worker's medical leave and employer refusing to pay for or provide medical treatment (including letter of guarantee for medical operations or treatment). Some of the workers also found that they were not given sufficient care during their recovery and decides to move in with their friends or relatives. For example, an injured workers having mobility problem was not given the necessary assistance while in the employer provided dormitory.

Table 1 Ranking of importance of factors causing workers to runaway

Factors leading to post-accident dispute	Sum of ranks	Importance
Employer threaten to repatriate foreign worker back	81	1
Employer refuses to pay salary during medical leave	110	2
Employer refuses to pay for medical bill	193	3
Employer refuses to provide medical treatment	242	4
Employer refuses to give Letter of Guarantee (LOG)	310	5
Being force to work when on Medical Leaves	350	6
Employer did not arrange for post-accident care during recovery	394	7

1=most important and 7=least important

4.1.4 Kickbacks

Of the 60 respondents, 47 were asked if they paid a 'fee' (kickback) for the job and all 47 (100%) indicated 'yes'. The remaining 13 respondents were not asked on this question because it was inserted after a review of the questionnaire. The average amount paid for the kickback was SGD4,687. According to some of the workers, the 'fee' ranges from SGD3,000 to SGD4,500. However, anecdotally, the 'fee' were reported to have been increased to about $7,000 for the first placement and the fee for subsequent contracts varies. One interviewed worker mentioned that for a subsequent job, there was usually a need to pay a fee of about SGD1,000 to SGD3,000. The survey finding is aligned with the results of TWC2's study (Transient worker count too, 2012), which found that despite MOM's enforcement, the problem of kickbacks was still very prevalent in the industry.

4.1.5 Involvement of Lawyers

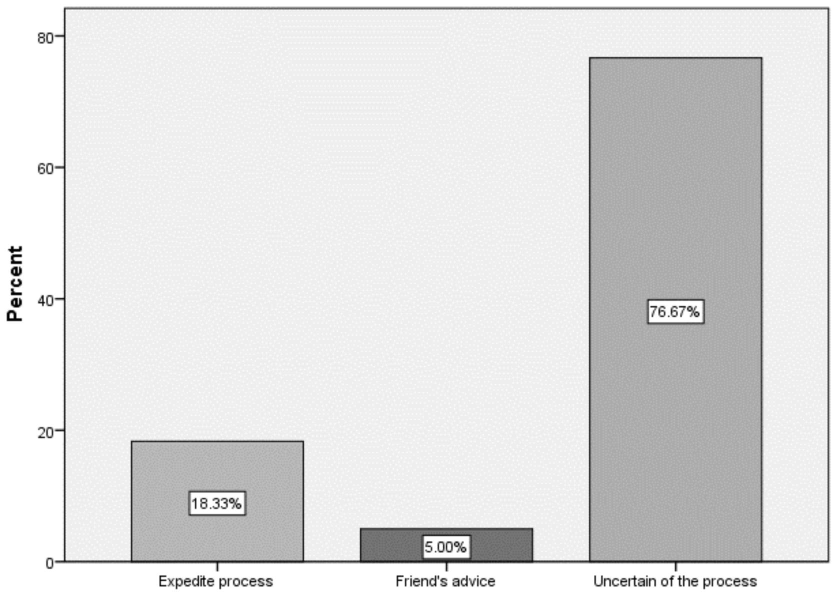

Figure 3 Reasons for consulting a lawyer

Out of the 60 respondents, 56 (93%) indicated that they engaged a lawyer to assist in their WICA claim. This contradicts the aim of WICA, which is meant to be a low cost and expedient channel to help injured workers obtain their compensation. For those that sought the help of lawyers (see Figure 3), 77% were uncertain of the compensation process, 18% were hoping that the lawyers can expedite the process and the remaining 5% engaged the lawyer based on the advice provided by their friends. The lawyers' assistance may be perceived to be necessary because of the disputes, but the legal fees will decrease the final compensation obtained by the injured worker.

4.2 Unstructured Interviews

Two employers (interviewee A and B) were interviewed. Interviewee A is the owner of a small construction contractor focusing on Bungalow construction. He had at least 1 incident of a worker running away after an accident. The injured worker claimed that he injured his back when carrying a bag of cement. The task was instructed by the main contractor and, according to interviewee A, the injured worker could not clearly specify who instructed the task. The worker also claimed that he was not allowed to see a doctor after the injury, but interviewee A insisted that this was untrue. Apparently, the worker got a relatively small compensation amount of SGD1,800, out of which the worker's lawyer obtained SGD1,200 for the legal expenses.

Interviewee A felt that the work injury compensation quantum was perceived to be very lucrative and the quantum can tempt some migrant workers into faking their injuries to obtain compensation. He also suspected that some lawyers may be promising a much larger compensation than reality. In terms of the illegal practice of repatriating a worker home to avoid accident reporting, interviewee A felt that it is not possible because repatriation companies are required by MOM to ensure that the workers do not have any outstanding issues, e.g. outstanding salary payment and injury compensation claims, before they can repatriate the worker. Interviewee A also shared that employers are required by MOM to purchase a SGD5,000 bond for each migrant worker, so if a worker runs away, the employer will lose the bond. This means that many employers will try their best to prevent runaways by providing proper accommodation and upkeep after an accident. However, he shared candidly that most employers may become "fed up *[sic]* because the injured worker cannot work for months and the employer has to continue to pay for the salary and medical expenses."

Interviewee B works as a sales general manager for a labour supplier company for about 5 years. His company has about 300 migrant workers and the company "loan them out" to construction companies with short term labour needs. He had about 2-3 runaway injured workers per year, but the number varies. According to interviewee B, many of these runaway workers did so on the advice of lawyers who teach them "tricks" to get higher injury compensation. One example is that he observed an injured worker who, after an injury, got only "light duty" medical certificate from a doctor. The "light duty" certificate indicates that the worker is not unfit for work and is an indication that the injury is relatively minor. Subsequently, the worker visits a government hospital and then obtain sufficient medical leave to make the injury reportable to MOM. Interviewee B noted that such "false claims" seem to be more common among certain sub-group of migrant workers (his opinion tallies with interviewee A's perception). He also shared that he noticed many of these injuries happen when "no one is watching" and investigators had to depend on the injured worker's word for the details of the accident. From what he knows, his company only had to repatriate workers that had "attitude problem" and these cases were not related to work injuries. He highlighted the following as possible signs of a worker moonlighting, (1) the worker is absent from work for a long period of time (e.g. one month), (2) the worker becomes uninterested in having over-time to earn more income, and (3) the worker insists that work has to stop at certain time.

The last interviewee (interviewee C) was a lawyer specialising in workplace safety and health for the past 10 years. However, he had not handled work injury compensation (WIC) cases. He shared that most of the injured workers were represented by various law firms ranging from small to mid-size firms as well as sole-proprietor firms. In terms of WIC dispute cases, interviewee C felt that the lawyer's main role is to obtain just and equitable compensation, but this role is relatively minimal. In terms of payment for legal costs, there are generally two categories: solicitor-client costs (S&C) and party-to-party costs (P&P). S&C costs are what the injured worker pays the lawyer and is subject to their agreement. The amount ranges between firms as it depends on the complexity of the case, experience of the lawyer, time spent on the file etc. In a civil suit, the losing party will typically be ordered to pay costs i.e. P&P costs. Generally, P&P costs are lower than S&C costs. It is not uncommon for some law firms to agree to bill the injured worker on a P&P costs basis i.e. the injured worker will not have out of pocket legal expenses.

4.3 Summary of Key Findings

The key issues gathered from the various sources, including newspaper reports and online articles, are summarised in Table 2.

Table 2: Summary of the key factors leading to post-accident disputes

Type of Issue	***Brief Description of Factors Contributing to Disputes***
Employer not willing to bear cost of accident or report accident	*- Injured worker becomes unproductive and employer not willing to pay for accommodation, medical treatment and salary*
	- Employer failed to purchase or renew work injury compensation for injured worker
	- Employer refuses to provide Letter of Guarantee as required by hospitals to conduct operations or treatment
	- Employer is concerned that the reported accident will attract MOM's inspections, or affect their safety track record leading to difficulties in obtaining new contracts or earning safety incentives.
	- Many injured workers are concerned that their employer may repatriate them without compensation for the injury. MOM has reported cases of repatriation companies being taken to task for forcibly sending workers home.
Labour suppliers	*- The labour supplier will typically require the main contractor to claim for the injured worker, but the main contractor may refuse to do so*
	- There can be confusion about where the injury was sustained and hence which company should be responsible for the compensation claim
Workers making false claims	*- Injury may be false, exaggerated, or not work-related. Worker may go to more than one doctor to ensure that he receives sufficient days of medical leave to assure compensation*
	- An illustration of the temptation to make false claims: compensation "for fractured fingers may be as high as SGD44,000, which is 75 years' pay for the average Chinese farmer" (Basu, 2009)
Medical certificates and light duties	*- Employers complain that doctors are giving medical certificates too liberally*
	- Doctors give light duties to injured workers, but employer has no light duties for injured worker. Employer may decide not to pay injured worker because he/she does not have light duties for the worker and the employer is not required to pay medical leave salary as the worker does not have medical certificate.

Workers encouraged to run away by friends and/or lawyers	*- Injured workers are generally uncertain about the work injury compensation procedures and may be encouraged by friends or lawyers to run away from the employer during the claim process. Employers feel that certain sub-groups among migrant workers are more prone to such problems.*
	- Lawyers are perceived by employers to be teaching "tricks" to injured workers and promising large amount of compensation. The lawyers can be paid on party-to-party basis by taking a cut of the compensation and the injured workers do not have to pay for any legal cost upfront.
Moonlighting	*- Runaway injured workers are typically on special pass and they are not allowed to work. As the investigation of compensation claim drags on, those that are well enough to work may be forced to take up illegal work to cover the cost of their accommodation and food.*
	- Injured workers may abuse the system to use the special pass to moonlight so as to earn higher income.
	- Ministry of Manpower offers a Temporary Job Scheme to help workers on special pass to look for short term work to sustain themselves.
Debts and kickbacks	*- As the supply of migrant workers to Singapore is very much higher than the demand for the workers, agents, training centres (workers are required to attend training courses prior to coming to Singapore) and employers may ask for illegal kickbacks from the workers. This causes many migrant workers to be severely debt-ridden and will be more motivated to make false injury compensation claims and/or moonlight.*

5. Discussion and Conclusions

As can be observed from Table 2, the problem of post-accident dispute is complicated and many parties, including migrant worker, employer, labour supplier, doctors, lawyers, authorities, and worker agencies are involved. On the migrant worker side of the story, they incurred huge debts paying for kickbacks and other costs to enter Singapore to work. They have very low bargaining power and they have very low income. Thus, one of the greatest fear that an injured migrant worker have is the possibility of being repatriated home without obtaining their injury compensation. On the other hand, accidents lead to unproductive workers and are costly to the company. Employers may suspect the injured workers of moonlighting or are making false injury claims. The employers face a lot of pressure due to market competition and their frustration can result in verbal or physical abuse of the workers, which further fuel the dispute. The employers failed to understand that their failure to care for the workers and their threat to repatriate the workers cause the workers to run away, resulting in more problems and trouble. This forms a vicious cycle of poor labour relations, disputes and lengthy investigation, which are detrimental to migrant all stakeholders.

There is a need for regulators to enforce their regulations to ensure that employers take care of their migrant workers after the accidents. At the same time, false injury compensation claims must be uncovered and dealt with severely. However, bearing in mind the vulnerability of the migrant workers, it is important to allocate sufficient resources to house and support the injured migrant workers that have separated from their employers and are having their injury compensation claim investigated. This role can be filled by NGOs, but government levy on migrant workers' employers should be used to fund the NGOs.

Education of migrant workers and employers are critical. It is important to be able to reach out to migrant workers and educate them on the injury compensation process. Letting them know their rights will reduce the need for lawyers' assistance, who may not add significant value and can be costly to the workers. Migrant workers can be trained as ambassadors to educate their own community on their rights and understand the dangers of moonlighting and false injury claims.

One of the most fundamental problems in the system is kickbacks, which place migrant workers in heavy debts and creating behaviours detrimental to workplace safety and health. For example, workers will only be focused on earning money as quickly and this can cause them to ignore their own safety during work. Migrant workers in severe debt can also be more easily tempted to moonlight or even make false claims. Tight enforcement and detailed employment guidelines must be established to prevent kickbacks.

This study surfaced several key issues behind post-accident disputes involving migrant workers. It is believed that these findings are useful inputs for countries that have a significant proportion of migrant workers. Future research should focus on designing interventions to assure faire and transparent handling of accident-related disputes involving migrant workers.

6. Limitations

This study has its limitations. First, convenience sampling was used to select interviewees and respondents. Second, communication with the migrant workers were done using simple English and there could be misinterpretation of information. These limitations were reduced through triangulation of the different data sources and the internal checks conducted between the authors.

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Behavioural Health and Safety: Links to Reporting of Close Calls in Construction

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Abstract

Over the last decade behavioural health and safety has become one of the construction industry's target areas for major improvement with countless systems created to attempt to combat the risks associated with poor behaviour. However, on their own, good systems do not ensure successful occupational health and safety. The reporting of incidents and close calls (sometimes called 'near misses) in particular can significantly improve health and safety through the sharing of experiences and learning from the mistakes of others. This study evaluated current systems and analysed the opinions of key construction stakeholders (n=104). The respondents included managers and workers across four different construction sites with two different principal contractors. The findings show that there is agreement that reporting close calls are an important factor in improving health and safety. However, at the moment, site operatives are not being given enough motivation to take time out of their paid work to report close calls. More convenient systems should be trialled and developed to find solutions that have more apparent benefit for the site operatives. To ensure successful teamwork everybody must be willing to participate. Any real industry-wide culture change would require the system of reporting close calls to be consistent throughout all construction sites across the country. This will then confront the issue of the transitional and itinerant nature of subcontractors and give them a system which they can become familiar with in their everyday work life.

Keywords: Behaviour, Health and Safety, Close Calls, Near Misses

1. Introduction

The construction industry by nature is a hazardous place of work. There has always been a need to improve the health and safety of the workforce. *'Over the last two to three decades, an increase in research and awareness in safety has reduced fatalities by over half. However, 22% of UK employee fatalities and 10% of reported major injuries are in the construction industry despite only accounting for 5% of British employment'* (HSE, 2012). These levels are high due to the nature of construction. Working with large-scale machinery and equipment has a much higher potential for harm compared to the dangers faced with other typical jobs sat behind a desk or even in a fixed-site facility. Therefore to enable the industry to continue to recruit good people, safety has been a major target for improvement. '*During this period, construction safety has reduced fatalities mainly through focusing on improving the managerial systems, policies and better safety technology e.g. nets, MEWPs, harnesses. However, in recent times, many organisations have realised that their accident rates have 'levelled off'. This has ignited a search for improvements in other areas to reduce accident numbers, leading to the research into behavioural safety issues of the workforce*.' (Oswald, 2013). Within any industry, even the best systems are not effective if they are not being cooperated with properly. Before any system can achieve its purpose it must be accepted and adopted by the workforce. The behaviour towards any system will decide whether it is successful or not.

Analyzing historical events can show that most loss producing events were preceded by warnings or close calls, sometimes also referred to as near misses, narrow escapes or near hits. However they are largely ignored because no injury, damage or loss occurred. McKinnon (2012), states that '*most health and safety policies are reactive not proactive. Companies wait for losses to occur before taking steps to prevent a reoccurrence. Employees are not motivated to report these close calls as there has been no disruption in the form of injuries or property damage.'* Recognising and reporting close calls can make a major difference to the safety of workers within construction. Behavioural health and safety then closely links to the reporting of close calls due to the fact that, for this system to work, it must have the full cooperation of the workforce. If the workforce does not behave in the desired way then the system will fail. Therefore the recent increase in demand for reporting close calls requires research into behavioural health and safety.

This study originated in the knowledge that there have been previous studies undertaken regarding health and safety reporting. This area within construction has always been difficult to gain full cooperation of the workforce. It has led to the requirement for research into ways in which to address this ongoing issue. A previous study by Williamsen (2013) showed that some site operatives believe reporting a close call may tarnish a workman's reputation. This ethical issue and the '*blame culture'* within construction could be seen as main reasons for the industry struggling with the reporting of close calls. However the full discussion of this topic is outside the scope of this paper. The intended benefits of the close call reporting system are very important. However, without cooperation from the site operatives these benefits cannot fully be achieved. The UK's Health and Safety Executive (2000) states that '*behaviour modification techniques are effective in promoting desired health and safety behaviours provided they are implemented thoroughly*.' This study considered different opinions and proposed potential solutions to achieving desired behaviour for reporting close calls.

2. Methods

The foundation of this research project was the assumption that there was an issue with behavioural health and safety with regards to reporting close calls, therefore a mixed methods, deductive approach was employed. A survey questionnaire was followed by interviews to gain the opinions of health and safety professionals from the industry. The following section describes the techniques and procedures for the data collection and analysis.

The main source of primary data came from a questionnaire to industry professionals in a variety of different roles including site operatives and site management. This was then compared with the current industry systems. The survey was designed to be straightforward in simple English to facilitate its completion. It did not require a computer and could therefore be completed at any time in any location to suit most construction operatives. The survey was emailed around to site managers who then handed it out to their employees. The completed surveys were then scanned and sent back to the researcher. The questionnaire included four statements with responses on a 1-5 Likert scale. The Likert survey enabled the required opinions to be extracted with a minimal amount of time or effort from the participants. The questionnaire was completed between September 2014 and January 2015. There was a 95% response rate achieved with 104 recipients completing the questionnaire across four different sites from a mixture of main contractors and building and civil engineering sectors. There were 59 managerial respondents and 45 site operatives with 50 having more than 20 years' experience and 54 less than 20 years' experience.

This second phase of the research involved structured email correspondence with two experienced construction health and safety professionals whose opinions could then be compared with existing literature and results from the questionnaire. Two main questions guided the interactions to enable the answers to be compared and critically analysed. The two professionals chosen had many years' experience were from different sectors of the UK construction industry to give a broader scope. Respondent A is currently health and safety manager for a major building contractor. Respondent B has over 30 years' experience in the construction industry working on a variety of building, civil engineering and infrastructure projects. He is currently health, safety, quality and environmental manager on a major civil engineering project.

Reviewing current industry literature and other health and safety research enabled insight into issues surrounding the nature of reporting close calls within the construction industry. This allowed the author to gain a broader understanding of the issues faced with reporting of incidents and close calls within the industry today. The UK's Health and Safety Executive was used as a reliable source of information to form the foundations of the study and provide an insight into how behaviour can have a major effect on health and safety. Other literature was used to compare this to close call reporting.

3. Results and Discussion

The results and discussion draw on the email exchange with the two experienced health and safety managers and the questionnaire survey (n=104) and is organised in line with the main questions that were addressed in the research.

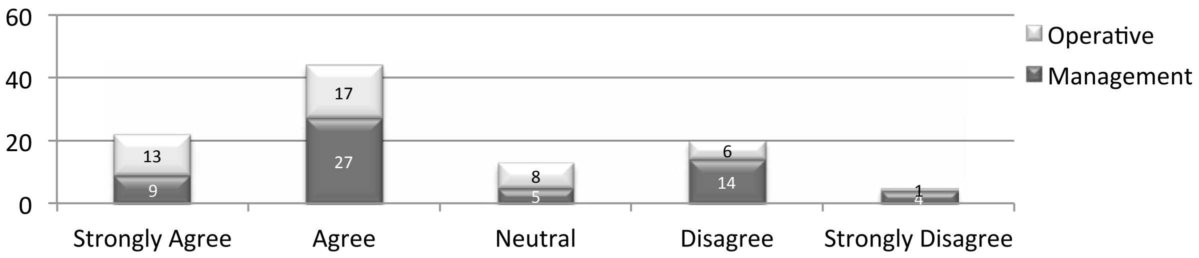

Figure 1:'Close calls get reported correctly according to the system in place' – Likert responses

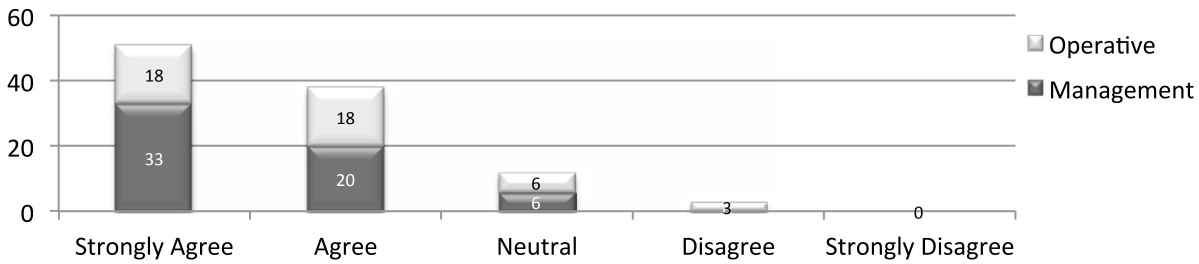

Figure 2: 'Reporting close calls reduces the chance of incidents occurring' – Likert responses

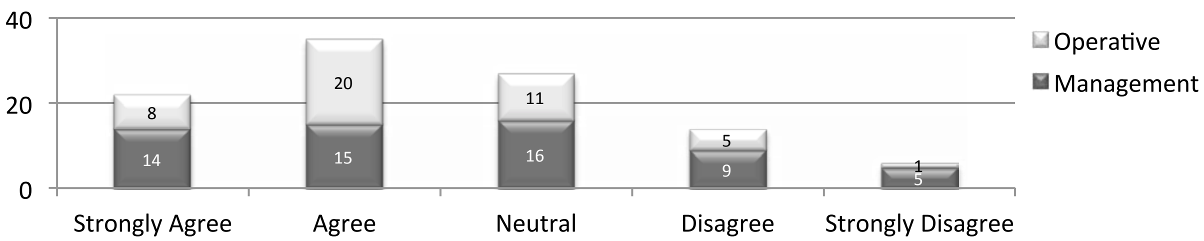

Figure 3: 'Reporting cards are the most efficient way to report close calls' – Likert responses

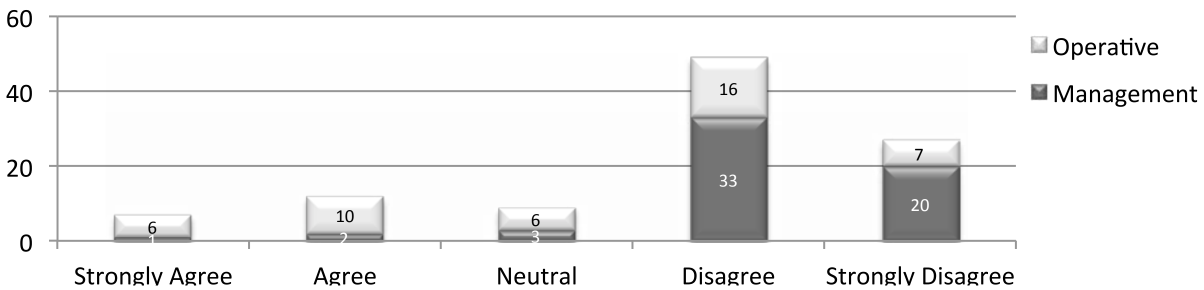

Figure 4:'Operatives don't have time to stop their works and report every close call' – Likert Responses

3.1 Do close calls get reported correctly?

Figure 1 shows a spread of results, however there is a trend towards agreement. Interestingly the responses that agreed largely came from both the site management as well as the site operatives, whereas the responses that disagreed came mostly from management. When surveying different construction sites the issue with close call reporting may be less apparent on some sites for various reasons with different managers enforcing the reporting systems in different ways. Alternatively they may not want to give the impression of a failing system and may answer survey questions with a more positive outlook so as not to cause any problems with upper management. Possibly because it is a recent system, older workers with an imbedded work routine may have had worse opinions regarding reporting close calls. Site based workers generally felt that close calls were being reported correctly and with a mixed response from management there are signs of disagreement. The difference in view of management and operatives can lead to issues and failure of a system. If operatives believe they are already complying with the system they will not feel the need to improve. Williamsen (2013) suggests *'one way to overcome issues with reporting is to actively involve the site workers and increase their participation in the process.'* This apparent disagreement would suggest that communication and involvement of both parties together has not been present regarding reporting close calls and is where the main issue of improper reporting may lie. If the reporting of close calls was properly discussed and communicated with the site based workers then they could have valuable input into the system. If there was effective communication of a failing system to the workforce they could collectively agree on ways to improve and reach targets that suits everyone involved.

3.2 Does reporting close calls reduce the chance of incidents occurring?

Figure 2 shows a strong trend of agreement from management and operative both having no participants strongly disagreeing. Out of both groups there were only three operatives that disagreed, showing how strong the trend of agreement is. Stating the key purpose of reporting close calls exposed whether current industry professionals agree that reporting close calls are important and have positive influences. This indicates that everybody is aware of the importance and benefits. However the ABC theory of behaviour (Flemming, 2002) suggests reasons why there are still issues to be faced. Even though there may be an understanding of importance in a situation, if there is a stronger influence at the time, e.g. knowing the supervisor is not enforcing the rules, the behaviour adopted may ignore the fact that reporting close calls is known to be important. With the significant trend shown in figure 2 it also suggests that all levels of experience agree with the fact that reporting close calls reduces incidents. Nobody within construction wants incidents or injuries, so any way to prevent them occurring should be a high priority on everyone's list. Albert's (2014) research presented an alternative reason for the issues faced. The analysis states that '*most construction safety management processes rely on the hazard recognition capability of workers. Hazards that remain unidentified can potentially result in injuries. Despite its importance, a large proportion of hazards remain unrecognized, exposing workers to unmitigated risks.'* Therefore, it is not so much the opinion of reporting close calls working as a system that is an issue. It is the education and collective understanding of what a defines a close call combined with the attitude that there is not enough motivation for operatives to stop their work and make close call reporting a priority.

3.3 Are reporting cards the most efficient way to report close calls?

Figure 3 shows a mixed spread of responses but the majority of responses generally agreed. This is most likely due to that fact that they are not aware of any other systems. The range of responses is relatively high across all 5 categories showing the spread of opinions. The only group to be in real disagreement is the management. There were a few management responses that were unhappy with the process and this is possibly because it can take up a lot of the supervisor's time filling out the close call cards and uploading them on to the company database. This is backed up by Williamsen (2013) who states that '*supervisors do not wish to be burdened by work of questionable worth.'* So in order to combat this inconvenience to the supervisors there needs to be a way of uploading close calls with minimal time consumed, or allowance in the day for the supervisor to take time away from site to upload all the close calls. With the increase in smartphone use today, it would make the process much more attainable if this technology was utilised for the system. If there was a smartphone app where site operatives can immediately take photos and share them with the site supervisor, he could then check and upload it on the data base with minimal amount of time or effort. It can be hard to keep tabs on whether closes calls are being reported properly due to the nature of the close call card system and the fact that no loss or damage occurs. If no supervisor witnessed it then it is very easy for operatives to shrug it off and carry on with their work. This is the required need for behaviour change and for operatives to start acting, there needs to be a system put in place that is convenient for them.

3.4 Do site operatives have enough time to stop their works and report every close call?

Figure 4 shows the responses to a statement that was thought to be a main reason why site operatives may not be happy about having to report close calls. Interestingly it shows a significant trend towards disagreement, unsurprisingly the majority being management. Management are almost entirely in disagreement with only 10% of all management participants surveyed not disagreeing. Meaning management feel site operatives have enough time to complete their work and report a sufficient amount of close calls each week. However figure 4 also shows there is a much more varied spread of site operative responses ranging across all five categories. There is a major difference between management and operative responses which is a significant finding with regards to operations within the industry. This then again relates to Williamsen's (2013) theory which indicates that site operatives have a desire to avoid work interruption because they have not got enough time in the day for unpaid distractions such as reporting close calls. The majority of operatives surveyed back up this theory and agree they do not have sufficient time to stop their works. This then contrasts with the management opinions creating a potential reason for friction on sites around the topic. If there is to be a successful system both operatives and management must agree. They must decide on a suitable number of close calls reports required that the operatives agree with and feel they can achieve without disruption to their works. Alternatively the system must be changed to find a way to take up less of the operative's time to report each close call. It could be argued that, regardless of how time consuming, it is a requirement of the operatives to report close calls and as such they simply have to report them. On the other hand, with the nature of the construction industry and the always increasing pressure on time, any reduction on time required away from measured works benefits everyone.

3.5 Is it possible to achieve behavioural safety perfection in the construction industry?

These following two sections present the findings from the email interaction with the two experienced health and safety advisors. Both respondents agreed that there is generally a negative opinion about behaviour when it comes to the construction industry. Both stated that, due to the transitional nature of construction workers it is almost impossible to embed behavioural safety into the workforce. Respondent A stated that whilst the industry has made great strides in trying to standardise construction through the skills card schemes, some businesses have very wide parameters in expectations of behaviours from the workforce. This coincides with Lin (2000) who states that '*employees must be actively involved in a system for it to have success.*' When operatives work in different places with different regulations every week it is hard to keep continuous positive behaviour. They cannot be involved within a behavioural system if they move around all the time.

Respondent A also stated that due to the wide gulf in expectations throughout the UK when subcontractor tradespersons who have not been exposed to health and safety culture come to main contractor projects, teams almost have to undertake a behavioural re-alignment and there is often too large a difference to overcome. The second respondent agreed that it is highly unlikely perfection will ever be achieved; however he stated that it is possible if the whole industry was committed to it. He admitted that efforts have been made to change such as The Construction (Design and Management) CDM Regulations and small steps have been made but there has been no accompanying cultural change. He stated that he believes organisations do things because they have to, not because they want to. He considered that we live in a 'tick box' industry where more effort is put into avoiding blame for an incident rather than preventing the incident in the first place. Daniels (1999) agrees that this is a major issue '*as motivation for something you have to do is much weaker than motivation for something you want to do.*' Too many individuals beyond the construction site are not motivated to make efforts to contribute to health and safety and are solely rewarded on financial performance.

Respondent A concluded saying that "unless the construction industry ever achieves the permanent employment status of nuclear, power generation, petro-chemical, which is highly unlikely, the best we can hope for is a core of workers who understand the principles of behavioural safety whilst we invest our time in trying to educate and change the behaviour of the remainder". Respondent B considered that the promotion of behavioural safety in parts of the industry in the previous 10 years had introduced significant benefits that extend beyond safety. The culture it encourages improves productivity and quality and that is why he thinks behavioural safety is still a worthwhile investment.

It is therefore a general agreement from these responses that too many people think safety is the responsibility of the contractor and only happens on site. Therefore getting everyone to commit to the culture change will be too much of a task. It is highly unlikely to ever achieve behavioural safety perfection but there are many benefits and safety improvements that can be achieved.

3.6 Is reporting close calls improving health and safety enough to invest in further?

From the responses it is clear that both respondents strongly agreed that reporting close calls is a fundamental process to improve health and safety within construction. Respondent B believed that it encourages everyone to get involved with safety and promotes a proactive rather than a reactive attitude. He felt it is a stepping stone to wide spread and continual hazard and improvement reporting. Unfortunately he also stated that there are very few motivated and suitably skilled people that can lead this process to ensure the potential is fully realised. He feels there is a lack of genuine high level effort meaning a lack of adequate resources to maintain a long term commitment that will see a cultural change. This supports Petersen (1993) who states that '*for a policy to become successful there must be sufficient support and commitment from upper management.'* Therefore, as Respondent B stated, without this support failure is more than likely. He believes the management of many large organisations are only interested in short term targets for personal gain rather than investing resources in something that may take many years to provide a noticeable return. Therefore although he stated that reporting close calls is worthwhile and beneficial he feels due to the lack of support from upper management there will not be any significant improvements any time soon.

Respondent A agreed with the fact that reporting close calls are a worthy investment and states that if a business is serious about behavioural safety and engaging with the workforce it must invest time and capital in maintaining a healthy close call process. He felt that there were clear indicators that an engaged and a 'listened to' workforce is more likely to work in a safe manner, so improvements in health and safety may be a by-product of having a robust close call process in place. Both respondents therefore had a common opinion: reporting close calls as a process itself may not always directly improve health and safety. However having the process in place actively involves the workforce and should naturally have a positive effect on their attitude towards safety on site.

In contrast to Respondent B's opinion that upper management are not actively committed to improving the process Respondent A stated how his health and safety management department are aiming to improve the process. He stated that, in his organisation, three times as many close calls are reported by direct employees compared to subcontracted workers. This disparity has led to a business target for 2015 to improve subcontractor reporting by 10%, by their site teams investing time during the induction, site briefings and Tool Box Talks in stressing the importance to their company that their partners tell them what is wrong. The success of this policy depends on the commitment from middle management to implement the process. But, on the whole, it is a step in the right direction to improving the behaviour of subcontractors.

4. Conclusions and Recommendations

The reporting of close calls is becoming increasingly valued within the construction industry as a preventative way of reducing property damage and injuries. However, this research has shown that the industry is struggling to keep up with the number of close calls being requested by managing directors of top companies with the UK. There are many views of the potential reasons behind this but mainly it comes down to the communication and participation gap between management and site operatives. The less communication and participation from the site operatives, the more problems faced when trying to achieve goals. Especially with the major issue that subcontractors are very transitional and never usually stay long enough on each site to learn appropriate (i.e. compliant) behaviour. Furthermore, as close calls have no real measure or specific description, they can easily be ignored. Therefore examples and standards should be set at all site inductions to ensure everybody is thinking along the same lines. The system then needs to be effectively managed by all to ensure close calls are not being ignored.

The other underlying issue with the process of reporting close calls is that it takes too long and is inconvenient for site personnel. It requires being brought up to date with current technology to become fast and efficient for everyone involved. By creating an easy way to report close calls, site operatives and supervisors will not be as inclined to ignore them and it can become part of the culture on site. As discussed in the analysis, an important opportunity is the use of smartphones. The creation of a smartphone app where site operatives could immediately take photos and write comments anywhere at any time would mean that they would not have to make such a 'big deal' about reporting. This should then increase the number of close calls being reported, resulting in valuable experiences being shared and learned. This should then lead to a reduction of incidents on a much larger scale, as is the desire of the industry.

This paper has only drawn responses from two of the top UK contractors and only from one geographical region of the companies. Further clarity of results would require a wider investigation throughout all regions of the UK and into all the separate disciplines. The next step would be for the these findings to be incorporated into systems within the industry. This would require an industry-wide initiative and trialling of new systems. A way in which to approach this could be the trialling of the smart phone app with the intention for it to be consistent throughout the industry. For there to be any real culture change industry-wide the system of reporting close calls should be made consistent throughout all UK construction sites. This will then confront the issue of the transitory nature of subcontractors and give them a system which they can become familiar with in everyday work life.

5. Acknowledgements

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Workaholics on site! Sustainability of site managers' work situations?

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Abstract

Site-managerial practice in construction has been depicted as a 'muddling through', being everywhere at the same time and skilfully solving problems as these crop up. The purpose of this paper is to explore work patterns and related well-being implications of site managers in construction. Drawing on the work-life stories of 21 site managers, which have been analysed using narrative analysis we argue that muddling through put high demands on these managers' abilities and possibilities of coping with and balancing their work situations. In all the accounts, several features of workaholism were identified as driving forces, often leading to negative well-being symptoms. The site managers were passionate about their work, but deplored organisational and institutional constraints, which mostly obstructed rather than supported or facilitated their work. This resulted in periods of exhaustion and stress, leaving little energy over for family and life outside work. We conclude that the warnings we perceive concerning the unsustainable work situations of site managers warrant further research.

Keywords: muddling through, site managers, stress, well-being, workaholism

1. Introduction

Recent studies (Styhre, 2011; 2012) have depicted the work of construction site managers as a "muddling through"; they skilfully solve problems as these inevitably crop up, and they try to be everywhere at the same time. It is argued that this behaviour is produced by the masculine culture in construction and puts high demands on managers' abilities to cope with their work situations. These and other studies witness that over the last two decades, little has changed in the behaviour and attitudes of site managers (e.g. Styhre and Josephson, 2006; Mäki and Kerusuo, 2015). What has changed, however, is the nature of site managers' work: more areas of responsibility and stricter accountability seem to be prevalent trends. Seen from a social sustainability perspective, the scenario does not bode well for the well-being of these managers. Research in the late 90s and early 2000 warned that apart from being one of the most demanding jobs in the construction process, requiring particular skill sets and experience, job dissatisfaction and stress among site managers seemed to be higher than among other middle managerial categories (e.g. Djerbani, 1996; Fraser 2000; Haynes and Love, 2004; Lingard and Francis 2004). These conditions are widespread still today (Styhre and Josephson, 2006; Dossick and Neff, 2011; Styhre 2011; Mäki and Kerosuo 2015), and warrant qualitative studies of the lived work-life situations of middle managers in the industry.

Drawing on the studies cited above and on interviews with site managers in several representative large and SMEs constructors in Sweden, we explore the work patterns and related well-being implications for site managers. Our data show that all the site managers interviewed exhibit one common characteristic: they are over-achievers, or as we argue workaholics. The aim of this paper is to examine the site managers' experiences of work and well-being, and reveal possible connections between (i) involvement with work, drive and work enjoyment and (ii) well-being.

2. Framing: well-being and workaholism

Research on well-being, especially within psychology is extensive. Journals such as Personality and Individual Differences report on its connections with personality (Garcia, 2011), attachment (Karreman and Vingerhoets, 2012), connectedness to nature (Howell et al, 2011) and emotional intelligence (Extremera et al, 2011), among other interesting themes. Well-being is also one of the core concepts in sociology and public policy (Jordan, 2008). Within business and management, and HRM specifically, it is a relatively new area of interest. The 'business case' has tended to trump the ethical or moral argument about 'employee welfare' or 'employee focus' (Van Buren III et al, 2011). While some models of HRM, such as the Business Partnering approach (Ulrich, 1997) perhaps began as an attempt to redress this imbalance, practice quickly revised the ideas, and so Ulrich's complete model became the three-legged stool. The business focus came to dominate, pushing well-being to the side.

Recent developments in the HRM literature have begun to engage more seriously with concepts such as well-being. The justification or rationale for this interest may stem from practical concerns about absenteeism and also presenteeism, and stress in particular (CIPD, 2013), but also renewed importance of ethics (Losey et al, 2005: 332). The practitioner press has become inundated with reports and papers on stress as a key concern in the modern workplace, and well-being initiatives are designed to address this issue (see for example the many CIPD resources, including reports and 'how to' guides on well-being at www.cipd.co.uk). However well-intentioned organisational well-being initiatives may just be treating the symptoms of much more severe concerns within the contemporary workplace instead of addressing the actual problems that lead to experiences of stress. On the level of the individual, 'workaholism' is one relevant construct that may explain workplace behaviours related to presenteeism and maintenance of patterns of work that lead to stress.

Workaholism is a term that refers to an employee's strong, irresistible inner drive that tends to result in working excessively hard (Spence and Robbins, 1992; Schaufeli et al, 2008:175). Behaviour patterns typical for workaholics include: compulsive-dependency, perfectionism and achievement-orientation (Burke, 2000). Over the past decades, workaholism has often been seen in a positive light, characterising the corporate ideal worker: "an employer's dream" (Bonebright et al, 2000; Burke, 2000). This view is based on the workaholic-triad that consists of work involvement, drive and work enjoyment (Spence and Robbins, 1992; Burke, 2000; Schaufeli et al, 2008). Different combinations of these three elements are said to produce six types of workaholism as shown in Table 1 below.

More recently increasing concerns over excessive work and related stress and potential burnout have initiated interest in examining the downsides of workaholism. Studies that consider workaholism and well-being outcomes tend to fall into two types: those that closely link workaholism and related well-being outcomes (e.g. Bonebright et al, 2000; Burke, 2000), and those that argue that the six types of workaholism and different types of well-being outcomes are best considered separately (e.g. Schaufeli et al, 2008).

The studies that closely link workaholism and related well-being outcomes (e.g. Bonebright et al, 2000; Burke, 2000) tend to argue that work context and managers play a significant role in developing workaholism and maintaining such behaviours (e.g. Burke, 2000), and that specific types of workaholism can be linked to particular well-being outcomes (Bonebright et al, 2000). For example the non-enthusiastic workaholics have been found to have significantly more work-life conflict and significantly less life satisfaction and purpose in life than non-workaholics (ibid). Also, enthusiastic workaholics have been found to have significantly more life satisfaction and purpose in life than non-enthusiastic workaholics (ibid).

In contrast, those that argue that the six types of workaholism (after Spence and Robbins, 1992) and different types of well-being outcomes are best considered separately (e.g. Schaufeli et al, 2008) show that workaholism and burnout (possible negative well-being outcome) and work engagement (possible positive well-being outcome) are not intrinsically linked. The relationships between the three concepts depend on

- working hours,
- job characteristics,
- work outcomes,
- quality of social relationships, and
- perceived health (ibid).

Table 1: Types of workaholics (after Bonebright et al, 2000; Spence and Robbins, 1992)

Type of workaholics (Bonebright et al, 2000)	Type of workaholics (Spence and Robbins, 1992)
Enthusiastic workaholics	• *Real workaholism* – high in involvement, high in drive and low in work enjoyment • *Enthusiastic workaholics* – high on involvement, drive and enjoyment
Non-enthusiastic workaholics	• *Work enthusiasts* – high in involvement and enjoyment, low in drive (resembling engaged workers) • *Relaxed workers* – low on involvement and drive, high on enjoyment • *Unengaged workers* – low in involvement, drive and enjoyment • *Disenchanted workers* – low in involvement and enjoyment, high in drive (resembling burned-out workers)

In this paper, we use this framework to explore site managers' experiences of their work role.

3. Study design and method

An interpretative approach was chosen, based on interviews. The data included in-depth interviews with 21 site managers. Most of the typical construction contexts and projects were represented, e.g. infrastructure, residential and commercial development projects. The data collection strategy was purposive: since we wanted to understand the unfolding of lived, everyday managerial practices on site, we asked CEO's and top managers from large and mid-sized contractors in Sweden to name their "best" site managers. We did not define what we meant by "best", but left it to them to decide. The result was 21 site managers of whom 3 were women aged 30 to 50. The rest were men: half of them aged 50 to 65 and the other half 25 to 40. The respondents were ensured anonymity in that all specificities enabling identification would be neutralised, and we offered them the possibility of reading the transcripts should they wish. The interviews were informal, taking the form of casual conversations lasting from 60 to 90 minutes each. They were audio-recorded and transcribed verbatim. The location for the interview was either a meeting venue or the respondent's office on location. A brief interview guide was used to keep interviewer intervention at a minimum.

The respondents were asked to provide the essential bio-data concerning career trajectories. After these preliminaries, they were encouraged to talk freely. Our prompts were open-ended; we wanted them to tell us about their workdays, how they generally went about planning and managing site activities, what issues arose and how they dealt with them. 'Free' storytelling has been suggested as an appropriate interview technique for the purpose we had in mind where interviewees' personal stories are allowed to evolve, and in which their underlying assumptions and beliefs guide the conversation (Clandinin and Connelly, 2000).

Drawing on Polkinghorne (1995) and Lindebaum and Cassell (2012), narrative analysis was applied on the data in order to identify and code the various fragments that made up the narratives. These fragments were then sorted under themes that linked to the overall plot concerning the narrators' coping with their work situations. *It is important to note here that the theme 'workaholism' emerged during our data analysis.* They were not asked to identify themselves as one type of workaholic or another, nor did we employ specific instruments to collect data to determine the respondents' involvement with work, drive and work enjoyment. During the data analysis we drew on the workaholic framework to sort the respondents' behaviours and associations to their well-being into workaholics types.

4. Findings

Three core themes emerged as central to the site managers' narratives of their work days: coping with their work situation, with their work-life and family, and their associations to their feelings of well-being. Overall the managers depicted their work situations as highly demanding with multiple expectations both from others and on themselves. They described how they were constantly being pulled between planning tasks, administration duties and the solving of countless ad-hoc problems, large and small, serious and trivial. Simultaneously, the respondents showed remarkable commitment and motivation for their work. They all took pride in the products of their labour, the final constructions.

> … seeing it [the construction] grow in front of me … that is something that can never be taken away from a site manager … that when I drive past the construction I can say 'I built that'.

Within these three themes, the two different types of workaholics: enthusiastic and non-enthusiastic according to Bonebright et al (2000) could clearly be identified. We have chosen to allow the voices of the respondents to be heard in this section since they express their views and feelings much more directly than we ever could.

4.1 Coping with work situation

The respondents described incredibly high workloads and very long working hours. Their work situations were demanding and fragmented. One manager mentioned a several-year long period when she worked practically 24/7.

> During the whole of last year, I got up at 4.30 am and left work at 7 pm, and went to bed at 9. How does one count work time from such a schedule? During the weekends I sat with the budget. During this period, I easily worked a 100 hour week. But that is extreme and isn't always the case […] on average, maybe I work 55 hours per week.

The respondents described how they developed ad-hoc strategies to cope with the abundance of work tasks, which differed significantly from the standardized approaches they were supposed to avail themselves of.

> You do what you can to make things work … you don't pay much attention to the role description, you just do…

> We have a business system and decision structures that we are meant to follow but there is no time for that. I have to take many shortcuts in order to get my workweek anywhere near to 40 hours.

There was a general consensus among the respondents that their managers in turn understood and accepted that they carried out their duties and responsibilities as best they could.

> They [superiors] understand that one does the best one can. But if there was to be an internal audit I would have to fill in the papers afterward so I don't get smacked on my fingers.

At the same time a strong sense of responsibility and commitment to work reveal a tendency among the managers to take on too many tasks, thus further straining their already heavy workloads.

> It is all about the projects. As long as I can work with what I want in the way I want, I enjoy working here. Today I am definitely in such a position.

> [the most tasking job is] … all the paperwork … but I have only myself to blame, for I let go of nothing. The purchasing I keep for myself, the economy I keep for myself… (…) It would have been a relief to get rid of the economy (Laughing)

> Despite everything, I enjoy the responsibilities I have … and of course you build your own indispensability … that's how it is. You're not indispensable in any way, but you make yourself memorable and see yourself as extraordinary in some sense.

A female respondent described the high demands on site managers in construction, and why it was difficult to fill managerial positions at the production level.

> What stops civil engineers from becoming production managers … or rather why we can't appoint them is that they are often on parental leave [days off when children are ill] especially when they have two children. We have some staff that are on parental leave approximately 50% of the time. No one on site has a clue about his or her planning and decisions. What materials are coming in, what cranes have been ordered etc … this is a huge problem for production.

Simultaneously, as another respondent stated, the managers felt guilty when they had to take parental-leave days:

> It is very tough for the site manager who is absent. We know that if we are at home things become difficult as hell for the others. You have to be really cold not to care about what's happening on site.

4.2 Coping with work-life-family balance

The respondents convey a mixed; yet rather negative view of their work-life balance situation.

> I have this work-family puzzle that needs to be managed, especially if a child becomes ill. During the weekday it works out ok. I leave at preschool and she picks up. Then you take care of children until they fall asleep and then you try to watch some TV before falling asleep. It is pretty hectic!
>
> As a site manager you are never free on weekends. You have maybe ten weekends per year where you don't open your computer and work. Most of us start on Sunday to plan for the workweek ahead.
>
> It has happened that I have slept at my desk waiting for a morning meeting … with work charts and drawings as covers to protect me from the cold.
>
> I have sat in front of Bollibompa [children's TV program] and worked. I see myself as there for my daughter even when I am working. That is something I am satisfied with.

The respondents complained about their work-life imbalance, and in some cases even expressed sorrow over how work has obscured their needs of recreational time and spending time with family and friends. One manager even went so far as to describe these impediments as collateral damage of work.

I don't have any alone time. I definitely don't have time to meet friends. My family I hardly see at all … so these bits are the collateral damage. I never go to the

> cinema; I don't have time for those kinds of things. But I do travel a lot … that is my breathing space … that I always know that I will be travelling somewhere within a few weeks. That is when I switch off completely.

4.3 Well-being

The respondents' reported worrying consequences of their hectic work lives on their health and well-being

> The previous year was chaotic. Then I was on the verge of quitting my job … I couldn't cope. Then I worked … uhm … it was still at the time when I dropped of at day care. In principle I worked my 9 hours, every day, and then I also often worked [at home] from 8 pm until 12 pm many days a week … several weekends as well to get it to work. I was close to burnout then.

The respondents felt that there was little support from the organisation for their plight, and they felt that they had a large responsibility in procuring jobs for their subordinates.

> I have coped with it [the stress], but it was really a lot of work …I'm really tired. Time to train ... I never bloody well have time for physical training. That is why I don't lose weight. Now I have to because I have a bad hip

> I can say this much. I had my second blood clot last year and had salmonella at the same time. I had a vomiting bucket with me when I went to work … that's the way it is. So I go to work, and I have a bucket. It functions. I'm not that ill!

5. Discussion

All the respondents in our cohort exhibited evidence of workaholism, of which the six types are represented in the quotes. They showcase a representative sample. Specifically where we present the respondents' experiences of their work situation, a diverse range of all six types of workaholism is identifiable. In our sample we thus include both enthusiastic workaholics and non-enthusiastic workaholics (after Bonebright et al, 2000), and find evidence of real workaholism, enthusiastic workaholics, work enthusiasts, relaxed workers, unengaged workers and disenchanted workers (after Spence and Robbins, 1992). There were many respondents that showcase high work involvement and work enjoyment. These respondents resemble engaged workers and can be categorised as *enthusiastic workaholics* or work enthusiasts. However, not all respondents talk of their work experiences in a positive light, hence these respondents have been sorted under the category *non-enthusiastic workaholics*.

With regards to 'coping with work-life-family balance' an interesting trend emerges: it is the respondents who fall under Bonebright et al's (2000) broad category *enthusiastic workaholics* that reported most concerns with coping with work-life-family balance. This is not that surprising given that these workers were likely to prioritise work in balancing aspects of work-life-family blend and thus found it challenging to manage the balance. What is interesting is that they did consider and talk freely about their work-life-family balance concerns, which shows that these issues were of importance to them.

Those respondents who reported the most worrying consequences of their hectic work lives on their health and well-being all fall under the category *disenchanted worker*. Spence and Robbins (1992) identify this type of workaholism to be connected with low involvement with work and low work enjoyment, but high drive. This is a group that is clearly in the risk zone for ill health and burnout. Here a link with the organisational circumstances and job context emerges as a significant variable that influences the respondents' views, and therefore would warrant much more research and attention from HRM. The respondents referred to lack of organisational support, long working hours and presenteeism. Burke (2000) argues that it is these kinds of contextual circumstances that play a significant role in individuals developing workaholism and thereafter maintaining such behaviours.

The link between the job context and the managers' experiences can be understood through Styhres (2012) concept of 'muddling through'. The respondents expressed a lack of social support from superiors that they felt strained their work situation. These conditions caused them to work long hours, and bear responsibility for practically all the processes and relations on site, which further increased their feelings of stress. Styhre (2011, 2012) has argued that these conditions are due to the loosely coupled configurations in the construction industry, which increase expectations on self-sufficiency, autonomy and presenteeism of the manager. The site managers, thus, become the centre of all the activities on which the success or failure of the project revolve. Such conditions inevitably put considerable pressure on site managers.

The respondents complained about long work hours and referred to their job characteristics as both demanding and stressful. Work outcomes, however, tended to be described in positive terms, particularly in terms of organisational performance, yet this positive performance was often attained at the expense of strenuous and challenging effort by the individuals. The overall quality of social relationships and recreational outlets were unanimously seen as difficult to achieve. Many sacrificed time with friends and/or family as well as time for training to dedicate time to work or they referred to situations where they were multitasking, e.g. spending time with children while working. Several respondents conveyed that this caused them to neglect their individual and social needs, and in some cases this gave rise to poor health and well-being.

Besides the effects on the individual site managers, their workaholism may also have had negative effects on their subordinates and the organization. Site managers have formal responsibility for subordinates and for the work environment on site. They are responsible for preventing accidents and injuries. Our data indicate that site manager often work when they are ill, and they often have to take "shortcuts" to keep up with their workload. This raises concerns regarding safety issues on site, which would need to be further investigated. Furthermore, the industry is in need of recruiting new competent construction workers. In our data the ideal site manager is portrayed as a person who devotes his or her life to work and often neglects family and private life. This raises questions regarding the ability to attract a younger generation of workers more keen in upholding a balance between work and private life.

6. Conclusion

Using a practice lens, this paper has examined the work situations and possible related well-being implications of site managers in the construction industry. Site managers talked freely about their day-to-day activities, tasks and responsibilities, their interactions and interpersonal relationships with their subordinates, superiors and suppliers, and the difficulties they perceived in balancing work, family and personal life. All their accounts describe an all encompassing work context and managerial duties that put considerable mental and physical strain on them. Yet, these same accounts articulated a strong commitment to their work and sense of responsibility for all the workers on site. Their criticism concerning their excessive workload was mainly directed toward the organisational level and the increasing demands and control from the top down. The data indicated that the site-managers work conditions has and does lead to negative implications on their health and well-being, which in the long-run may prove costly for the organisation. The question which needs to be asked is how much of the strain is the result of organisational demands and how much is due to the demands the individuals put on themselves.

Inspired by the framework of workaholic types, we found representations of all the types described in the framework: both enthusiastic workaholics and non-enthusiastic workaholics (after Bonebright et al, 2000), and real workaholism, enthusiastic workaholics, work enthusiasts, relaxed workers, unengaged workers and disenchanted workers (after Spence and Robbins, 1992). An important finding is that linkages to negative well-being could be found in most of the site managers' accounts despite their strong feelings of involvement, drive and enjoyment in their work. High *enthusiastic workers* tended to experience increased work-life conflict and decreased time for recreation, which can be seen as negative well-being in terms of social relationships and health. It should be noted though that their high enjoyment of their work signalled positive experiences of psychological well-being. The data also indicated that *non-enthusiastic workers* are a risk group for ill-health and stress. Especially the group characterized as *disenchanted workers* are in a high-risk zone for burnout. Long working hours, lack of organizational support and presenteeism seem to be the reasons for these negative perceptions. These findings raise warning signals for the unsustainable work situation of site managers in the construction industry. This situation warrants further research on how an organizational context may 'force' managers to develop workaholic behaviours as a defence and/or rationalisation mechanism. It would also be very interesting to explore both the site context and individuals from a social psychological perspective: what is it that makes individuals fall into one or the other of these categories, and what can be done to prevent and support them? To sum up, what our data tell us is that 'muddling through' seems to be a lot more complex than the concept may lead us to expect.

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Part II: Constructing Commitment and acknowledging human experiences

TAMPERE UNIVERSITY OF TECHNOLOGY

Importance of Retaining Knowledge at Water Works - Findings from Finnish Water Works

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Abstract

Knowledge management has received some attention in the water sector during the last few years. However, its importance is still underestimated and the interpretations of knowledge management are versatile. Because knowledge management and especially tacit knowledge is a critical success factor for both water utilities as organizations and their personnel, this longitudinal research focused on the changes between 2004 and 2013 in a case water works. The objective was to find out what information needs and acquisition channels the personnel used, what was considered knowledge and tacit knowledge and how knowledge was shared.

This research was carried out by a qualitative method and a semi-structured questionnaire was used in the interviews. The research was conducted at Pori Water, which is a medium-size water works in Finland. The company's area of operation was expanded and the number of citizens served was increased by 10 per cent between 2004 and 2013. At the same time the size of personnel was decreased by 26 per cent.

Information needs and usage in the utility were versatile and depended on the tasks performed by the employees. The results of this research showed that the personnel used personal files, document collections, the Internet and the intranet more often in 2013 than in 2004. The shift from printed material to electronic material has increased over the years and that had happened in Pori Water, too. Surprisingly, discussion with closest co-workers and other personnel had decreased. Social media did not play any role in the case water utility.

Interpretations of knowledge management had changed from informing people to personal, individual property. The personnel were proud of the knowledge they had of water treatment processes. Several reasons were found why knowledge sharing was considered difficult. The most important difficulties mentioned included lack of time, competing priorities, a gap between older and younger generations and unwillingness to share. Knowledge management requires long-term planning and actions, which should be integrated in the strategy of Pori Water. Attention should also be paid to master-apprenticeship relationships, mentoring programmes, knowledge transfer processes and critical knowledge documentation practices.

Keywords: Knowledge Retention, Tacit Knowledge, Water Works, Longitudinal Research, 2004 - 2013

1. Introduction

Knowledge and information management have been discussed and debated world-wide since the beginning of the 1990's. Knowledge management has been studied especially in information and communication technology (ICT), information management, behavioural sciences, and business studies. The ICT sector has mainly used ICT in managing data and information. Information management has concentrated on individuals' and organisations' information needs, sources and use. Companies' key interest is in knowledge management, organisational learning, and information and knowledge flows. The role of tacit knowledge in personal and organisational development is significant. Several studies have shown that up to 80–90 per cent of decision making is not based on explicit knowledge.

The shared opinion is that in today's global and turbulent world both explicit and tacit knowledge form a key strategic asset for any company or organisation. The concept of knowledge management includes several other concepts, for example data, information, knowledge, wisdom, explicit knowledge, implicit knowledge, tacit knowledge, knowledge creation, knowledge sharing, intellectual capital, human capital, social capital. These concepts are understood differently depending on the context.

This longitudinal research focused on the changes between the years 2004 and 2013 in a case water works. The objective was to find out how the following themes have changed between these two focus points: the meaning of knowledge management in a water utility, the concept of tacit knowledge, sharing of tacit knowledge and the difficulties related to sharing tacit knowledge. In addition, the study focused on water utility personnel's information needs and knowledge acquisition channels.

2. Knowledge management and knowledge retention

2.1 Turbulent knowledge environment

In today's global and turbulent world both explicit and tacit knowledge comprise strategic assets for organisations which have to cope with a complex and turbulent knowledge environment. Turbulence is mainly due to the fast growing amount of knowledge and its fragmented and global nature. A complex knowledge environment creates both opportunities and threats. For example products may be developed to be more intelligent, services may include knowledge components, and Internet of Things will connect several systems, thus creating opportunities for new markets. One of the threats is that the lifetime of strategic knowledge will be short, and creating new knowledge may open doors for competitors. (Probst et.al. 2000).

In the future, turbulence at water utilities will be similar to turbulence in any other organisation. There are several things which pose challenges to water utilities, for example technological developments both in processes and analysing equipment, new legislative decrees and acts, more stringent environmental permits, demanding customers, economic constraints, digitalisation and ageing personnel. It is especially important in any water utility not to lose the personnel's expertise and knowledge.

2.2 Critical knowledge at water utilities

Critical knowledge will disappear, if not captured for example in case of retirement. Post and Breen (2005) used the expressions "inherent expertise" and "work legacy" when they emphasized the experience and hands on know-how of processes, equipment, and systems possessed by the leaving employees. This knowledge is undocumented yet crucial to the water utility and therefore it should be captured. According to Post and Breen (2005) the widest knowledge gap occurs in engineering, skilled crafts and trades as well as in technical expertise. Knowledge gaps can be severe, when water systems become more complex and technology becomes more advanced.

O'Berry (2007) emphasizes the fact that the livelihood of the utility depends on critical knowledge. Therefore, it is extremely important for them to know who has knowledge and what kind of knowledge they have. Blankenship and Brueck (2008) stated that critical knowledge cannot be written down, neither can it be learned by reading someone's notes.

According to Frigo (2006) critical knowledge at water utilities can be divided into three types of knowledge, i.e. technical, social, and structural knowledge. Individual capabilities and skills are technical knowledge, while relationships and working cultures are social knowledge. Structural knowledge is embedded in the organization, its systems, processes, policies, and procedures. Explicit and rule-based knowledge is typical of structural knowledge.

2.3 Tacit knowledge

Tacit knowledge is the most valuable asset an organisation possesses. Sustainable competitive advantages can only be developed by capturing and transferring tacit knowledge. Tacit knowledge is internalised in organisations and their people and processes, and is thus not readily or easily available and transferable throughout the whole organisation. There are several definitions for tacit knowledge which share the same elements. The existence of tacit knowledge has been known for a long time, but it has gained increasing attention since the beginning of the 1990's and is now also considered in organisational strategies.

2.4 Difficulties in sharing knowledge and information

There are several possible reasons why knowledge is not necessarily shared in organisations. They can be organisational or individual. Difficulties in sharing knowledge can occur, for example, in relation to the following aspects: hierarchical barriers, functional barriers, organisational strategies and policies, perception (personal knowledge), language, individual's talents and social behaviour, time, value, distance, attitude, willingness to share, organisational culture, power, resistance to change, atmosphere of trust, management and leadership, different generations, work norms, lack of training, lack of up-to-date information and communication infrastructures, vocational practices (compensation, recognition, ability utilisation, creativity, good work environment, autonomy, job security, moral values, advancement, variety, achievement, independence, social status), and knowledge drain when workers leave the company (Awad & Ghaziri 2004; Boiral 2002; CEN 2004; Devlin 1999; IRC 2004; Haldin-Herrgard 2000; Probst et.al.2000; Wilson 2009).

2.5 Knowledge retention

Knowledge retention is an important issue at any organisation. Blankenship and Brueck (2008) divided difficulties in retaining knowledge in technology-based, interaction-based, and learning culture-based categories. Difficulties in knowledge retention vary between these three approaches. Technology-based methods deliver information and facts, which are easy to capture and write down. It stands at the lowest level of a knowledge value chain. Blankenship and Brueck (2008) included also document systems and document repository forms of knowledge retention in this approach. Processes and practices are part of the interaction-based category, which includes the core competencies in a water works and which can be difficult to capture. A milestones reviews project is an example of processes and practices. However, the most difficult approach is the learning culture-based approach, which comprises knowledge in complex systems and best practices. Tacit knowledge incorporated in learning culture-based approach has the highest value in the value chain of knowledge. It gives answers to “know-how” and “know-who”.

Tacit knowledge can be transferred by mentoring. Especially technical and operational knowledge, organizational culture, and leadership knowledge can be transferred effectively during a mentoring process. The best practices can be transferred in facilitated organizational learning and training sessions. Special apprenticeship training programmes have been used in integrating new personnel in water utilities. (Blankenship and Brueck 2008)

An easy way to keep critical knowledge within the utility is to make generations work together. Other knowledge sharing tools include training, mentoring, coaching, career development, and shadowing, where a younger employee follows how a senior employee works. Hurley et.al. (2007) emphasized open organisational culture, effective communication, and support from all employee levels in knowledge transfer. Post and Breen (2005) stressed not only the skills and knowledge but also enthusiasm and loyalty features transferred during mentoring.

Knowledge losses may occur in another case than retirement, too. Blankenship and Brueck (2008) anticipated that younger generations will have shorter tenures, because they seek other job opportunities. Their knowledge should therefore also be captured. Therefore, commitment and support by the top management is a basic requirement for knowledge retention. Water utilities need to develop workforce planning schemes, hiring practices, personnel level compensation, rewarding, recognition, and promotion actions that support knowledge retention. Development of workforce strategy should be one of the priorities in the utility.

Frigo (2006) has described the need for integrated knowledge retention strategies at water utilities. According to him the key focus of the top management should be placed on the strategies, which link together human resources processes and practices, information technology solutions and knowledge transfer practices and recovery initiatives. A knowledge retaining strategy and its implementation should be an ongoing activity in the utility.

3. Research approach

This research was conducted in a medium-size water works on the south-western coast of Finland. In 2004 Pori Water supplied water to about 76 100 inhabitants and treated their waste water and the waste water of several companies. The area of operation was larger in 2013 than it was in 2004, because of new municipalities and cooperatives connected to the water mains and sewers. In 2013 Pori Water supplied water to about 83 500 inhabitants, which was about 10 per cent higher than in 2004. However, between 2004 and 2013 the number of personnel decreased from 94 to 70.

The approach of this research is qualitative. The literature review deals with knowledge management, the role of tacit knowledge in water utilities and knowledge retention. A longitudinal case method was used in this research, because it provides information of in-depth events or individuals in one organization over time. In addition, data were collected by an inquiry. The questionnaire used in the research focused on the following areas: how the interviewees interpreted knowledge management and tacit knowledge and how they described knowledge sharing and knowledge retention at the utility.

The first empirical part of the research was carried out at Pori Water, where 61 employees were interviewed in June–October 2004. Individual interviews were conducted with all personnel groups. Altogether 66 per cent of the employees were interviewed. The second empirical part was carried out at the same water works where 33 employees were interviewed, representing 48 per cent of the whole personnel in September-October 2013. The interview process was the same in both empirical parts, and the same type of semi-structured questionnaire was used in the interviews. A question on social media was added to the questionnaire in 2013. The interviews were analysed by combining qualitative and statistical methods. The Microsoft Excel package was used to transcribe the interviews.

4. Results of the research

4.1 Information needs and acquisition channels

The personnel needed different kinds of information in their daily work. Some of it was related to decisions in Pori Water and its services, personnel policy and development. Some was related to terms and conditions of employment and terms of purchase. Legislation was also very important: the water works must obey laws and regulations in delivering good quality water to its customers and treating wastewaters and discharging them into water bodies. Information needs depended on the tasks the employees were performing. Table 1 summarizes the changes in the use of information channels among all interviewed staff members at Pori Water from 2004 to 2013. The table shows only non-users, daily users and weekly users (once a week or a couple of times a week). All other users (once or twice a month or a couple of times in a year) were left out. Thus the total percentage does not add to 100 per cent.

Table 1. Change in the use of information channels at Pori Water. Only daily users, weekly users and non-users are reviewed. Thus the total percentage in different information channels does not add to 100 per cent.

Information channels in 2004 and in 2013	*Daily users %, 2004*	*Daily users %, 2013*	*Trend*	*Weekly users %, 2004*	*Weekly users %, 2013*	*Trend*	*Non-users %, 2004*	*Non-users %, 2013*	*Trend*
Personal files/collections	*23*	*39*	↑	*23*	*18*	↓	*23*	*15*	↓
Library/document collection of Pori Water	*0*	*6*	↑	*3*	*15*	↑	*84*	*70*	↓
Local libraries	*2*	*0*	↓	*0*	*0*	–	*84*	*94*	↑
Discussions with closest co-workers	*84*	*82*	↓	*98*	*91*	↓	*2*	*6*	↑
Discussions with other staff members in Pori Water	*15*	*15*	–	*20*	*15*	↓	*11*	*18*	↑
Discussions with personnel of other water works	*0*	*0*	–	*3*	*0*	↓	*48*	*39*	↓
Discussions with other experts outside Pori Water	*5*	*0*	↓	*18*	*30*	↑	*34*	*27*	↓
Technical journals	*0*	*0*	–	*3*	*0*	↓	*61*	*79*	↑
Professional books	*3*	*0*	↓	*3*	*6*	↑	*59*	*70*	↑
Pori Water internal reports	*7*	*3*	↓	*8*	*12*	↑	*20*	*52*	↑
External reports (outside Pori Water)	*0*	*0*	–	*3*	*6*	↑	*55*	*61*	↑
Conference and seminar papers	*2*	*0*	↓	*0*	*3*	↑	*59*	*61*	↑

Equipment manuals and brochures	*7*	*9*	↑	*5*	*18*	↑	*20*	*39*	↑
Pori Water notices/bulletins	*2*	*9*	↑	*8*	*15*	↑	*25*	*36*	↑
Intranet of City of Pori	*12*	*21*	↑	*28*	*18*	↓	*52*	*27*	↓
Internet	*26*	*52*	↑	*16*	*15*	↓	*41*	*27*	↓
Standards	*5*	*3*	↓	*5*	*3*	↓	*66*	*82*	↑
Patents	*0*	*6*	↑	*0*	*0*	–	*95*	*91*	↓
Electronic databases	*15*	*27*	↑	*7*	*12*	↑	*64*	*55*	↓
Chat channels, discussion forums	*0*	*0*	–	*0*	*3*	↑	*98*	*88*	↓
Others	*10*	*15*	↑	*3*	*0*	↓	*60*	*70*	↑

The use of personal files, document collections, the Internet and the intranet has increased over the years, while the role of discussion with closest co-workers and other personnel has decreased. Contacts with other water works and attendance in seminars were not considered at all important. All kinds of equipment manuals and brochures especially in electronic form were the most important information sources in 2013. The personnel relied on outside experts more often in 2013 than in 2004.

The concept of social media was included in the interviews in 2013. Twenty- one per cent of the interviewees could not give any definition of social media. More than half of the interviewees (55 per cent) referred to Facebook and Twitter communities as social media. Twelve per cent considered general information forums as social media and six per cent thought that newspapers and broadcast news are part of social media. The remaining six per cent referred to it as unnecessary activity.

4.2 Interpretations of knowledge management

In 2004 very few interviewees knew what knowledge management really meant. Altogether 38 per cent of the interviewed employees said that knowledge management means informing the personnel. In 2013 fifteen per cent connected knowledge management to computers and data management systems; 73 per cent said knowledge management is a personal issue and 12 per cent could not give any definition at all. The percentage of answers referring to individual property increased considerably from 2004 to 2013.

The responses concerning knowledge management were grouped as follows: individual property, organisational property, system information, and miscellaneous. Almost all of the interviewees indicated that knowledge management is controlled individually. The knowledge part was equated with information. They utilise their own knowledge in their work and are always eager and ready to learn more. The type of information was emphasised. They valued in particular information related to practical tasks.

The management part was associated with personal filing systems – either mental or document filing systems. Most of the interviewees referred to their own memory as the store of information from which they find the needed pieces of information. Many also said that knowledge management is related to their own work. In other words, how well they can perform the given tasks and whether they are sure they are doing the right things. In their opinion, it is also knowledge management, if they can manage their knowledge and use it in the right way. They emphasised that water treatment processes are so complicated that one should understand what is really happening in the process, not just turn the button routinely.

4.3 Interpretations of tacit knowledge

In 2004 tacit knowledge was rather unknown to most of the employees at Pori Water. Some 47 per cent of the interviewees had either never heard the word or could not define it. Twenty-three per cent said that tacit means that you keep quiet and say nothing even if you know something. The remaining 30 per cent could explain the word tacit knowledge. When the question was formulated in a different way, all interviewees understood it to mean the knowledge and skills gained over many years at work. Some employees told spontaneously about situations or instances that included a tacit component.

In 2013 as many as 82 per cent knew the concept of tacit without any reformulation, three per cent did not know the concept and 15 per cent thought it means keeping quiet. The concept of tacit knowledge has been discussed in different media, both written and broadcast, during the past 10 years. It has often been linked to the retirement boom with the conclusion that tacit knowledge walks out of the office with retirement. In conclusion, as a result of the public discussion on tacit knowledge the personnel at Pori Water have often heard the word “tacit knowledge” since the year 2004.

Tacit knowledge takes many forms. Based on the interviews in 2004, tacit knowledge could be associated with the following: work experience, craftsmanship, co-workers, something in your head, something not told anyone and miscellaneous. The interviews in 2013 highlighted two new aspects, namely “something not heard” and “hidden”.

Tacit knowledge was associated to the following:

- noises that pumps make: an experienced employee could tell from the noise whether a pump is working properly or the problem with it

- noises from structures: an experienced employee could tell from the noise, if there is a problem or the kind of a possible problem
- smell of the waste water process: a certain type of smell indicates process failure
- colour and structure of activated sludge indicates how the process works
- colour of the foam indicates pH value
- valves and their location in buildings: several valves have special features known only to those working in the area
- network information; all data is not available in maps, so information should be drawn from employees or through site observation.

Tacit knowledge based on work experience is knowledge workers have gathered over several years when doing the same tasks. Workers know on the basis of previous tasks and from their long working experience, how they should handle the tasks they are facing. Experiences, trials and errors have developed into tacit knowledge. It is personal and shared only if someone asks for it. The value of work-based tacit knowledge was considered high and was somehow considered much better than other knowledge. Workers work instinctively to some extent, and as one of them said, they could do the work with their eyes closed. Their work involved some routine phases and the procedures have been developed over the years.

4.4 Sharing of tacit knowledge

Tacit knowledge was mainly shared during daily tasks. The personnel highly valued the professional skills and knowledge of the employee who had a long working history at Pori Water. Tacit knowledge sharing happened at the actual work site where problems arose. The work procedures were demonstrated step by step, if necessary. There was no way of learning the tasks and tricks from books or in the office. The closest co-workers were the key persons whose help was asked.

Knowledge, in particular, tacit knowledge was shared automatically during normal work. As one of the employees said, it is a question of transferring a tradition. There seemed to be an established practice of performing tasks and documenting them in a fixed format.

The role of a more experienced co-worker was emphasised both in 2004 and in 2013. Knowledge sharing took place between newcomers and those with long work experience. Sharing was also common between co-workers. Some of them had been working with the same team, person or persons for more than ten years. However, the research showed that there are some difficulties in knowledge sharing practices. They are summarised below:

- high retirement rate, distorted age structure, mean age close to 50 years
- new personnel not employed, no one to share knowledge with
- no master-apprentice system
- management and organisational structure does not favour sharing

- exceptional cases or problems – for example manual operation of processes or special situations with processes seldom occur and they are always case sensitive, in other words exact knowledge cannot be documented
- lack of time due to work burden
- network maps partly out of date, older employees have knowledge which is not documented or shared
- negative attitude towards sharing, unwillingness to share, employees prefer to keep knowledge as their private property
- internal information flow incomplete, supervisors do not get information, for example of problems occurring with the equipment
- gap between older and younger generation – they do not speak the same language
- personal characteristics and inactivity, people do not seek knowledge actively.

Both in 2004 and in 2013 many of the interviewees tackled the question of a generation gap between younger and older employees, where the older do not necessarily understand the younger and vice versa. The inability of older employees to absorb new knowledge quickly enough may irritate the younger employees, while the know-it-all attitude of the young irritates the old. Teams were also so inflexible in their working procedures that instead of integrating younger members into teams, they tended to direct younger employees to other tasks. Some of this behaviour was explained by older employees as reluctance to guide the younger ones. On the other hand, younger people should be able to discuss and treat older workers in a certain way. They have to know "how to fish for knowledge" from them. Also, decision makers should start to pay more attention to ageing and its implications.

4.5 Knowledge retention

On the one hand, the personnel were fully aware of the importance of undocumented data, information, and knowledge. On the other hand, they were not certain about which information and knowledge are valuable enough to be documented.

Tacit knowledge was both shared and concealed. Some said that they actively shared any information and knowledge they had. Others emphasised that sharing depends partly on the receiver: the receiving person had to be active him or herself and be brave enough to ask. Some were not willing to share knowledge at all.

Difficulties in sharing tacit knowledge were revealed by the interviews indirectly. Personnel, from top to bottom, were concerned about the ageing of the personnel and knowledge disappearing with them the day they retire or otherwise leave the utility. Few new employment contracts were made and this was one of the main reasons why tacit knowledge sharing was insufficient: there is no one to transfer knowledge to.

The knowledge retiring employees had, was revered. Mentoring and master-apprentice systems could be a good means to share knowledge between a newcomer and the personnel retiring soon. The young and old working side by side has been applied at Pori Water, but the time allocated for simultaneous working was too short according to the interviewees.

5. Discussion and conclusions

Information needs and usage in the utility were versatile and depended on the tasks performed by the employees. This research showed that the personnel used personal files, document collections, the Internet and the intranet more often in 2013 than in 2004. The shift from printed material to electronic material has increased over the years and this development was also evident in Pori Water. At the same time discussion with closest co-workers and other personnel had decreased. Social media did not play any role in the case water utility.

Interpretations of knowledge management had changed from informing people to understanding knowledge management as personal, individual property. The personnel were proud of the knowledge they owned of water treatment processes. This knowledge is considered technical knowledge, which is critical to the livelihood of the utility. In this sense the research corresponded well to other research findings.

In 2004 tacit knowledge was an unknown concept while in 2013 the concept was quite clear to most of the personnel. Tacit knowledge was highly valued and it was associated with the skills and knowledge gathered over the years working at the same water works. Tacit knowledge was shared in normal daily work and especially during malfunctions. Unfortunately, part of the personnel still thought that tacit knowledge means that they should not tell anyone what they know. The personnel also worried about the retirement boom and loss of knowledge. The situation with ageing water utility personnel is similar all over the world. Water utilities do not attract younger people, and the retiring people's valuable know-how disappears if water utilities do not properly address this problem.

The research showed that there were several reasons why it was difficult to share knowledge, especially tacit knowledge. The difficulties included for example lack of time and competing priorities. People also mentioned the gap between older and younger generations, managerial and organisational barriers as well as problems in gaining information and unwillingness to share knowledge. These results are in line with other research findings.

Knowledge management requires long-term planning and actions and they should be integrated in the strategy of Pori Water. They should also pay attention to master-apprenticeship relationships, mentoring programmes, knowledge transfer processes and critical knowledge documentation practices.

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Nuisance in communication between facility users and builder: a language barrier

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Abstract

The aim of this research is to observe the barriers in communication between the construction project organisation and facility user organisation. Along the project the user organisation and the construction project organisation have many occasions where they communicate about the future premises but their perspectives are quite different: the user organisation's main concern is how the premises can be used whereas the construction project organisation's main concern is how the premises can be built. Moreover, both organisations deal with the concerns with their own professional jargons. The research question is how the communication and terminology should be established in order to co-create a mutual goal for the project?

The method of the research is case study. The case is a learning space retrofit project in the Musica building that is located in the university campus in Jyväskylä, Finland. The new learning space was co-created through user-centered design workshops. The case is studied by using content analysis to various documents. Documents include materials produced during design workshops (drawings, summaries of discussions, expert-evaluations, and concept designs), memos from official meetings and the user-satisfaction survey comprising statements and open-ended questions regarding the new space and its potential.

Results are indicating that the construction project organisation struggles to understand which features of the project are necessary from the user organisation's point of view. In addition, there are indications that the success of the project is understood very differently between these organisations.

Keywords: retrofit, user-centered approach, co-creation, construction project management, customer satisfaction

1. Introduction

The focus of the builders and the users of the buildings can be very different from each other. So can be the language they use. The communication problems have been identified as a major element in problematic cases (Thomas et al 1998) and consequently, there are studies of communication tools (e.g. Nitithamyong and Skibniewski 2004). However, the perspective of the language used in everyday communication of building projects has not reached such interest. There are some studies about how cultural differences including language problems may make project management more difficult (Ochienga and Priceb 2010), but the language barrier may exist even if the stakeholders have a common cultural background. The purpose of this research is to provide additional understanding about communication problems by studying the differences of the language and jargon that is used by the construction professionals and the users of the building.

The building project team consists of stakeholder with different roles. There are at least the roles of designers, implementers (builders), property owners and users (tenants) (Savolainen et al 2015). In addition, there are the roles of project management and design coordinator, who orchestrates all the other roles. As the value chain goes the tenant organisation pay rent to the property owner who does the investment and pays to the designers and implementers. It is understandable that each stakeholder develops their competence and communication in relation to their purpose of existence i.e. in stem with the value chain.

The roles can be divided into two categories according to the purpose of existence: the users and the others. The purpose of all the others is to ensure that there will be premises to use whereas the users' purpose of existence in most cases has nothing to do with the existence of the premises. Premises are simply one tool among others and the user could implement its purpose in any other premises as well. Thus, the competence and jargon of the users have a little to do with the competence and jargon of all the others. The purpose of the existence also determines the focus of each stakeholder: The users focus on how the premises may be used whereas all the other roles focus on how the premises may be built up.

The data of this study consists of the documents from co-creation workshops that were used for concept designing, the meeting memos of the technical designing and construction phases and the satisfaction survey that was implemented after the occupation of the premises. In the concept design phase, the user role was well represented and the documents are written in users' language. In the technical design phase, the user was still represented, but the focus in the documents was shifted into the accomplishment of the project. In the construction phase meetings, the user role was absent. The user role was re-established immediately after the contract handover when the user group took over the premises and the occupation begun.

The satisfaction survey was implemented twice in the first half year of occupation. The survey was designed so that on the one side there were questions that evaluated the premises' fitness for the activities it was designed for, and on the other side, there were questions to assess the success of the design and implementation. That way it was possible to observe differences in satisfaction expressions between the evaluation based on activities (users' language) and the design and implementation quality assessment (construction professionals' language).

The research gave an interesting insight into the fundamental problems of communication between the professionals of the construction industry and real-estate management and their clients. It gave a novel understanding about how the professionals and their clients view the result of the building project from significantly different perspectives.

2. Theoretical background

2.1 Understanding the importance of professional communication and language

The ways in which experts in the field of real-estate project development understand communication and language, as a dimension of their professional competence, are questions barely explored. In our current knowledge-intensive and meaning-based work culture where shared understanding becomes extremely important, work processes are fundamentally communicative (Kostiainen 2003). Alongside to concrete matters considering the building projects experts in the field of real-estate project development must be capable of abstract and symbolic thinking when doing business with various clientele. Communication and language have a very important role when users evaluate and construct their experience of built environment, spaces and places (e.g. Airo 2014, 12). Information has to be shared for the benefit of everyone who needs to exploit that information in the user-organization. Information mediation and development happen in diverse interactional situations in which appropriate communication competence and understanding of each fields' professional language is needed.

Thus, evaluation of professional competence is less based on employees' status or activities than on their skilful expression of competence in various contexts. Professionals must speak on behalf of themselves and the results of their work, which may be very abstract ideas as well as the creation of common knowledge. The impression of an employee's competence or incompetence in their work is increasingly based on interaction with others. (Kostiainen 2003; Laajalahti 2014.)

In general, communication processes in working life can be considered from the point of view of information exchange or meaning (see Frey et al, 2000, 27-28; Littlejohn, 1999, 6-9). The former emphasizes communication as a tool for transferring information from one source to another. Communication is seen as intentional message production and information exchange. A meaning-based perspective, on the other hand, emphasizes reception and interpretation. As Airo (2014, 19) states 'the built environment is always the institutionalised object of a social process'. Thus, in the field of real-estate project development, the communication process should primarily be seen as a receiver-centred, and as user-centred sense-making process. Nowadays it is extremely important to have a profound understanding of the connection between communication, language and ones' expertise in built environment business and management.

Interpersonal communication in relation to professional competence is increasingly a theoretical as well as a strategic way of thinking, understanding and orientating oneself, as well as a way of taking a stand, viewing and comprehending work and interpersonal relationships there. In relation to interpersonal communication competence, it is less important to define how we should do something or what we must able to do, than what kind of thoughts about communication we should hold. (Kostiainen 2003.)

2.2 Users' role in construction project

Cherns and Bryant (1984) point out that the role of the client is hard to examine because there are things that people are willing to state differently depending whether they are talking privately or in public. Their research is based on private confidential discussions, and thus, it is supposed to give quite an accurate image of the essence of the client's role. About the role, they point out that the client should not be regarded as a unitary concept. Even though the project would be organised so that there is only one nominated contact person who communicates with the construction professionals, behind of that is a complex system of interest groups that sometimes even compete against each other. As the construction project organisation is temporary multiorganisation (TMO), which means that there are lots of people from different firms that are gathered together to accomplish a project within a limited time period, the construction professionals have very limited time and mental capacities to take over all the complexities of the client organisation. That makes them impatient and vulnerable to oversimplifications. The involvement of the client system and its influence within the TMO is high in the initial phases. Thereafter involvement tends to be remitted to the lower levels of hierarchy within the client system which retreats into a reactive mode. So in many cases, the objectives may be initially insufficiently understood because of the oversimplification of client organisation and needs, and the client organisation is not suggested to correcting the misunderstandings as they are supposed to be in a reactive mode. (Cherns and Bryant 1984)

Of course, this is just a general description and there have occurred initials to break this vicious loop of oversimplification and reactive mode. Lindahl (2004) for example has described the method of workplace design that originates from the 1970s. Initially, the workplace design meant that the architect concentrated on employees' perspective and the quality of working environment was embraced. The embracement of the employees' perspective leads to the development of the participatory design methods, especially in Scandinavia. But even though the participatory methods did enhance the possibilities to understand the complexity of the client organisation such elaborate design has not necessarily guaranteed the promised improvement in the performance of work. On the other hand, some workplaces without perfect working conditions or carefully designed aesthetics are recognized as well accepted by employees and effective environments. Hence, Lindahl (2004, 254) suggests that "there is a lack of terms that facilitate a discussion on workspace design and organisational performance". In the research there are identified four aspects to categorize terminology and discussion: Work environment qualities (health and safety), metaphoric and symbolic qualities (corporate image), dynamic and contextual interdependence (actions of the organisation) and degree of participation in the design process (Lindahl 2004).

There has emerged quite significant interest in many industries towards co-operating with the customer. For example, the service dominant logic that states that “customer is always a co-producer” (Vargo and Lusch 2004) has gained recognition as a key marketing concept (Grönroos and Voima 2013). Prahalad and Ramaswamy (2004, 1-2) takes the level of co-operation a bit further as they embrace the significance of co-creation as a driving force for competitive advantage. The basic distinction is that Vargo and Lusch (2004) suggest that customer may be part of the value creation process in every stage of the production whereas Prahalad and Ramaswamy (2004, 49-50) suggest that production process should be designed so that it is actually a chain of value co-creation experiences. Grönroos and Voima (2013) points out that there are still lots of unambiguous concept definitions missing, like the concepts of value and value creation, that are needed in order to find usable managerial implications.

3. Data and Methods

3.1 Case study description

In this case study, 400 m2 premises were retrofitted at the University of Jyväskylä, Finland to better support the core activities of the organization. Before the project, there was a quite popular lunch café at premises, but the café was moving to another building at the campus, so there were well know premises becoming vacant. All other premises in the building were occupied by the department of music so it was decided to develop the premises to support learning, presenting and exploring music.

In our research case, the property owner University Properties of Finland Ltd. recognized that the users’ vast knowhow about learning, presenting and exploring music cannot be embedded into architectural designs with traditional design processes. Therefore, a facilitated design workshop method called charrette was chosen as the main approach in order to improve the quality of the design and to find opportunities to co-create value-in-use. The co-creation project is divided into four phases that follow each other: visioning and concept design, technical design, construction and premises in use. The visioning and concept design phase of the project comprises the initial meetings with the key stakeholders and the charrette co-creation workshops. The technical design comprises the steering group and design meetings. The construction includes both construction and final planning ending with the handover, which started the final phase with the location in use. The co-creation project was part of a national Indoor Environment research project that aimed at designing evidence-based educational spaces for knowledge creation.

3.2 Research method

This research case was divided into three steps:

Step 1: What kind of guidelines and aims for the project were outlined and what kind of needs were generated during participatory workshops (charrette)?
Step 2: Was the evaluation of achieving those aims successful using a satisfactory survey?

Step 3: What kinds of observations were made related to language and communication in the project documentation?

Various types of data were gathered systematically throughout the project in order to examine the whole process: charrette material (data produced during design workshops), memos and minutes and satisfaction survey. All this data combined forms a rich base for the analysis and offers essential information about each phase of the project.

Materials from technical design and construction phases comprise all the memos and minutes from various project meetings. These materials can be seen as a perception of the person responsible for managing the project at the time. It reveals the builders' perspective and their jargon. During the next six months after the implementation, user-experiences and first impressions were gathered by using a satisfactory survey.

The survey was designed so that there were on one side statements that evaluated the premises' fitness for the activities it was designed for (fitness for purpose). On the other side, there were statements that assessed the success of the design and implementation as well as included five open-ended questions regarding the possible use of the space in the future, the atmosphere of the space, the positive and negative aspects of the space and other comments. That way it was possible to observe differences in satisfaction expressions between the evaluation based on activities (users' language) and the design and implementation quality assessment (builders' language) (Step 2). A total of 54 users answered the survey. The majority ($f=32$, $N=54$) of the respondents were students from the Faculty of Human sciences, which includes the Department of Music. Altogether, 48 students, five staff members and one musician completed the survey.

Charrette materials and open-ended questions from the survey were analyzed using a predominantly inductive content analysis (e.g. Thomas, 2006) in order to identify the aims of the design, e.g. requirements for the space. Data was segmented into meaningful analytical units that were encoded. Codes were then divided into (one or more) categories.

The analysis of the multiple choices was conducted by applying the logic of Net Promoter Score (NPS). NPS is developed by Reichheld (2006). The main logic is to divide respondents into three categories: promoters, passive and detractors. The score is calculated by subtracting the number of detractors from the promoters and dividing the sum by the number of all respondents. Those respondents that give undisputedly positive signal on satisfaction can be recognized as promoters. By following that logic, the analysis was conducted by examining the strongest positive answers in relation to other answers in each question.

4. Findings

4.1 Communication in the project

The broad vision of the new space was constructed during the visioning phase that was implemented by participatory workshop process called charrette. The result of the charrette was a spatial concept which included several spaces with different purposes: the stage which was place for presenting live music, the club which was place for both studying in groups and listening the music played on stage, the studio for focused working, the bar that could be used for refreshment providing in organized event or for making coffee if the club was on study use, the show room for place where achievements of the university's department of music, and entrance that would welcome the visitor to building. Analysis of the charrette materials revealed the framework which comprises four guidelines for the concept design: future-orientation, music-orientation, research-orientation and academic-orientation. Later three more defined goals for the project were created: 1) increased use of space, 2) sense of ownership and, 3) improved image of the discipline. In the visioning and concept design phase goals, guidelines and users' needs were communicated in users' language within their context.

At the end of the concept design phase, the objectives of the development were shaped into a form of feasible project. Also, the way of managing the meeting was changed. The focus was shifted from the creative discussions of what should be done into how to accomplish the project within the schedule and the budget. But despite this shift, the user perspective was not forgotten during the technical design phase. However, when the construction phase begun, the users' role was diminished so that they were present in hardly any meetings. User group was reorganized after the handover meeting. The minutes of the user group meeting, which was held immediately after contract delivery handover meeting, present indisputably that there has been a major misunderstanding between the users and builders, and the project management organisation was not capable of dealing with it.

We don't present all the possible misunderstanding that there were, but we take three enlightening examples to present the nature of the language barrier between the users and the construction professionals: curtains, fire detector system modification and outdoor speakers. Common to these three examples is that users' requested all of them in the technical design meetings, but only the fire detector system modifications were delivered. Curtains were discussed in the design meetings because blocking the windows was considered as a vital part of the acoustics. There was a written statement in the minutes that the acoustical curtains will be included in the construction contract. The curtains were also presented in the contract drawings but they were not delivered by the handover. The story is quite similar to the outdoor speakers. They were decided to include in the project because it is important to the place's image that there is an option to play music from the stage straight to the outdoor. The procurement divided so that the user should provide the speakers and the contractor should install the cable and arrange the demolitions and fix-ups for the cable route. Both the speaker cable and the curtains were installed after the handover.

The story of the fire detector modifications was a bit simpler. The modification for the detector was needed because the artists want to use theatre smoke at the stage. It was stated that this can be done by changing a couple of detector units and adding a module to the central unit of the system. The modifications were implemented according to the plan. When comparing these three stories there occurs a question, whether this is random behaviour to accomplish some assignments and ignore others or not.

4.2 Satisfaction expressions

Answers to the open-ended questions were divided into three major categories: infrastructural, practical and emotional. These categories have been described below. The answers were analysed by first recognizing which category each comment fall into and then forming a comprehensive picture of the content of each category.

Emotional factors were mentioned 140 times in the satisfaction survey. Emotional factors refer to experiences through senses by comprising visual, auditory and tactile sensations, as well as cognitive processes and subjective experiences. Comfort was the most commented theme, especially the atmosphere and aesthetics. Respondents described the new space as peaceful, casual and welcoming. Most of the responses were positive but there were also negative aspects. Few respondents stated that the space is uncomfortable or even depressing.

Practical factors were mentioned 117 times. Practical factors refer to elements that are related to or resulting from action. It comprises the key activities and factors that facilitate the core processes of the organization, in this case, learning, presenting and researching. Practical factors were related to all the same themes as in the charrette material: information sharing, learning, the new culture of activities and layout. New space was seen also seen as an environment for creating new cultural activities and organizing music events as well as deep cross-disciplinary cooperative learning and co-teaching.

The infrastructural factors were mentioned 8 times. They refer to the fundamental underlying systems and services necessary for a built environment to function. It compasses all the services and technical structures that enable activities in the space. These comments were related to information sharing and facility management.

Maybe the clearest indication of the significance of the language used can be found in the multiple-choice questions. When comparing the first survey answers to the second survey answers the change in the proportion of the best 5 = "completely agree" answers is striking. However, the development from the first survey to the second one is opposed between the question sets. The satisfaction seems to increase in the set that evaluates the usability of the premises (fitness to purpose) and decrease in the set that assesses the quality of design and implementation. The logical reason was searched from the terminology, and it seems that user is more capable of doing evaluation if the question directs to think the activity first and the space after that. The second set instead directs to think the space first and the effect on action after that.

When the question sets that evaluate usability are compared, it can be observed that the proportion of the best 5 = "completely agree" answers is significantly increased in the second set. This increase can be observed best in the questions "supports individual studying", "supports small group studying", "increases the wellbeing of the students" and "Increases the free association among the students". It seems that during the first half of year the users became familiar with the space and the satisfaction of using the premises grew alongside.

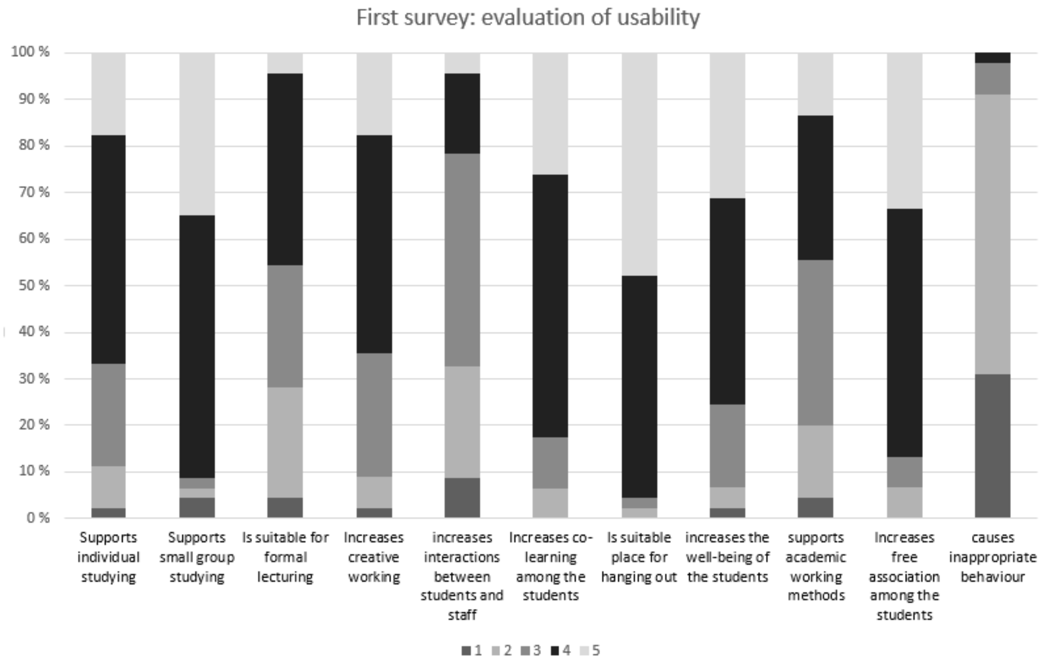

Figure 1: Evaluation of usability question set from the first survey

The growing share of extremely positive answers indicates that the growing satisfaction is not just about the increased understanding how the premises work, but that users actually like to work there i.e. they have become emotionally attached to the premises. Even though the development of the sense of ownership was expected, the result of the first set of the questions (evaluation of usability), the results of the other set (design quality assessment) was not. The best 5 = "Very good" answers had almost disappeared.

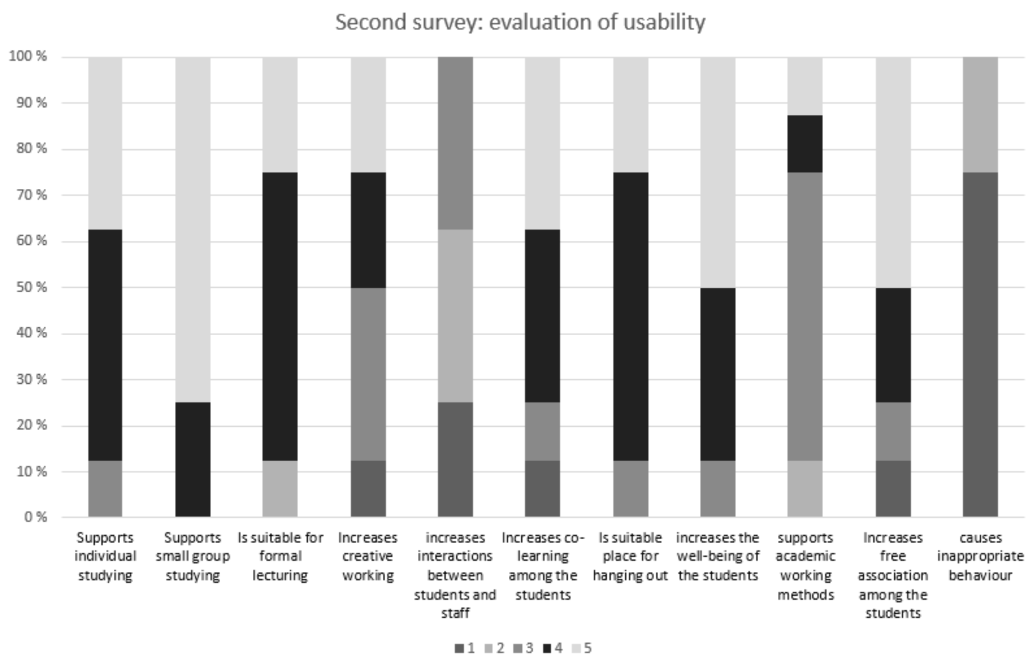

Figure 2: Evaluation of usability question set from the second survey

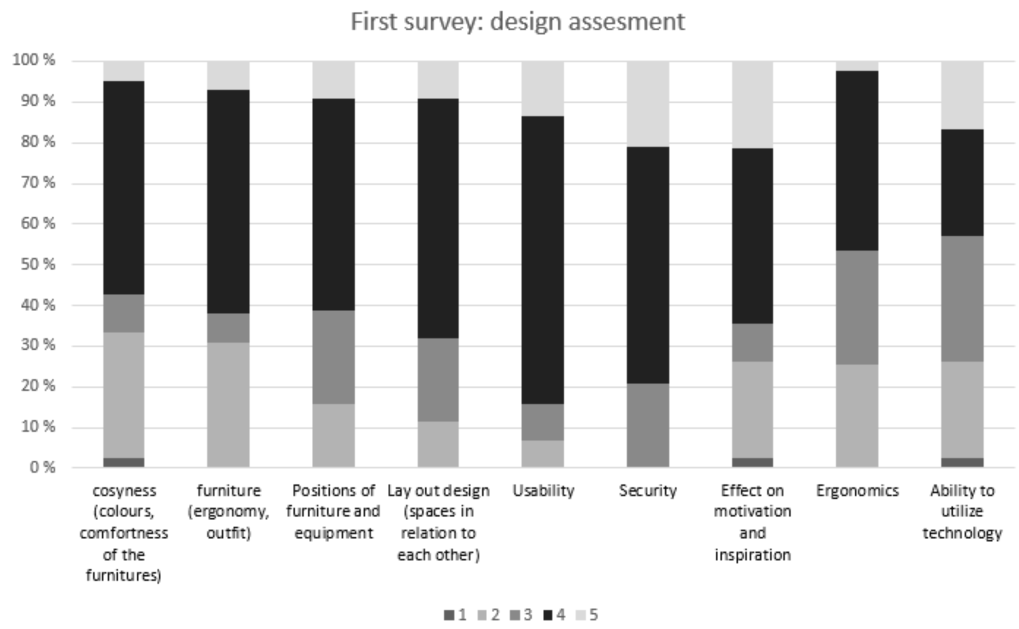

Figure 3: Assessment of the design and implementation question set from the first survey

The best answers were still present only in three questions "lay out design (spaces in relation to each other)", "security" and "ability to utilize technology". And the amount (around 20 %) was small compared with the results of the other set (around 50 % - 70 % at best). The greatest surprise was that even though the increase had been observed in the emotional attachment and sense of ownership, the question "effect on motivation and inspiration" totally lacked the 5 = "Very good" answers. So even though the space is an extremely popular place, the popularity is not perceived as a feature of the space.

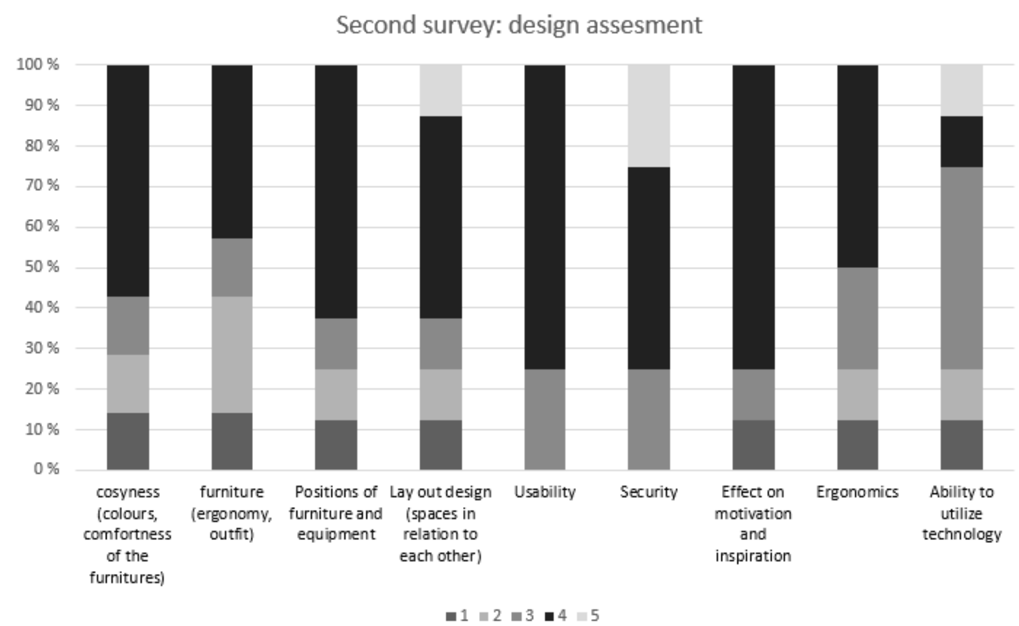

Figure 4: Assessment of the design and implementation question set from the second survey

5. Discussion

Our research supports Lindahl's (2004) perception of the user need categorization. The research confirms that there are needs concerning mainly health and safety (we call these infrastructural needs), needs concerning activities of the user (practical needs) and needs concerning metaphoric qualities and symbols (emotional needs). Lindahl (2004) also presents the fourth aspect that is a degree of participatory in the design process. Our research supports the assumption that it is a crucial aspect, but we would rather separate it from the first three. The first three aspects can be understood as user needs whereas the fourth one may be understood as a meter of which level of needs the service process has reached.

Our three examples of how user needs were treated during the design and construction phases (curtains, fire detector system modification and outdoor speakers) indicate that construction professionals tend to deal only with the features related to the infrastructural needs. There was no significant difference between these three tasks in schedule wise or budget wise. Neither there was a difference about how they were stated in the meetings. It was made clear that all of these are important for the user. The need for the fire detector system modification was related to infrastructural needs whereas the other two was related to practical and emotional needs.

6. Conclusions

Our study and our results are all but comprehensive description of the communication problems between construction industry professionals and their clients. Despite the fact that there were only eight answers in the second survey, our research provides evidence that the emotional attachment and sense of ownership are such qualities that are hard if not impossible to embed into space. The culture of the user group seems to have much stronger relation to these qualities than the premises itself.

If the infrastructural needs are compared with the other two categories, it can be realized that engineering safe and healthy indoor climate differs quite a bit from designing how the premises effect on human behaviour or human emotions. It may be that most of the engineers are willing to settle for handling the infrastructural needs: The outcome is much more predictable and needs much fewer adjustments afterwards. That way the engineer can be sure about the value he/she has to offer. But the downside is that the service and the terminology concerning the practical and emotional needs remain underdeveloped. As the oversimplification of the communication problems is supposed to be malicious, these problems will require a lot more research in order to find ways to offer services not only to the infrastructural level of needs but all the needs users have. We suggest that project management service providers could gain significant competition advantage via better understanding of needs.

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Exploring Dimensions of Job Satisfaction and Relationships with Performance: Evidences from Construction Professionals

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Abstract

Theoretical explorations and empirical demonstrations of the nexus between job satisfaction and job performance have never ceased. Some argue "happier workers produce more", while some insist that workers with better performance achieve satisfaction through bigger chances of rewards. In a review of previous studies, weak empirical evidence may be attributed to changing definitions of concepts. This study conducts a fine-grained analysis to propose a new conceptual model based on the S-P nexus. Firstly, job satisfaction is divided into economic satisfaction (ES) and production-related/noneconomic satisfaction (PS). This assumption is validated in this study by principal component analysis of empirical evidence from a questionnaire survey of construction professionals in China. It is found that the effects of ES and PS on job performance are different and warrant further study. The proposed model will be helpful to both academics and practitioners when investigating the nature of the satisfaction-performance nexus and making strategic decisions on personnel management.

Keywords: Job satisfaction, job performance, questionnaire survey, fine-grained analysis, construction professional

1. Introduction

The relationship between job satisfaction and performance (S-P) has been an important topic of study for academics and organisation managers for many decades since the Hawthorne studies and the human relations movement in the 1930s (Judge et al., 2001). It is initially proposed that "happier workers produce more" which gains popularity as an argument because of its consistency with intuition. In the 1960s, some researchers (Lawler and Porter, 1967) argued that job satisfaction was induced by performance for rewards, and that good performers gain more rewards and are happier. Both opinions are supported by theory. The former opinion is supported by the theory of reciprocity — that an employee has a natural intention to respond reciprocally to perceived kindness and unkindness (Falk & Fischbacher, 2006). The latter opinion is based on motivation theory, which reasons that rewards, led by the job performance of employees, result in satisfaction and even higher subsequent performance in response to the effects of organisational commitment and goal setting (Latham & Pinder, 2005). However, convincing empirical evidence for both assumptions are still lacking. Some researchers (Fisher, (2003) describe the S-P nexus as simple "folk wisdom".

Reviewing previous studies, weak and inconsistent empirical evidence for the S-P nexus can be attributed to changing definitions of concepts and divisibility of abstract terms. For example, satisfaction may have several facets, especially economic satisfaction (ES) and production-related/noneconomic satisfaction (PS) (Xiong et al., 2014). Similarly, dimensions of job performance include task performance, organisational citizen behaviour and even anti-productive behaviours (Viswesvaran & Ones, 2000). This study divides job satisfaction into economic satisfaction and noneconomic satisfaction, and uses task performance (TP) as the measure of job performance. It is proposed that PS increases TP and then TP increases ES. A literature review is firstly conducted and then a conceptual framework is proposed. Statistical analyses are further applied to validate the hypothesised model.

2. Literature review

2.1 Linkage between individual satisfaction and performance

Studies on the relationships between job satisfaction and job performance comprise an appreciable portion of behaviour research in management (Organ, 1988b). Additionally, the discrepancy between the strong intuition among practitioners that satisfaction has an obvious influence on productivity and low correlations for these elements of performance obtained in empirical studies has made this an appealing topic for researchers for decades (Judge et al., 2001). There are three mainstream hypotheses on the S-P nexus: (1) job satisfaction causes job performance; (2) job performance causes job satisfaction; (3) there are other complex relationships between the two including moderators, mediators or antecedent variables.

The first of these hypotheses again goes back to the Hawthorne studies and human relations movement, when the idea that improvement in employee morale leads to production improvement became widely accepted (Schwab & Cummings, 1970). Despite little supporting empirical evidence, the hypothesis that job attitudes affect employee behaviour became accepted as logically reasonable (Judge et al., 2001) and used as a common assumption in many studies. The second hypothesis reverses the cause and the effect, with Lawler and Porter (1967), for example, pointing out that rewards were not adequately considered in previous research, and it was therefore reasonable to assume that satisfaction follows the rewards produced by performance. Although there is some empirical evidence in favour of the second hypothesis (Judge et al., 2001), it is still insufficient to be convincing and has been criticised as containing a hidden and questionable presumption that performance and rewards are closely linked for individual workers (Fisher, 2003).

Because of the weak empirical evidence relating to the first two hypotheses, some researchers have turned to exploring common antecedent variables for satisfaction and performance in terms of mediators and moderators in the job S-P linkage (Judge et al., 2001; Schwab & Cummings, 1970). Some researchers such as Schwab and Cummings, 1970) argue that the unsatisfactory outcomes of S-P linkage research have been mainly caused by the ambiguity of definitions of job satisfaction. Although some measures of job satisfaction such as the Job Descriptive Index (Smith, 1969) and Minnesota Satisfaction Questionnaire (Weiss, Dawis, & England, 1967) have been developed, job satisfaction is still seen as a holistic concept in applications connecting satisfaction and job performance. It has been suggested that researchers should explore the relationship between specific attitude measures and specific job behaviours, rather than the link between general satisfaction and a specific behaviour (Fisher, 2003). Lai (2007), for example, divided the job satisfaction of dealers in the motor industry into social satisfaction and economic satisfaction, and found that noneconomic satisfaction was much more important than economic satisfaction in influencing performance. This dichotomy is also consistent with Brown's (2001) finding that economic satisfaction should be treated separately for analysis, since it is highly related to pay factors like pay equity.

However, some previous studies (Janssen and Van Yperen, 2004) fail to connect satisfaction with performance, while other studies (Lai, 2007; Nerkar et al., 1996) assume that all disaggregated satisfaction facets share common unidirectional relationships with performance; for instance, all satisfaction sub-dimensions lead to performance. Therefore, the vital unanswered question is whether it is possible that the low correlation observed in previous studies between overall satisfaction and performance was caused by different or even conflicting causal relationships between satisfaction sub-dimensions and performance. For example, economic satisfaction (satisfaction with pay) generated by receiving rewards is caused by performance rather than being a cause of performance, while some other satisfaction dimensions (such as satisfaction with co-workers and supervisors) may enhance performance.

Another explanation for unsatisfactory previous research results can also be attributed to changes in the conceptualisation of job performance. In early organisational studies such as the Hawthorne studies, job performance is considered to be virtually the same as task performance, defined as

> the proficiency with which incumbents perform activities that are formally recognized as part of their jobs; activities that contribute to the organization's technical core either directly by implementing a part of its technological process, or indirectly by providing it with needed materials or services. (Borman & Motowidlo, 1993a, p73)

In recent decades, another category of employee behaviour, known as organisational citizen behaviour (OCB), has been identified and accepted by both academics and practitioners. This assumes that job responsibilities, expressed active involvement in the organisation, and innovation for the benefit of the organisation take place even without reward expectations (Eisenberger et al., 1990). Job performance nowadays includes task performance, OCB and even counterproductive behaviours in some situations (Viswesvaran & Ones, 2000). As an early stage exploration, this study focuses on task performance (TP).

2.2 Conceptual model development

Many conceptual models describing job satisfaction and performance have been proposed, as presented in Figure 1 adapted from Judge, et al. (2001). The first three models assume there are causal relationships between job satisfaction and job performance. Model 4 and Model 5 assume there are antecedents or moderators affecting the S-P nexus. Model 6 is the null model that assuming there is no relationship.

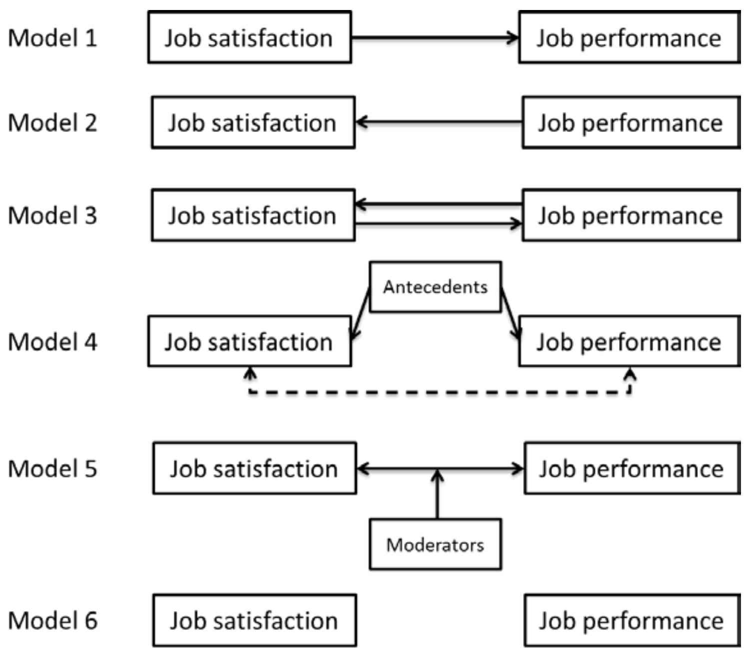


Figure 1: Main conceptual models of the S-P nexus

Following the majority of previous studies (Judge et al., 2001; Organ, 1988), this paper assumes there is a positive correlation between overall job satisfaction and job performance. In addition to the overall S-P nexus, a fine-grained hypothesized model is developed by using two broad dimensions of job satisfaction in terms of ES and PS. The theory of reciprocity and motivation theory are used to develop the conceptual model, as presented in Figure 2.

Figure 2: Proposed conceptual model in this study

3. Research method

3.1 Questionnaire survey

To explore the S-P nexus, related items of the questionnaire survey concerning interactions between person and environment are used, as presented in Table 1. Respondents are construction cost engineers also known as quantity surveyors. To measure job satisfaction, eight items as presented in Table 1 are used based on previous works of Smith (1969), Cotton and Tuttle (1986) and Xiong et al. (2014). Following previous works of Skitmore and Marston (1999) and Leung, Olomolaiye, Chong, and Lam (2005), five items such as "I estimate the budget of the project without overrunning" are used to measure task performance of those professionals.

Table 1: Measures of Job satisfaction

No.	Job satisfaction measures	1-not at all to 7 very intensive	Don't know
Q1	*Satisfaction with pay*	*1 2 3 4 5 6 7*	□
Q2	*Satisfaction with promotional opportunities*	*1 2 3 4 5 6 7*	□
Q3	*Satisfaction with organizational welfare*	*1 2 3 4 5 6 7*	□
Q4	*Satisfaction with work itself*	*1 2 3 4 5 6 7*	□
Q5	*Satisfaction with supervision*	*1 2 3 4 5 6 7*	□
Q6	*Satisfaction with co-workers*	*1 2 3 4 5 6 7*	□
Q7	*Satisfaction with workload*	*1 2 3 4 5 6 7*	□
Q8	*Satisfaction with current tasks*	*1 2 3 4 5 6 7*	□

Because of cultural and linguistic differences, the translation of questionnaires from English to Chinese needs be carried out with care. To keep sure of content validity, the translation and back translation technique (see detailed steps in Xiong, Skitmore, and Xia (2015)) was applied with assistance of four bilingual researchers.

3.2 Data collection and demographics

The snowball sampling technique is useful to gather sensitive information, especially in a situation where random sampling is not available. Snowball sampling allows researchers to access informants through contact information provided by other informants, and has been the most widely employed sampling method in many disciplines across the social sciences (Noy, 2008). Considering the study context, this technique is appropriate to this study. 285 complete responses among 310 returned ones were considered valid for further analysis in this study. The majority of respondents have a bachelor degree or higher education level. Respondents are almost evenly distributed across some characteristics, including gender (male/female), working city/state, company type (property developer/construction company/consulting company) and employment sector (public/private). To evaluate the internal consistency of the questionnaire items, Cronbach's alpha is calculated in SPSS 21.0, with the overall value equal to 0.868, indicating good consistency.

4. Result

4.1 Principal component analysis

The PCA confirms a two-dimensional structure of job satisfaction, with a 0.836 Kaiser-Mayer-Olkin measure of sampling adequacy higher than the a cut-off value of 0.5 and a highly significant $p<0.0001$ for Bartlett's test for sphericity indicating that the items are suitable for factor analyses. The solution with applying varimax rotation explains 65.7% variance of overall variance with component 1 and component 2 accounting for 50.5% and 15.2% respectively. Loadings with components, means, standard deviations and communities (h^2) of items are summarised in Table 2.

Table 2: Principal component analysis with varimax rotation

Items	Components		Item parameters		
	1	2	Mean	SD	h^2
Q1	*0.130*	*0.857*	*3.860*	*1.325*	*0.751*
Q2	*0.263*	*0.813*	*3.912*	*1.328*	*0.730*
Q3	*0.242*	*0.817*	*3.891*	*1.391*	*0.726*
Q4	*0.652*	*0.387*	*4.488*	*1.165*	*0.576*
Q5	*0.628*	*0.383*	*4.656*	*1.439*	*0.540*
Q6	*0.792*	*-0.087*	*5.193*	*1.163*	*0.635*
Q7	*0.680*	*0.347*	*4.284*	*1.327*	*0.583*
Q8	*0.797*	*0.287*	*4.442*	*1.254*	*0.717*

4.2 Correlation and regression analysis

To investigate the necessity to distinguish ES and PS, effects of sub-dimensional satisfaction on task performance are explored by applying regression analysis. Average values of ES, PS, and task performance are calculated. Overall satisfaction is attained by calculating the average of ES and PS with assuming equal weight. Correlations of these factors are firstly presented in Table 3. Regression analysis is firstly applied as Model A. If these two dimensions share consistency (e.g. Nerkar et al. (1996)), their effects on task performance should be consistent. However, it is found that only PS has a significant positive effect on task performance. Model B is then developed as conceptual model presented in Figure 2. The attained results are reasonable that PS positively affects task performance, and TP positively affects ES.

Table 3:Correlations between factors

Factors	A	B	C
A. task Performance	1		
B. ES_A	0.193**	1	
C. PS_A	0.344**	0.558**	1
D. overall satisfaction	0.296**	0.905**	0.858**

Note: **. Correlation is significant at the 0.01 level (2-tailed).

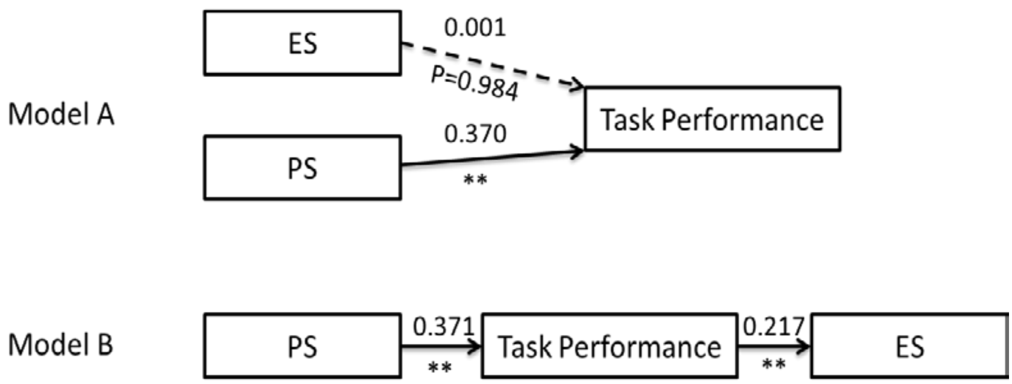
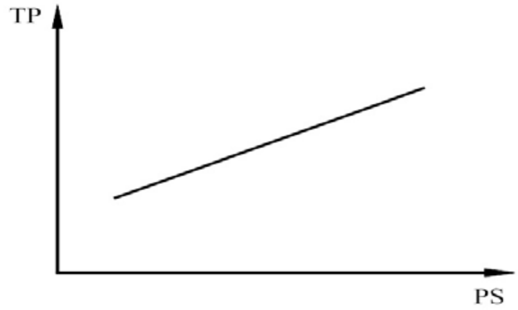


Figure 3: Model evaluations by regression analysis

4.3 The form of interaction

The above linear regression results reveal overall positive effects of PS on TP and TP on ES. It is found in studies of stress that although work stress has an overall negative effect on job performance, the relationship would be better to be descripted as n-shaped or inverted U-shaped form that there is a quadratic effect of stress on performance (Leung et al., 2005; Xiong et al., 2015). Considering similarity between stress and satisfaction, this study explores relationship form of two relationships in terms of PS-TP, TP-ES. Results are presented in Table 4.

Table 4: forms of effects

<table>
<tr><td>Relationships</td><td>Relationship form</td></tr>
<tr><td>PS-TP</td><td>
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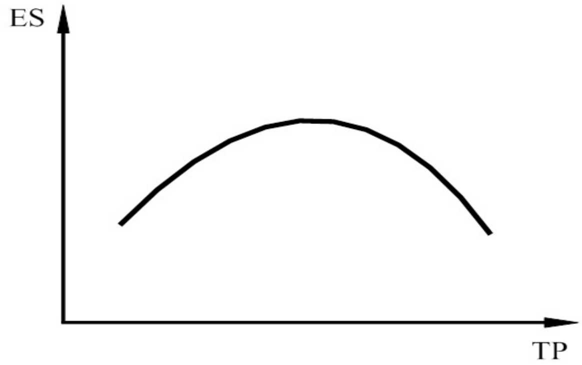
<tr><td>TP-ES</td><td>
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5. Discussion and Conclusions

n previous studies on the nexus between job satisfaction and job performance, job satisfaction has been widely taken as a holistic term without investigating the internal dimensions. In the literature review, a two-dimensional structure of job satisfaction is proposed. As presented in Table 2, economic satisfaction (ES) and production-related satisfaction (PS) are different components. Similarly, job performance is a multi-attribute concept. This study focuses on task performance only.

To evaluate the validity of the proposed model in Figure 2, correlation and regression analyses are applied. Comparing the modelling results of Model A and Model B, it is necessary to distinguish ES and PS. Additionally, this study proposes a new model to describe relationships between the sub-dimensions of job satisfaction and performance. In addition to support from theories including reciprocity theory and motivation theory, this model is demonstrated as valid by empirical evidence gained from construction professionals in China.

In addition to overall positive linear effects of PS-TP and TP-ES as presented in Figure 3, it is found that n-shaped relationship would be better to describe the effect of TP on ES. Findings in this study would benefit further studies on the nexus between job satisfaction and performance.

There are a few limitations worth to be mentioned. Following the stimulus-organism-response paradigm in studying employee behaviour, antecedents of job satisfaction and performance include working environment factors like organizational support and individual characteristics (Xiong, 2015). Without considering these factors thoroughly, situations like Model 4 and Model 5 pointed by Judge et al. (2001) are needed to be further investigated in future research.

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Towards new shores in the Norwegian AEC-industry – A review of building process-related R&D initiatives and their impact

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Abstract

The overall and increasing awareness about the need to rethink traditional building processes has kicked-off a number of efforts in Norway. This conceptual paper presents a review of building process related R&D initiatives in the Norwegian AEC-industry. The paper reflects on the role of these initiatives as change drivers; in the transformation process from where the AEC-industry is today, towards new shores. The initiatives are many and there is a lack of holistic understanding of how the initiatives work (or not work) together in an ecosystem of change. The paper suggests a holistic framework for gaining better overview and understanding of the interrelationships between initiatives aiming to improve how we organize and execute building projects.

The framework contains two main dimensions. The first dimension is the definition of three levels of activity; the societal/authority level, the AEC-industry level, and the project level. The paper describes several examples of initiatives on each level. The second dimension is the identification of four groups of change drivers and measures; 1) game-changers, 2) top-down initiatives, 3) bottom-up initiatives and 4) incubators. These four groups are characterized by various degrees of being planned or random, and by having long-termed/global impact or short-termed/local impact perspectives. Strengths and weaknesses of the groups are discussed, as well as interrelationships across levels and interfaces. The paper applies a reflective approach, based on observations of practice in the Norwegian AEC-industry, through participation in workshops, discussions, and conferences. The discussions are furthermore based on reviews of key documents such as policy documents, strategies, and research proposals.

The increasing complexity and the rapid development on all levels in the AEC-industry calls for a more systematic, interdisciplinary, continuous and holistic competence and knowledge building. A better understanding of how the related R&D initiatives work, or counteract, can be helpful in optimizing their effect on the building processes.

Keywords: building process, change, holistic framework, R&D, overview.

1. Introduction

"I have yet to see any problem, however complicated, which, when looked at in the right way did not become still more complicated." Poul Anderson.

There seems to be a widespread consensus in the Norwegian AEC-industry (architecture, engineering, construction) about the urgent need for more research-based knowledge on how we should organize and execute our building projects. A number of initiatives with the aim to address this need have been kicked off during the last years.

This conceptual paper presents a review of these initiatives. The paper reflects on their role as change drivers in the transformation from where the AEC-industry is today, to where it should be, according to a number of national policies and strategies. The initiatives are many and there is a lack of holistic understanding of how the initiatives work (or not work) together in an ecosystem of change. The paper suggests a framework for gaining better overview and understanding of the driving forces of building process-related change and improvement in the AEC-industry. The framework is intended as a support for decision- and strategy makers, for funding institutions, and for research environments.

Firstly, the paper describes the backdrop which motivates the current building process-improvement efforts in the Norwegian AEC-industry. The paper briefly presents some theories, which have inspired the approach of the framework. The main part of the paper presents the review and related discussions of the current status in the AEC-industry, based on the application of the holistic framework. The paper concludes with a summary of trends and suggestions for further work.

2. Backdrop

Building, real estate, and infrastructure together represent the largest land-based industry in Norway when it comes to value creation. The sector consists of some few large enterprises and many SMEs. Approximately 320 000 workers in more than 85 000 enterprises are employed in the industry. Thus, directly or indirectly, the industry ensures economic growth and the income of a substantial part of Norwegian employees (Espelien, Theie and Bygballe, 2015). Simultaneously, the industry is responsible for creating and maintaining the built environment which affects us both as a society and as individuals.

In the last decades, groundbreaking innovations in means and modes of collaboration, enabling technologies, and standardization/industrialization of products and processes have unfolded. It is a paradox that the AEC-industry still underperforms when it comes to the quality of its end-products, innovation, and productivity. These aspects affect, in turn, value creation for the end-users and the society. The report of Egan (1998) still seems to be relevant in describing the AEC-industry as "adversarial", "ineffective", "fragmented", and "incapable of delivering for its clients". This is well illustrated in a quote from an American report, stating: "Construction projects frequently suffer from adversarial relationships, low rates of productivity, high rates of inefficiency and rework, frequent disputes, and lack of innovation, resulting in too many projects that cost too much and/or take too long to build. Also, projects continue to injure or kill too many workers, and owners are often disappointed with the quality of the end product" (Darrington et. al 2010). Key actors in the Norwegian AEC-industry pointed in 2014[1] to industry challenges such as:

- *Dysfunctional and fragmented industry:* The tender structure is competitive. There is a conflict-oriented mode materializing in disagreements and trials. There is a need for efforts and measures way beyond the ability of the individual actor;
- *Communication barriers and lack of trust:* There is a lack of transparency in work- and decision-making processes, as well as trust-based relationships and empowered employees;
- There is a need for collaborative efforts engaging and involving actors across the organizational barriers we traditionally face;
- *Short-term goals and focus on the "lowest bid":* Actors of the building process sub-optimize due to short-term focus on economy as decision criteria, rather than contract and order regimes that focuses on performance. There is a need to focus on long term goals, results/end products, user needs and value creation;
- *Increasing complexity:* The numbers of specialists, with different and often divergent needs and aims have increased and add complexity to the process. There is a need for cross-disciplinary approaches and multidisciplinary research activities;
- *Lack of implementation and adaption of projects to new technology and vice-versa:* The technology develops rapidly. This poses great challenges to the actors of the building process in adjusting and keeping up with the pace and the industry lacks trained personnel;
- *Lack of superior role models:* There are few locomotives of innovation within the industry, as it can be found in other successful industries (e.g. the offshore industry). There is a need for superior role models to push forward the innovation front.

This paints a rather gloomy picture of the AEC-industry. However, in several industry-wide discussions, participants emphasize that we should not disregard the stories of success and not forget to look critically on established industry "myths and truths". Yet the overall opinion of the AEC-industry seems to be that there is a need for change in how building projects are organized and executed, and that more R&D is urgently required. This need is further accentuated by:

- Societal challenges such as health and welfare, scarcity of resources, climate change, mitigation and adaptation;
- Urbanization, population growth and related productivity pressure;
- Increased globalization and international market competition, workforce migration;
- Changing markets and user needs, new legal requirements, and clients who are more demanding.

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[1] Identified in industry workshops and gatherings arranged by NTNU (2012-2013) and Bygg21.

Why does the AEC-industry underperform, in spite of all R&D-efforts and groundbreaking innovations, which obviously have enhanced great improvements in other industries? Past efforts show that there is no obvious or easy formula or recipe to success. A better understanding of the interrelationships between the drivers and measures that change how we organize and execute building projects can be helpful. In order to achieve such understanding, we need applicable tools and frameworks.

3. A holistic framework

3.1 Change one thing, change everything?

The current societal, economic and technological trends are requiring, driving and enabling change of practice, research and education across traditional disciplines and curricula. The AEC-industry can be said to be in a transition phase, on its way towards new shores. As a bi-product of this transition phase we see that the AEC-community face an increasing complexity which makes it highly challenging to address the various, partly conflicting, aims and values of all parties involved. The mix of uncertainty, uniqueness, interdependencies and unpredictable cause-effect relations create a context in which AEC-practitioners sometimes are managing mess rather than solving problems. Researchers such as Schön (1991) and Gibbons et al (1994) regards the traditions of Technical Rationality and Mode 1 knowledge production as insufficient in a real-world situation where many solutions cannot be found in a book or manual. Schön (1991) introduces Reflection-in-Action and Reflection-on-Action as fruitful approaches to better understanding how we learn, acquire and apply knowledge. Gibbons et al 1994) introduces Mode 2 knowledge production, which is transdisciplinary, transient, heterarchical and carried out in a context of application.

The awareness that many problems cannot be solved within a single tradition, organization, or on a single level in the AEC-industry, is increasing. This seems to have resulted in a shift from technology-biased focus and "silothinking" approaches, towards more integrated and holistic and interdisciplinary ways of thinking and working in the AEC-industry. There are a growing number of R&D initiatives which are looking at interfaces between entities and traditions, on value-creating synergies and integrated models, on life-cycle scenarios, on "soft" as well as "hard" skills and issues. One of these is consolidated in the CIB priority theme IDDS (Integrated Design and Delivery Systems) (Owen et al, 2010).

3.2 The framework, data and limitations

The idea behind the framework arises out of previous work with developing holistic approaches for better understanding complex phenomena in the AEC-industry (Moum, 2008). It is also based on reflective and explorative analyzes inspired by the thinking of researchers such as Schön (1991) and Gibbons et al (1994). The dimensions and elements of the framework will be explained and demonstrated throughout the review and the discussions which follow in the next section.

This paper is primarily based on observations of practice in the Norwegian AEC-industry, through participation in workshops, discussions, conferences, and on review of key documents such as policy documents, strategies and research proposals. The author has furthermore held key positions in some of the initiatives described. The framework idea and related overview/review is thus based on the reflections of the author, and on a Norwegian context. The paper presents examples of R&D activities, and not a complete summary of everything going on. In the further development of the framework, an extended review of supporting or challenging theories should be carried out, as the framework should be applied on similar situations in other countries. Through this conceptual paper, research fellows are invited to give their view on the framework and its usefulness. The framework and the related reflections are meant to kick off discussions and inspire further R&D activities in the field.

4. A multi-level review of the Status quo

The overall and increasing awareness about the need to rethink traditional building processes has kicked-off efforts on various levels. Three levels represent the first main dimension in the framework: 1) the societal/authority level, 2) the AEC-industry level and 3) the project level. In the following section, a brief overview of change-driving initiatives and measures related to each level is given.

4.1 Societal/authority level

"Buildings and infrastructure create great value and quality for its users and the society. They are flexible and use technology in smart ways. The construction industry contributes to solving social, health-related and environmental challenges in the society. The industry produces error-free, environmental-friendly and cost-efficient buildings and infrastructure, and improves the existing built environment. The construction sector is productive, innovative, competitive and strongly positioned on the global arena. The sector is effective, has a good reputation and it provides highly attractive work-places." (Ministry of Local Government and Regional Development, 2012. Authors translation).

This 2030-vision is stated in the White paper Good Buildings for a Better Society (2012), which was handed over to the Norwegian Parliament in 2012 by the Ministry of Local Government and Regional Development. The White paper is based on around 30 contributions from academia, organizations and companies/actors representing the entire value chain of the AEC-industry. As a result of the objectives and intentions described in this paper, a collaborative and interactive arena between the public authorities and the AEC-industry was established in 2013. This collaborative program is called Bygg21 (Construction 21), and is hosted by the Agency for Construction Quality (Direktoratet for Byggkvalitet/DiBK).

4.2 AEC-industry level

Bygg21 has developed an overall strategy for the AEC-industry (Bygg21, 2014), which addresses three main activity areas; 1) R&D and innovation, 2) education and 3) knowledge dissemination. Four building process-related focus-areas of R&D have been identified in this strategy; 1) Standardization and industrial design, 2) Value-creating collaboration, 3) KPIs and benchmarking, and 4) Simplification of laws and regulations.

The board of Bygg21 consists of people representing the CEO-level in leading Norwegian R&D- and AEC-companies. Bygg21 has initiated and partly also funded several ongoing activities on national level. One of these is the "Next step" project – a national guideline which organizes the building process in 8 key stages, from "cradle to grave" (from strategic definition to demolition). The guideline is a modified and Norway-tailored version of RIBAs plan of work[2], and shall contribute to an AEC-industry wide terminology and common understanding of the main stages of the building process. Another important activity is the so-called "performance benchmarking project", where the American Construction Industry Institute's 10-10 benchmarking system[3] is tested out by a number of companies in the Norwegian AEC industry.

In 2012, several key players in the AEC-industry formulated a collective call for more knowledge on building processes. NTNU carried out, on their assignment, a feasibility study on how to organize a national joint effort. This resulted in the establishment of Project Norway in 2014 – The Norwegian Centre of Project-Related Activity[4]. Project Norway includes a program dedicated to the AEC-industry and building process-related R&D (the BAE-program). Today, the program has around 15 partners including NTNU, SINTEF and BI Norwegian Business School. In its strategy, the program states that its partners shall actively contribute to initiating and stimulating experience exchange between R&D projects and activities. The program seeks furthermore to improve the framework conditions for process-related R&D and innovation (funding models, national policies etc.).

Other Norwegian AEC-networks, organizations and communities which have process-related R&D and innovation on their agenda is BuildingSMART Norway, Lean Construction Norway and the professional associations and organizations. Examples of thematic collaborative initiatives (stimulated by the authorities) are joint efforts with the aim to improve HSE (no mortal injuries on the construction site) or avoid AEC-industry criminality and "black" working. One of the latest initiatives on AEC-industry level is to develop a roadmap for a digital AEC-industry (the first gathering took place in October 2015, hosted by The Federation of Norwegian Construction Industries/BNL).

4.3 Project level

Throughout the last five years, a number of building-process related R&D projects have been established. Typically, these are so-called Innovation projects. Innovation Projects for the Industrial Sector are funded by User-driven Research based Innovation (BIA), a programme of

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[2] http://www.ribaplanofwork.com/Download.aspx
[3] https://www.construction-institute.org/scriptcontent/10-10_promo.cfm
[4] http://www.prosjektnorge.no

The Research Council of Norway (RCN). The BIA programme aims to promote value creation in Norwegian trade and industry through research-based innovation in companies and the R&D groups with which they cooperate (RCN, 2015). Innovation Projects are owned by a company or organization, and they include research activities and knowledge development needed for implementing innovations and value-creating renewals. These projects call for a research methodology which enables a high degree of interaction between the industrial partners and the involved R&D environments. A successful implementation which enables a subsequently value-creating effect in the companies is crucial.

Table 1 shows ongoing Innovation projects (except BA2015, which is a consortium funded project). This funding model is dominating in the current Norwegian AEC-industry. The projects are commonly based on real-life demonstration projects and/or case-studies. Building projects are actively used as a living lab for collecting data, learning and testing out new solutions. The possibility of in-kind contribution instead of cash seems to lower the threshold for industry partner involvement. This might to some degree explain the dominance of this funding model within building process related R&D.

"Hot topics" are lean design and production, BIM, new collaborative models, value creation, efficiency, project management and the learning from other industries (such as oil and gas).

Table 1: Overview of ongoing R&D projects (Source: BAE-program)

Project	***Purpose***	***Periode***	***Project owner and partners***
OSCAR – Creating value for owner and user (innovation project)	*Focus on early stage planning and experiences from operation and use. Effectiveness.*	*2014-2017*	*Multiconsult AS (consultant company)*
SpeedUp (innovation project)	*50% shorter execution time. Eliminating time-thieves and making processes more efficient.*	*2014 - 2018*	*Reinertsen (consultant company, former contractor)*
SamBIM - BIM-driven collaboration in the building process. (innovation project)	*Develop BIM-driven processes and collaborative models that boost value creation.*	*2012-2016*	*Skanska Norway (contractor)*
HPWS - High Performance Work. (innovation project)	*Development of the Norwegian collaborative model for efficient production in periods with hired workforce.*	*2013-2017*	*Grande Entreprenør (contractor)*
INPRO - Integrated methodology for design management. (innovation project)	*Better understanding management of production based processes, based on involving planning (Involverende Planlegging).*	*2013-2017*	*Veidekke Entreprenør (contractor)*
BA2015	*Improve efficiency and sustainability of the AEC-industry. Focus on benchmarking (collaboration with CII in the USA), and demonstration projects.*	*2013 - 2015*	*Consortium-funded program with 18 partners from industry and academia. Project management by Metier, SINTEF and NTNU.*

5. Discussion

The multi-level status quo shows that there are many process-relevant R&D initiatives going on or on their way. How do they contribute to change and impact, across levels, actors and projects? To which degree are these initiatives drivers or measures for change – and what are their weaknesses? In order to discuss this, the following section explains the second dimension of the conceptual framework: the four groups of change-drivers and measures.

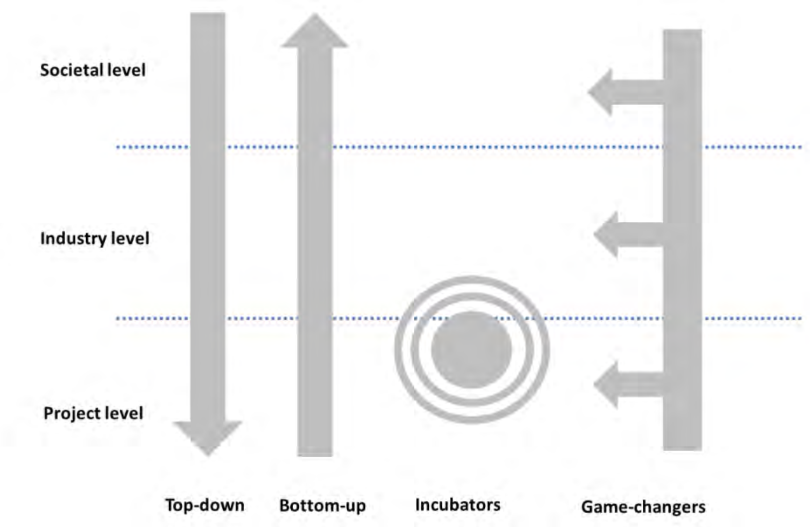

Figure 1: Change drivers

5.1 Game-changers

Game-changers, as we use the term in this paper, are people, products or processes with the power to change mindsets and how we live, collaborate and work. Enabling technologies are obvious examples of game-changers. The last few years have shown us how much Internet, new user-interfaces such as touch-screens, apps, and the social media can influence our daily work and social lives. Future powerful game-changers are expected to be, for instance, 3D printing, nano-technology and the Internet of Things. Non-technological examples of game-changers are political systems, market-mechanisms (global markets and competition) and environmental issues (e.g. earthquakes, global warming, and scarcity of resources).

Technological game-changers can trigger chaos or quantum leaps. They can enable improvement, new businesses, innovation and value creation, *if* we are able to see their possibilities and to implement them, modify them or adjust to them. They create possibilities and challenges on and across all levels. To be an early adapter or even creator of a game-changer, can create completely new business possibilities. Steve Jobs with his Apple-products is a much used example. It is, however, hard to predict what are actual game-changers and not only a dead-end development (the Kodak-effect) or a mayfly phenomenon. It can, on the one hand, be a cost- and time high risk-activity to hop-on an early stage development. As it can, on the other hand, be a risk not to participate. To make the right decision requires a good understanding of trends and market mechanisms.

In the AEC-industry, much focus has been put on implementing Building Information Modelling and the related standards and software-solutions. Already ten years ago BuildingSMART prophesized a paradigm shift in how we manage and handle information.

5.2 Top-down

Standards, laws and regulations are powerful examples of top-down change-drivers. Other examples are policies, strategies and charters. They are placed on the scale between compulsory and voluntary. Top-down initiatives are mostly strategic and goal-oriented, with a long-term view. They are often initiated by authorities or by the management level in companies and organizations. Thus their creators possess great authority and influence. A weakness of laws, regulations and standards, is that they can be conserving. They can thus hamper innovation and change if they do not match the societal development. In Norway, there is a tradition for involving citizens and employees in the process of establishing top-down initiatives (hearings, workshops etc.). Still, the weaknesses of measures such as strategies and policies, is related to ownership, alienation and commitment. One much used phrase is that "culture eats strategy for breakfast". Without people who are willing to commit, change or improve, it is hardly possible to realize strategies or goals (at least in our part of the world). Thus, many good plans and intentions remain in the management drawers, only to be mentioned in sales material and principal speeches.

Examples of top-down examples in the AEC-industry, apart from laws and regulations, are the governmental policy paper, the strategy of Bygg21 or the Project Norway-program, and the "Next step" initiative. In Norway, the public clients are important role models in the AEC-industry. Statsbygg did already in 2007 require the use of open BIM in their building projects – thus pushing the broad implementation of related technologies in the AEC-industry.

5.3 Bottom-up

"One-man" initiatives, based on personal engagement, belief and commitment are another powerful driver of change. This is particularly the case if the group or person is in the position to convince their companies or networks about the need to change or adapt to something new (for instance by being a project manager). Individuals or groups seem to be closer to the take-up of new ideas and ways of thinking than a big organization. Such initiatives might pop up and "grow" randomly. The management-level might not recognize or attend to them, and they might not be embedded in a strategy or directed towards a common long termed goal. Another weakness is the lack of robustness and the strong dependency on the initiators knowledge/competence and availability. Internal development projects within companies can also be regarded as a kind of "one-man-initiatives" in the AEC-industry, as they are mostly closed and decoupled from other similar activities in other companies.

An example of a bottom-up initiative is the implementation of lean principles in a Statsbygg project (Kunsthøyskolen i Bergen). The project manager is convinced of the usefulness of lean and is applying some of its tools and methods on the management of design and construction. Based on the experiences in this project (which, by the way, has got a lot of prices and awards for its innovative process approach), lean is now implemented in other Statsbygg projects (a shift from bottom-up to top-down).

5.4 Incubators

Incubators are collaborative "local" platforms or R&D projects where for instance research and industry partners join to find new solutions to identified problems (theoretically and/or practically). Such incubators are often closely linked to one single/some few companies' interests and business goals. They are temporary and involving a "closed" consortium of partners. Such projects can be important "low-threshold" incubators of change and improvement in the businesses involved. The strength of the incubators is that they are thematically focused arenas. It might be easier to commit and recruit partners to such initiatives than to permanent, thematically open "top-down" initiatives. Incubators might however have limited impact beyond the consortium and the life-time of the project. It is a risk that such projects can become separate silos of knowledge-development.

The innovation projects in Table 1 are examples of incubators. It is interesting to observe that most of these projects have very broad scopes, each of them aiming to address an array of the industry challenges.

5.5 The ecosystem of change drivers

How do these main groups of drivers and measures of change interact with each other? They are for instance characterized by various degrees of being planned or random, and long-termed or short-termed perspectives (Figure 2).

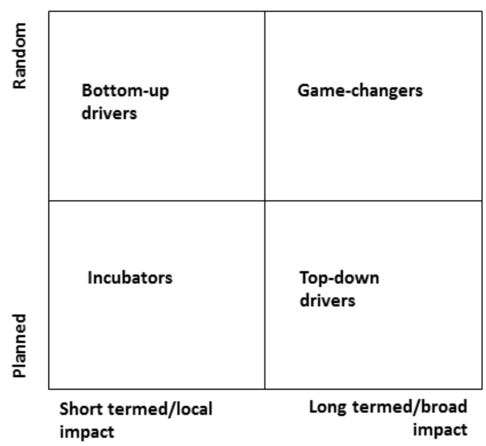

Figure 2: The conceptual framework

The interface between the "boxes" in Figure 2 is dynamic. Initiatives can initially be bottom-up driven, before they become an incubator, and/or integrated in a top-down strategy. Game-changers can inspire bottom-up or top-down initiatives. Incubators and bottom-up initiatives might catalyze new game-changers. The four groups of drivers impact on each-other. They work/play together in an eco-system, where the strengths lie in their additive impact, not in each single box. Game-changers without incubators or top-down/bottom-up initiatives would lack their instruments of implementation. Without game-changers, top-down or bottom-up initiatives would lack an important motivation. Incubators only would lead to a fragmented and unsystematic knowledge development. Top-down initiatives only might become conserving and not well rooted in real-life practice. Bottom-up initiatives only would lead to random and local change, without long-termed perspectives and goals.

The described initiatives did not emerge chronologically or develop step-by-step. They are rooted in a multi-level awareness-wave of the need to improve and change. There has also previously been carried out ambitious initiatives in Norway with the aim to improve processes. They mobilized a lot of partners and kicked-off many projects. Still, they did not have the impact hoped for after they were completed. Perhaps the Norwegian AEC-industry now, 10-15 years later, have reached the maturity, which is needed to improve how we organize and execute building projects.

6. Conclusions

The review in this paper indicates that there is a focus shift in the Norwegian AEC-industry and its process-related R&D:

- There is a growing awareness on all levels that process-improvement is needed in order to secure quality, productivity and competitiveness.
- More focus on life-cycle perspectives, the interfaces between people and process stages, and the need for interdisciplinary and holistic approaches.
- “Outside the box” thinking is increasingly called for. It is a paradox that many attempts of solving the problems are based on the same thinking that originally created them, and that an obvious solution to a problem within one area create new problems in other areas.
- There has been a shift from technology focus to people/culture focus (from "hard" to "soft" and qualitative/hard-to-measure issues).
- More focus on systematic and continuous learning and on the usefulness of looking to other countries and traditions (e.g. several Norwegian contractors have been hiring high-profiled Stanford researchers for implementing VDC).
- Process-Innovation is increasingly recognized and appreciated in the AEC-industry. In 2015 the AEC innovation price was awarded to a contractor for their effort on lean-based process-improvement.

The increasing complexity and the rapid development on all levels call for a more systematic, interdisciplinary, continuous and holistic competence and knowledge building. This greatly challenges the actors involved, due to capacity, openness, to balancing short- and long-termed goals and activities. Successful change and adjustment requires the ability to take risks, to prioritize, to understand possibilities, to understand what is possible to control and what should not be controlled, to adjust and modify. To bring good intentions and ambitions into action and effect will probably remain a challenging act.

This conceptual paper has presented a review of the current situation in the Norwegian AEC-industry, and suggested a holistic framework for better understanding the interdependencies between various drivers and measures of change. The next step for developing the framework would be to move towards theorizing and selecting relevant theoretical perspectives for understanding the phenomenon. The review indicate however that R&D initiatives, when working together in a balanced ecosystem, might guide the Norwegian AEC-industry towards new shores. On this voyage, a final reminder is appropriate: Change for a reason and not for the sake of change alone.

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Construction Camps in Building and Civil Engineering Construction

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Abstract

The establishment of construction camps needs to be addressed by contractors working outside of urban areas or in areas that are not readily accessible on a daily basis.

The establishment of construction camps is subject to legislation and international recommendations. However, construction camps, medical assistance and facilities, inter alia, living, sleeping, ablutions, cooking, washing and recreational, impact on labour relations, health, the environment, productivity and the achievement of quality. Given the aforementioned, the establishment of construction camps should form an integral part of any health and safety (H&S) programme, and be addressed in H&S specifications and H&S plans where applicable. South African literature pertaining to construction camp practices is perfunctory. To this end a descriptive survey was conducted among building and civil engineering contractors undertaking projects for the East Cape Department of Roads and Public Works (ECDRPW).

Findings include, inter alia: contractors provide spartan accommodation and sleeping facilities, rudimentary ablutions, minimal cooking and washing facilities; recreational facilities are marginal, and first aid constitutes medical assistance.

Conclusions include, *inter alia*: the conditions in construction camps are inadequate and could be enhanced; the providers of such camps are non-compliant and not committed to best practice, and the prevailing conditions are unlikely to complement workers' health and wellbeing, the environment, productivity, and the achievement of quality.

Recommendations include, *inter alia*, an industry standard should be evolved in terms of the types of construction camp accommodation and facilities, which should also be clearly identified during the early stages of projects, and during the 'tender documentation and procurement' stage.

Keywords: construction camps, living and ablution facilities

1. Introduction

The establishment of construction camps is subject to legislation and international recommendations. However, construction camps, medical assistance, and facilities, *inter alia*, living, sleeping, ablutions, cooking, washing and recreational, impact on labour relations, health, the environment, all affect productivity and the achievement of quality. Given the aforementioned, the establishment of construction camps should form an integral part of any health and safety (H&S) programme. Studies indicate that up to 30% of workers across construction organisations would be transient in nature and require rental and temporary accommodation (Chang-Richards *et al.,* 2014).

Construction work is tough, dirty and hazardous and involves high levels of manual and / or physical activity. Therefore, good welfare facilities not only improve workers' welfare, but enhance efficiency (ILO, 1995, Muiruri and Mulinge, 2014).

Transient construction sites, is where work is of short duration (up to a week) or completed over a number of locations. Work of longer duration may include working over continuous geographical areas, where major road works, cable laying contracts are examples cited by the Health and Safety Executive (HSE) (2011).

Given the abovementioned and the paucity of literature pertaining to the subject area, a study was conducted to determine practices relative to the accommodation of management, supervision, and workers working on construction projects in rural areas, and more specifically to determine mainstream construction camp practices.

2. Literature Review

South African literature pertaining to construction camp practices is perfunctory. Therefore, the literature was mostly sourced from international standards, guidelines, articles, and case studies. Construction occurs in mining and general industries within their general maintenance activities, so the literature is not only confined to infrastructure development.

2.1 The effect of camps on communities and construction workers

The Western Australia development boom over the past few years led to under-developed communities being overwhelmed with a new population that would arrive with new ventures. With such development come social and economic stresses. Local resources become stretched and result in local authorities being unable to meet such demands in terms of infrastructure, transportation, and even basic supplies. While this has advantages for the local community it could lead to shortages relative to accommodation, and workers having to walk distances to shops and for basic supplies not available where the site camps have been located (Mathiesen, 2003; McKenzie, 2015).

2.2 Standards

The European Bank for Reconstruction and Development (EBRD) and International Financial Corporation (IFC) (2009) refer to the ILO Workers' Housing Recommendation 115, which *inter alia*, states that it is generally not desirable that employers provide housing for their workers directly, and that they should seek alternatives. If there are no alternatives, employers should pay attention to workers' rights and housing standards. Housing standards should include special attention to: minimum space allocated per person; supply of potable water; adequate sewage and garbage disposal; adequate protection against heat, cold, damp, noise, fire, disease-carrying animals, and insects; adequate sanitary and washing facilities, ventilations, cooking and storage facilities, and natural and artificial lighting, and a minimum degree of privacy for individuals. Furthermore, where accommodations are provided for single workers, the following should be considered: a separate bed for each worker; separate gender accommodation; adequate sanitary conveniences, and common dining rooms, canteens, rest and recreation rooms and health facilities where otherwise not available in the community.

The International Labour Organization (ILO) (1992) states that suitable living accommodation should be made available for construction workers where work is undertaken in remote areas. Remote sites are noted as where adequate transportation between home and work is not available. The ILO note that genders should have separate facilities, such as sanitary, washing and sleeping facilities. Shelters, furthermore, should as far as practicable provide washing, eating facilities, and the storage of clothing where not available close by.

The ILO helpdesk has published a guideline as to how workers should be housed, and what could be taken into account. Minimum specifications and levels are provided. Workers housing should ensure that workers' are not affected by air pollution, surface run-off, sewage, or other waste. Provision of rest and recreation rooms, even health facilities should be available if not in the local community. Sleeping quarters should be between 7.5m^2 and 14.5m^2 where up to 4 persons share. Shifts should be separated so that workers are not disturbed. Aspects such as vermin, fire protection, emergency exits and planning, and regular inspections to ensure decent condition and that the premises are in a good state of repair (ILO, 1996).

A Danish study indicated that camps were created by the developers, were in remote areas around the construction site and lacked shops and welfare facilities. Workers could also use their own caravans, ablutions were shared and conditions were noted as poor. Communal areas were available, with a privately run canteen and a bar run by the occupants (Mathiesen, 2003). Maidment and Trotter (1967) define resilience from the perspective of risk as, "the capacity to foresee …" (pp23-24).

2.3 Long distance work commuting: fly-in fly-out (FIFO)

Western Australia has experienced heightened economic activity over the past few decades, resulting in a reduced unemployment rate and a high demand for labour. The results of the activity created the FIFO positions. The FIFO practice developed in the Gulf of Mexico, in the off-shore oil sector, and has since become pervasive across the mining world. The FIFO work-style that defined as "encompassing all those who travel to work, stay a pre-determined number of days ('roster') then return to a home location for a set break time." (McKenzie, 2010). Mathieson (2003) indicated that Danish workers had the option of staying on site, or commuting. The decision to stay on site is most often incentive related, and calculated accordingly. Nordic countries are further noted as having particular Regulations relative to travel allowances based on distance travelled, with Norway being most regulated.

2.4 Health issues, stress and working away from home

Increased stress related to working away from home has a number of possibly negative outcomes. Construction workers tend to work longer hours, drink more, do not exercise and eat badly. Loneliness is made worse where married employees are forced into a single-person status, which could stretch for years (Pearson and Broughton, 2015).

Mathieson (2003) reports that those in camps regard time off on-site as being still at work. Life on site covers three distinct areas, namely work, time off on-site (at the camp), and time off at home. The time between workdays is required for recuperation for the next day's work. Workers in camp describe a typical workday as work, meals, some television, time with fellow campers, and sleep. Washing, shopping, and contacting family are additional activities.

A number of studies regarding suicide among construction workers in the United Kingdom (UK) indicate that, while not unique to the UK, is reported as being due in part to the peripatetic nature of the workforce. Many construction workers are expected to work away from family and friends for weeks on end, often alone (Pearson and Broughton, 2015). All levels of construction workers are affected. Pearson and Broughton (2015) cite Mel Pritchard, a production leader for Mace, on the Heathrow Terminal 1 project, who has lived and worked abroad, who stated: "If you are on your own, it can be a miserable existence." Mathieson (2003) states that camp life is a lifestyle difficult to tackle, and the ability to withstand boredom, and resisting the temptation to have 'the bottle and get to bed on time'.

Higher levels of morbidity rates were noted where workers were on site, with the cardiovascular and digestive disorders prevalent from lack of rest, and respiratory and locomotor systems affected by general stress. Accident rates were also noted as higher risk among those at construction site camps (Mathieson, 2003).

2.5 Cultural issues

Cultural issues when working in different countries have an impact, for example those working in the Middle East work a six-day week, and according to Mel Pritchard, many do not make it and leave (Pearson and Broughton, 2015). McKenzie (2010) reports that many companies in the Western Australian mining sector are cognizant of the ripple effects of family breakdown caused by the FIFO form of work. As such employers provide wellness programmes, including counseling services to the employee and family. In stark contrast, in developing countries problems of low literacy resulting in poor communication, unregulated construction practices, extreme weather, and a general poor culture do not promote overall health and safety (H&S) standards (Muiruri and Mulinge, 2014).

2.6 The South African legislative framework

In terms of the South African Constitution, there are a number of rights that could be linked to the rights of workers in the context of this paper (Republic of South Africa (RSA), 1996). Section 24 states: "Everyone has a right to an environment that is not harmful to their health", and Section 27 (2) states that "Everyone has the right to have access to sufficient food and water."

Regulation 30(2) 'Construction Employees' Facilities' of the Construction Regulations (RSA, 2014) states: "A contractor must provide reasonable and suitable living accommodation for the workers at construction sites who are far removed from their homes and where adequate transportation between the site and their homes, or other suitable living accommodation, is not available." In theory and in practice, this aspect should be addressed in the H&S Specification and H&S Plan, which in turn requires that the client must ensure that there is adequate resourcing for this aspect when it is identified.

The Occupational Health and Safety Act (OHSA) No. 85 of 1993 requires employers to comply with the rights as stated in the Constitution, as they relate to employees. Employers have a further responsibility as it relates to those directly affected by activities and also are expected to ensure that all equipment and substances designed for use is safe and without risk to health (RSA, 1993a). While these duties apply to the working environment, in many cases accommodation could be adjacent, within or close to the construction works. Thus the line between being separated from the work place, and 'off-duty' could be deemed blurry at best.

Should a worker be injured from activities, equipment or substances on site, there is a strong likelihood of the Compensation Commissioner accepting a claim in terms of the Compensation for Occupational Injuries and Diseases Act (COIDA) (RSA, 1993b). Where a contractor provides transportation to and from site, the worker is deemed to be on site should there be an accident. South African media often reports high numbers of road traffic accidents among construction workers being transported on the back of light delivery vehicles, flat-bed or tip trucks, and motor vehicle accidents in the course of employment contribute approximately 40% of fatalities in construction. The result of excessive COIDA claims for such losses could result in the loading of COIDA premiums.

Smallwood and Wheeler (1998), state that the Facilities Regulations require a range of basic supplies for ablutions, that include soap, toilets, towels showers with hot and cold water. Potable water, separate dining facilities and adequate tables and chairs should be available.

2.7 South African literature

Only one previous study could be identified, conducted by Smallwood and Wheeler (1998). The study indicated that sleeping facilities were provided, and showers, wash hand basins and toilets available. Hand towels were not available and minimal availability of soap. Generally cooking facilities were available. Wash troughs were available for washing personal items and in almost 50% of cases, television, and other forms of recreational facilities were provided. The provision of first aid facilities with access to a doctor and hospital was apparent.

3. Research Findings

A descriptive survey was conducted among a convenience sample of building and civil and engineering contractors who are currently undertaking projects for the ECDRPW. The focus was on the accommodation of management, supervision, and workers working on construction projects in rural areas, and more specifically to determine mainstream construction camp practices. The questionnaires were disseminated by a Manager of the ECDRPW in the Alfred Nzo District, by Construction H&S Agents also working in the area, as well as the ECDRPW Construction H&S Manager for the province. The ECDRPW master H&S Specification used to guide construction H&S Agents and Designers, makes reference to the care of workers on site (Welfare), in that 'adequate toilets, clean, safe drinking water and decent shelter will be afforded workers at all times'. No further reference is made to actual accommodation standards or requirements.

A total of 22 responses were received and included in the analysis of the data. The mean age of respondents was 42.4 years, and 90.9% were male, and 9.1% female. The mean period worked in the construction sector was 17.4 years, and for current employer was 14.4 years. The respondents recorded a diverse range in terms of their level of education – thirteen in total. The highest percentage was 18.2% relative to each of Grade 9 and Grade 12.

27.3% respondents indicated they are building contractors, and 72.7% civil engineering contractors. A total of 68.4% respondents indicated they use construction camps, 10.5% provide such camps, and 21.1% do not use construction camps. In terms of the latter, due to space constraints a table cannot be presented. However, boarding houses, caravan parks, renting a house, and private accommodation were all identified relative to management, supervision, and workers. Bed & breakfasts were only identified relative to management and supervision.

Table 1 indicates the lowest, highest, and mean number of people staying in construction camps. Given the lowest, highest, and mean number per category, it is clear that in most cases, middle and site management are not accommodated on site, however supervisors and skilled, semi-skilled, and general workers are.

Table 1: Number of people staying in construction camps on site

Category	*Lowest*	*Highest*	*Mean No.*
Management:			
• *Middle*	*0*	*4*	*0.37*
• *Site*	*0*	*8*	*0.95*
Supervision	*0*	*12*	*3.68*
Workers:			
• *Skilled*	*1*	*20*	*5.95*
• *Semi-skilled*	*2*	*20*	*6.84*
• *General*	*0*	*50*	*10.11*

Table 2 indicates the extent to which management, supervision, and workers are accommodated on site. Only general workers (MS = 3.18) can be deemed to be accommodated frequently on site as the MS > 3.00. However, semi-skilled, and skilled workers have MSs marginally below 3.00, namely 2.95 and 2.86 respectively.

Table 2: Extent to which management, supervision, and workers are accommodated on site

Category	*Response (%)*						*MS*
	Unsure	*Never*	*Rarely*	*Some-times*	*Often*	*Always*	
Management:							
• *Middle*	*0.0*	*89.5*	*5.3*	*5.3*	*0.0*	*0.0*	*1.16*
• *Site*	*0.0*	*61.1*	*0.0*	*33.3*	*5.6*	*0.0*	*1.83*
Supervision	*0.0*	*38.1*	*28.6*	*33.3*	*0.0*	*0.0*	*1.95*
Workers:							
• *Skilled*	*4.5*	*31.8*	*22.7*	*0.0*	*9.1*	*31.8*	*2.86*
• *Semi-skilled*	*0.0*	*31.8*	*22.7*	*0.0*	*9.1*	*36.4*	*2.95*
• *General*	*0.0*	*31.8*	*0.0*	*22.7*	*9.1*	*36.4*	*3.18*

A total of 33.3% of respondents indicated that fenced-off compounds were 'always' provided for the construction camps, 4.8% 'often', 52.4% 'sometimes', 4.8% rarely, and 4.8% 'never'. The resultant MS of 3.57 indicates that the practice is between sometimes to often / often. Ideally construction camps should be fenced off for security reasons.

Table 3 indicates the type of living quarters provided in the construction camps. Park homes and tents predominate with MSs of 2.67, and given that the MSs > 2.60 ≤ 3.40, the provision is between rarely to sometimes / sometimes. MSs > 1.80 ≤ 2.60 indicate the frequency is between never to rarely / rarely (pre-fabs), and MSs ≥ 1.00 ≤ 1.80 indicate the frequency is between never to rarely (converted containers and caravans).

Table 3: Types of living quarters provided in the construction camps

Category	*Response (%)*						*MS*	*Rank*
	Unsure	*Never*	*Rarely*	*Some times*	*Often*	*Always*		
Park homes	*0.0*	*33.3*	*4.8*	*38.1*	*9.5*	*14.3*	*2.67*	*1*
Tents	*0.0*	*19.0*	*38.1*	*19.0*	*4.8*	*19.0*	*2.67*	*2*
Pre-fabs	*0.0*	*42.9*	*4.8*	*42.9*	*4.8*	*4.8*	*2.24*	*3*
Converted containers	*0.0*	*57.1*	*28.6*	*9.5*	*4.8*	*0.0*	*1.62*	*4*
Caravans	*0.0*	*76.2*	*0.0*	*23.8*	*0.0*	*0.0*	*1.48*	*5*

The facilities provided by the contractors in the construction camps can best be described as limited (Table 4). Not a single MS is > 3.00, which indicates that the provision of the facilities is infrequent as opposed to frequent. A mean MS was computed for the six categories of facilities: sleeping (1.54); ablutions (1.78); cooking (1.50); washing (1.09); recreational (1.17), and medical aid (1.21).

The highest MS relative to each of the six categories is: sleeping - bed (2.18); ablutions – toilets (2.82); cooking – stove (1.77); washing – outsourced (1.18); recreational – radio (1.50), and medical aid – first aid room (1.50).

Table 4: Types of facilities provided in the construction camps

Category	*Response (%)*						*MS*	*Rank*
	Unsure	*Never*	*Rarely*	*Some-times*	*Often*	*Always*		
Sleeping facilities:								
• *Bed*	*0.0*	*59.1*	*4.5*	*13.6*	*4.5*	*18.2*	*2.18*	*1*
• *Bed linen*	*0.0*	*68.2*	*4.5*	*13.6*	*0.0*	*13.6*	*1.86*	*2*
• *Fans*	*0.0*	*63.6*	*0.0*	*31.8*	*0.0*	*4.5*	*1.82*	*3*
• *Pillow(s)*	*0.0*	*77.3*	*4.5*	*4.5*	*0.0*	*13.6*	*1.68*	*4*
• *Mosquito nets*	*0.0*	*81.8*	*0.0*	*13.6*	*0.0*	*4.5*	*1.45*	*5*
• *Bunk*	*0.0*	*81.8*	*4.5*	*4.5*	*4.5*	*4.5*	*1.45*	*6*
• *Heaters*	*0.0*	*90.9*	*4.5*	*0.0*	*0.0*	*4.5*	*1.23*	*7*
• *Stretcher*	*0.0*	*95.5*	*0.0*	*0.0*	*0.0*	*4.5*	*1.18*	*8*

• *Sleeping bag*	*0.0*	*95.5*	*4.5*	*0.0*	*0.0*	*0.0*	*1.05*	*9*
• *Mean*							*1.54*	
Ablutions:								
• *Toilets*	*0.0*	*40.9*	*9.1*	*9.1*	*9.1*	*31.8*	*2.82*	*1*
• *Showers*	*0.0*	*72.7*	*0.0*	*4.5*	*0.0*	*22.7*	*2.00*	*2*
• *Soap*	*0.0*	*81.8*	*0.0*	*0.0*	*0.0*	*18.2*	*1.73*	*3*
• *Wash hand basins*	*0.0*	*86.4*	*0.0*	*0.0*	*0.0*	*13.6*	*1.55*	*4*
• *Towels*	*0.0*	*90.9*	*0.0*	*0.0*	*0.0*	*9.1*	*1.36*	*5*
• *Urinals*	*0.0*	*90.9*	*4.5*	*0.0*	*0.0*	*4.5*	*1.23*	*6*
• *Mean*							*1.78*	
Cooking facilities:								
• *Stove*	*0.0*	*77.3*	*0.0*	*4.5*	*4.5*	*13.6*	*1.77*	*1*
• *Fridge*	*0.0*	*77.3*	*0.0*	*9.1*	*0.0*	*13.6*	*1.73*	*2*
• *Microwave*	*0.0*	*77.3*	*0.0*	*9.1*	*0.0*	*13.6*	*1.73*	*3*
• *Sink*	*0.0*	*81.8*	*0.0*	*4.5*	*4.5*	*9.1*	*1.59*	*4*
• *Canteen*	*0.0*	*90.9*	*4.5*	*0.0*	*4.5*	*0.0*	*1.18*	*5*
• *Outsourced*	*0.0*	*100.0*	*0.0*	*0.0*	*0.0*	*0.0*	*1.00*	*6*
• *Mean*							*1.50*	
Washing facilities:								
• *Outsourced*	*0.0*	*95.5*	*0.0*	*0.0*	*0.0*	*4.5*	*1.18*	*1*
• *Wash trough*	*0.0*	*95.5*	*0.0*	*4.5*	*0.0*	*0.0*	*1.09*	*2*
• *Washing machine*	*0.0*	*95.5*	*4.5*	*0.0*	*0.0*	*0.0*	*1.05*	*3*
• *Tumble dryer*	*0.0*	*95.5*	*4.5*	*0.0*	*0.0*	*0.0*	*1.05*	*4*
• *Mean*							*1.09*	
Recreational facilities:								
• *Radio*	*0.0*	*81.8*	*0.0*	*9.1*	*4.5*	*4.5*	*1.50*	*1*
• *TV*	*0.0*	*90.9*	*0.0*	*0.0*	*4.5*	*4.5*	*1.32*	*2*
• *CD / DVD player*	*0.0*	*90.9*	*4.5*	*0.0*	*0.0*	*4.5*	*1.23*	*3*
• *Satellite TV*	*0.0*	*90.9*	*4.5*	*0.0*	*0.0*	*4.5*	*1.23*	*4*
• *Pool*	*0.0*	*95.5*	*0.0*	*4.5*	*0.0*	*0.0*	*1.09*	*5*
• *Darts*	*0.0*	*100.0*	*0.0*	*0.0*	*0.0*	*0.0*	*1.00*	*6*
• *Drafts*	*0.0*	*100.0*	*0.0*	*0.0*	*0.0*	*0.0*	*1.00*	*7*
• *Keerum*	*0.0*	*100.0*	*0.0*	*0.0*	*0.0*	*0.0*	*1.00*	*8*

• *Mean*							*1.17*	
Medical aid facilities:								
• *First aid room*	*0.0*	*85.0*	*0.0*	*5.0*	*0.0*	*10.0*	*1.50*	*1*
• *Clinic*	*0.0*	*95.2*	*0.0*	*0.0*	*0.0*	*4.8*	*1.19*	*2*
• *Occupational health nurse*	*0.0*	*95.0*	*0.0*	*0.0*	*5.0*	*0.0*	*1.15*	*3*
• *Paramedic*	*0.0*	*95.2*	*0.0*	*4.8*	*0.0*	*0.0*	*1.10*	*4*
• *Medical doctor*	*0.0*	*95.2*	*0.0*	*4.8*	*0.0*	*0.0*	*1.10*	*5*
• *Mean*							*1.21*	

Respondents were requested to provide comments in general regarding construction camps. A total of thirteen comments were received, which equates to an average of 0.59 per respondent. The responses recorded verbatim include: “They are not safe as they are supposed to be”; “Camps are in bad condition”; “Not safe at all”; “We rarely use construction camps as we found local people come and make trouble and things / equipment etc. go missing. We opted to find renting spaces for our staff”; “These camps are in bad condition” (3 No.); “Our camps are in very bad condition and need attention”; “Our camps are in very bad condition and need attention so that they can be in a good state by complying to OHS Act”; “Cultural observances compromise PPE compliance”; “It is our company policy to make use of private accommodation for all staff”; “Occupational Hygiene needs to improve”, and “Condition of the camps are very poor.”

4. Discussion

Although the area in which most of the participants were noted as working could be deemed rural in nature, with very scant if any supply of running water, electricity, or community resources, the Constitution, OHSA, and the Construction Regulations dictate the rights of workers, and that workers are kept well relative to the working environment. Despite the legal requirements, the level of compliance on the contracts can only be deemed poor to appalling. Given that middle and site management are not accommodated on site, and that supervisors and skilled, semi-skilled, and general workers are, indicates that the former are averse to construction camps. A range of living quarters are provided in the construction camps i.e. no standard type is adopted. The sleeping, ablution, cooking, washing, recreation, and medical aid facilities are virtually non-existent.

5. Conclusions and Recommendations

The finding that middle and site management are not accommodated on site, that supervisors are to a degree, and skilled, semi-skilled, and general workers are to a greater extent, and the ‘negative’ general comments received relative to construction camps leads to the conclusion that the level of employees in the hierarchy influences the standard of accommodation and that there is recognition that the conditions of construction camps are not ideal. A further conclusion is that contractors and the client are not committed to the health and wellbeing of their workers and in fact are non-compliant. The range of living quarters provided in the construction camps leads to the conclusion that no industry standard exists.

In terms of recommendations, the EC DRPW should be made aware of the findings of the research, as the client in this case. However, the results are equally important to other clients and employers, who are likely to require their workers to work in remote areas for extended periods. The level of employees in the hierarchy should not influence the standard of accommodation i.e. it should be appropriate, adequate, and decent. Ideally an industry standard should be evolved in terms of the types of construction camp accommodation and sleeping, ablution, cooking, washing, recreation, and medical aid facilities. Furthermore, temporary accommodation and facilities requirements should be clearly identified during the early stages of projects, namely 'project initiation and briefing' and 'concept and feasibility'. During the 'tender documentation and procurement' stage, tender documentation, and especially the H&S Specification, which details the client's H&S requirements, and the Bills of Quantities, should be explicit as opposed to implicit in terms of the requirements and facilitate adequate financial provision therefore. The latter will ensure that the 'playing fields are level', and that contractors making adequate financial provision for H&S will not compromise their chance of winning a bid. Community engagement and participation using social facilitators could enhance the level and standard of accommodation and general facilities, emergency, and general local facilities noted.

Voluntary (built environment and related) associations, and statutory built environment councils should be made aware of the issues relative to construction camps, the need for legal compliance, and also what constitutes 'appropriate, adequate, and decent', with a view to promoting 'better practice' construction camps.

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A heritage park as a form of communication

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Abstract

This article was devoted to research on methods of architectural and urban past commutation towards widespread public, in a scope of wooden and timber-framing vernacular architecture in central European region. It was crucial to determine whether a museum in a form of a heritage park (open-air museum) is still informative and appealing to local society and tourists. On the other hand contemporary commercial approach was discussed, which assumes re-use of old historical building by introduction of new functions (i.e. hotels) and adjustment of structure to nowadays needs. The elaboration is addressed to all: historians, architects, engineers, designers, museum workers, as well as governments and cultural institutions, focused on methods of preservation and popularisation of knowledge on vernacular architecture. Research was carried out on literature and case studies with use of: analysis, synthesis and critical overview. Conclusions present compare synthesis of both aforementioned solutions and an effort to formulate guidelines for the future. Also an attempt was taken to describe the most proper way of cultural education in vernacular architectural and urban heritage, with the highest respect towards original values and minimum loss to the historical verity or knowledge.

Keywords: A heritage park, communication of heritage, adaptation, re-use of architecture

1. Introduction

Architectural and urban heritage is a valid factor in development and transformation of ongoing city and rural planning. Based on long-term experience of past designers and builders, it may also serve as a set of guidelines and inspiration for contemporary movements in architecture (i.e. regional, sustainable, ecological, etc.). It is also a vast database of solutions responding to the human needs, climate requirements and proper building infill into a land or city scape. As Midura (1999) states, it stands as a witness of chosen societies groups' culture, as well as sanctuary of disappearing human natural environment. Important to the scientist and professionals, architectural and urban heritage is most of all, an observer to the history of residents living in a certain region or country at a given time. Their customs, everyday habits, religious believes and overall culture – in many cases already gone today – is reflected in a function, structure and architecture of their buildings.

Contemporarily there are two different methods for vernacular architecture re-use and exhibition. One – a Heritage Park – can be considered today as traditional method itself, while the other – refurbishment and adaptation to nowadays need – may seem innovative, but in some cases destructive for old substance. Worthwhile is the analysis of both cases, in order to find out which treatment will serve better presentation of past customs towards widespread public.

1.1 Scope and method

Central European region – similarly to Scandinavian area – offers expressive examples of vernacular architecture, especially in a range of wooden and timber-framing structures. Therefore, a large number of heritage parks were established in selected localization, starting from turn of XIX and XX century. Soon, a newer process became common, which was a growing interest of private investors' sector in adaptation of historical buildings for new purposes. Thus, both phenomena were included in the scope of presented study.

Research was carried out on: site, through literature and by interviews. The case studies as representative as possible (on site), were carefully selected in the central European area: Bucharest (Romania), Oliwa (Poland) and Seifhennersdorf (Germany). During buildings examination process (which was conducted on urban: arrangements, layouts, cross sections and elevations), there were used – analysis: graphical, comparative, critical and synthesis (for conclusion elaboration). The study focused mainly on how much of original substance was kept during regeneration process, what was preserved, what demolished and which method was used. These researches were preceded with literature studies, complemented by interviews and talks, carried out by authors with building owners and experts. The later turned out to be crucial in understanding of a process of old structures adjustment to contemporary users' needs, safety regulations, fire protection issues and many others.

2. Traditional Heritage Park

Especially vernacular architecture, as the one serving all basic human needs and purposes, is most informative of all for scientists and researches as well as for contemporary communities. Related mostly to the wooden and timber-framed village landscape, may be inaccessible to the wider public, due to a large spread of buildings at a certain regions. Moreover preservation of vernacular monuments may be impossible in their original environment (Midura 1999).

In XIX century village lifestyle started to transform, due to technological change in: tools, farming methods and overall living situation. In order to save disappearing buildings and barns, Artur Hazelius, who already took part in organization of previous national displays at worldwide exhibitions, started to gather monuments, creating in 1873 beginnings of Swedish ethnographical collections (Nor. *Skandinavisk-etnografiska samlingen*). In 1880 they have been transformed in Nordic Museum (Nor. *Nordiska Museum*). His next activities lead in 1891 to collection of historic houses and barns on Djůgarden Island and initiating new form of gathering and presenting of historical village buildings and items – on an open air. This exposition type became a model for emerging at the turn of XIX and XX century open-air museums (Nor. *Nordiska museet, Skansen*), i.e. already in 1881 new facility was opened near Oslo. (fig. 1) (Szolginia 1992) Interest in folk art and collecting of monumental building, intensively evolved at the beginning of XX century, thus in 1914 in Europe 104 *Skansen* museums were established (including 81 in Norway and Sweden). (Szolginia 1992), (Trocka-Leszczyńska 2001) Complexes of this type created in other countries, i.e. Germany (Germ. *Freiluftmuseum*. *Freilichtmuseum*) – forming a sort of a *heritage parks* – were popularized, as a method of presenting past architecture and achievements to the society and tourists. Such model of exhibition enabled visitors to analyse and compere buildings from different regions in a few hours, as the scientific researcher would do even during a life-time study. Arranged in increasingly innovative way heritage parks became very popular, and this process was intensified after WWII, when UNESCO and ICOM got involved between years 1956-1958. Only then, governments included open-air displays in official policies and scientific guidelines were established. Nowadays also in Poland there are about 60 of these museums, while in Europe their number reaches about 2000 complexes. (Błaszczyk 1972), (Czajkowski 1981), (Czajkowski 1984), (Midura 1999), (Sieraczkiewicz Święch 1999), (Trocka-Leszczyńska 2001)

Figure 1: First on the World open-air museum (1881 r.) in Oslo – contains 158 buildings dated back to XIII–XIX century. (Photograph E. Trocka-Leszczyńska)

2.1 Exhibition features

The concept of open-air museum assumes display of vernacular architecture objects from one or few selected ethnographic regions, according to a specific scientific plan. However, museums formula evolves in a spontaneous manner and each unit may differ. Among the obvious: cottages, farms, household equipment, there are many other categories of buildings or facilities displayed, like – industrial objects, i.e. mills (wind, water, lumber) – sacral, i.e. churches of diverse religions, campaniles – public use: schools, administration buildings or inns. (fig. 2) There are two types of an open-air museum display arrangement: park-like – where pieces of exhibition are placed loosely among tall trees and an exact re-creation of an original settlement structure. While, depending on a number of presented regions, heritage parks can be divided into: central – with large exhibitions from few provinces, and local – devoted to a certain smaller part of a country (occasionally in theirs place of origin). Czajkowski (1981) goes further and proposes subdivisions into: central, "supraregional" (original expression), regional, local, however he notices that practical use of this typology is difficult. (Błaszczyk 1972), (Czajkowski 1981), (Midura 1999), (Organization 1970), (Sieraczkiewicz Święch 1999)

Despite exposition model used, chosen items must be original and unique representatives of province tradition and culture. They should reflect skills and knowledge of builders or craftsmen of certain area, and usually show architectural preferences of local community. It should be pointed out, that: small architecture objects, furnishing and equipment, from given time and region, are one of the most important elements in display at heritage park. Museums of this type can offer presentations in expanded versions – be connected to i.e.: technical exhibitions, craftsmen workshops, folk culture displays, fishery collections, etc. Moreover there is a tendency to use types of plants characteristic for elaborated region, or even connecting architectural exhibits to museums of agriculture. (Czajkowski 1981), (Midura 1999), (Organization 1970), (Sieraczkiewicz Święch 1999), (Błaszczyk 1972)

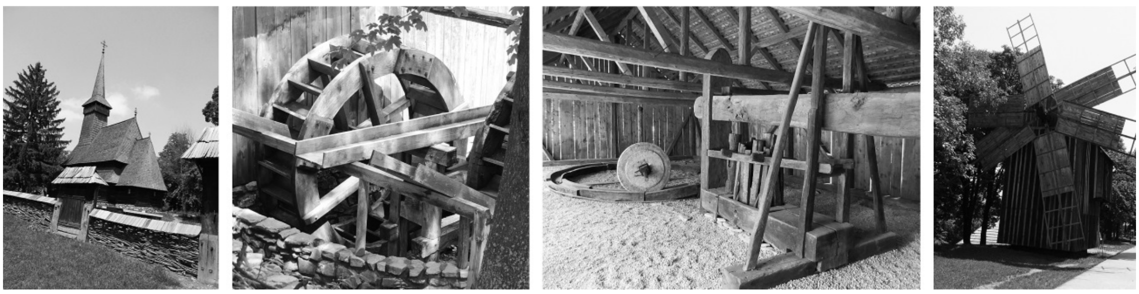

Figure 2: A public use and industrial buildings in Village Museum in Bucharest, Muzeul National al Satului 'Dimitrie Gusti'. (Photograph J. Jablonska)

2.2 Case study

Due to its scale and profile an exceptional example of such solution is "Muzeul National al Satului 'Dimitrie Gusti'" – so called 'Village Museum', located in Bucharest, Romania. The initial idea came from prof. Romulus Vuia in 1929, when he settled two peasants' houses near the city. Further on prof. Dmitri Gusti with large groups of students stared vast sociological studies, summarised by exhibition. It was containing reconstructions of parts of village buildings. (Focsa 1970) In 1936 the full village museum was created on the basis of royal decree and it collects 50 vernacular, wooden buildings on 30 acres of land. They origin from different regions of the country: Transilvania, Banat, Muntenia, Oltenia, Dobrogea or adjacent Moldova and can be dated back to the XVIII century. The exposition of carefully preserved wooden buildings contains: dwellings, logs, barns, churches, mills, gates, fences and is complemented by agricultural equipment. The arrangement of objects and elements of landscape, create illusion of a functioning village, which is strengthened by fully furnished interiors and presence of farm animals. Selection of houses aims at presentation of different functional and spatial solution depending on a regional culture, traditions, customs, climate, types of settlement units and houses, means of transport, geology, economy and other conditions as well as various structure organization and building methods. It is also crucial, that depending on a region, exhibition shows varied occupation, i.e.: shepherding form mountain region, agriculture, livestock or orchard in Podkarpacie area and agriculture in flat regions. Aforementioned diversity is expressed in architectural forms and building functional program, use of certain building materials, treatment of wood, solution of construction, connections and joints. Also types of decoration and colour are strongly exposed in this museum. (Fig. 2) (Focsa 1970), (Information 2012), (Information 2014), (Popoiu 2008)

Figure 3: Village Musem in Bucharest, Muzeul National al Satului 'Dimitrie Gusti', from left: general view, House form Moiseni, House form Moiseni – window frame detail (Photograph J. Jablonska)

Among others "Muzeul National al Satului 'Dimitrie Gusti'" presents interesting example of wooden house form Moiseni (from 1870), raised on rectangular plan (fig. 3). The simple program of function reflects in a spatial argument of interior, consistent of: porch, entrance hall, pantry and multi-use, large room. The usual wall structure was formed form three large oak logs, crossed at the corners of the house. High-picked, hipped roof was covered by wooden shingle. As an exterior decoration served carvings in wood, i.e.: handrails of the porch and window frames (fig. 3). Also highly intriguing is the house form Salciua, raised in 1815. Rectangular plan consentient of two interiors – larger serving as living room and smaller called entry room – is shaded by a deep porch, decorated with wooden, arched arcades. All covered by a very high hipped roof made from grain straw. The supporting structure of walls in prepared from several wooden logs, crossed at the corner of the building. (Information 2012) These examples illustrate very well a fact, that in traditional heritage park, a lot of attention is sacrificed into most true re-creation of past living conditions.

3. Contemporary past-presentation possibilities

Aforementioned heritage park model with all sub-types is understood as one group of possibilities for outdoor legacy preserving and communication of folk architecture to the widespread public. The other, more contemporary, is based on commercial approach. Good example of such solution would be complexes “Dwór Oliwski”, Gdańsk in Poland (fig. 4) or „Windmühle Seifhennersdorf”, Seifhennersdorf, in Germany (fig. 5 and 6). In both cases, historical vernacular architecture was used to create hotels. Though aiming at gathering income, their owners managed to preserve and expose heritage values of re-used buildings and sites. After proper conservation works existing historical architecture, was blended with new structures, enabling introducing contemporary functions, i.e.: hotel, gastronomy, workshops and other services. Also completely new buildings were erected, in form and styles harmonious to the heritage requirements, allowing fulfilment of a whole program for nowadays customers’ needs. (Jabłońska 2011), (Trocka-Leszczyńska and Jabłońska 2014)

3.1 Case study

“Dwór Oliwski” (fig. 4) (implementation between 2002-2009 by Anna Brzozowska-Baran – architect and owner) is a contemporary hotel complex surrounded by greenery area. Its structure was based on buildings connected to bygone manor house and facilities, dating back to XVIII and XIX century. 70 rooms are complemented by: restaurant, tearoom, bar, wine cellar, conference rooms and SPA with pool. There are several objects creating whole spatial arrangement and these are: the traditional polish court from XVIII (founded on spot of previous summer mansion from XVI century) – lately extended, the old granary and two reconstructed buildings – a barn and a stable (connected together with an extension). Both new buildings were erected at the beginning of XXI century, according to the patterns from turn of the XVIII and XIX century. (Jabłońska 2011)

Figure 4: Buildings from complex „ Dwór Oliwski”, in Poland
(fot. Artur Andrzej, licence: CC BY-SA 3.0, https://pl.wikipedia.org/wiki/Hotele_w_Gda%C5%84sku#/media/File:Gda%C5%84sk_ulica_Bytowska_4_i_staw.JPG, accessed on: 2015.11.26)

The idea assumed: preservation of traditional courtyard spatial agreement, protection and re-creation of as many traditional architectural forms as possible, inspiration by historical XVII century buildings still present in the surroundings, use of old-fashioned materials, conservational restauration of details (like painted or sculptured celling, banisters, doors), harmonization with context, nearby parks and greenery system. Due to such approach, visitors may get acquainted with many vernacular forms of architecture, like: wooden timber-framing (so called Prussian wall), mansard gables, dormers, traditional ceramic tiles or –reconstructed on the barn and the stable roof covered by thatch of reeds. (Jabłońska 2011)

„Windmühle Seifhennersdorf" in Germany (designed by Architekturbüro Gustavs + Lungwitz Dresden) (fig. 5, 6) also serves a hotel function, but what is interesting it was adjusted for training centre of people with different disabilities. Apart from rooms, it contains: a restaurant, workshops and a regional house. Overall complex is a blend of old and new architecture, where contemporary forms were strictly inspired by tradition. Visitors can admire – wooden: walls' overlay, timber-frame structures and foot bridges, traditional high-pitched roofs, doors, windows, dormers and old-style materials (also: stone, ceramics). New forms, like: full-wall glazing or solar-panels, were composed in a harmonious way, enriching historic landscape. The terrain agreement could not be re-created, for it was adjusted for wheelchairs movement. However a significant number of tall trees preserved, harmonizes well with complex historic character. The interior of restaurant is full of by-gone architectural details, while rooms, workshops and toilets have modest up-to-date design, so they will be as safe and comfortable as possible for their users. (Trocka-Leszczyńska Jabłońska 2014)

Figure 5: Buildings from complex „Windmühle Seifhennersdorf", Seifhennersdorf, in Germany. (Photograph E. Trocka-Leszczynska)

Figure 6: Buildings from complex „Windmühle Seifhennersdorf", Seifhennersdorf, in Germany. (Photograph E. Trocka-Leszczynska)

4. Discussion

The first approach allows for preserving all original assumptions of the vernacular architecture and urban structure, and usually is very appealing to the visitors. It is much more understandable than texts or illustration found in books (Błaszczyk 1972) or Internet. However in open air-museum buildings become exhibits, which cannot be touched or used by visitors. Kept in their basic form, they communicate knowledge but interaction of guests is limited. Moreover visited exclusively at a certain situations, become an isolated “islands” in the urban structures and social awareness.

It must also be stressed that open-air museums deal with a lot of expensive problems, like fire-protection (need for sprinkle and fire-alarms) for whole complexes or security from thieves. These issues were not handled in the past, when vernacular buildings were originally erected. Facing discovered problems a lot of heritage parks were forced to implement different additional services aiming at raising money for building maintenance. (Piasecka-Wilczyńska 1995) Usually these are: educational and craft workshops, expertise and conservation services, carpentry workshops (old patterns of furniture) inns, restaurants, shops, cultural festivals, family events organization, etc. And as Lasowa (1995) stresses they all must be carried out without the loss of quality of main museums’ activity. Sometimes there is a need of erecting additional buildings (in authority of museum or local town or village), like: gastronomy points, hotels and motels. (Lasowa 1995) Thus, a threat exists that o lot of monuments will not be preserved at all, due to high maintains costs.

The second solution, allows historical complexes to become alive and vibrant places of present-day human activities, with all required service function already build-in the complex. The architecture and urban fabric can be experienced by users on daily basis, allowing them to really “touch” history of past generation. However, the original structure and spatial arrangement of the buildings must be adjusted to the contemporary requirements, even if there are taken into consideration only: technical conditions, fire safety and sanitary reasons. Therefore, valid parts of original communication are irrevocably lost and knowledge becomes limited (i.e. need for additional evacuation staircases, introduction of elevators, additional sanitary rooms).

In advantage, re-used building substance becomes an attraction that interests clients and draws money. Thus, money can be earned, without the need of sub-funding from governments and institutions. At the same time, problems of: fire-protection solutions, monitoring and burglar prevention, have to be obligatory solved in all nowadays design. These seem like obvious benefits, when economy and functionality come together in one venture. However among disadvantages, on the contrary towards heritage park arrangement, furnishing form epoch is rear and equipment seldom. Also there is no possibility for re-creation of climate and character of bygone days (animals, plants, and arraignments) and todays’ needs and requirements may turn out to be more important than preservation and conservational issues.

5. Comparison

As a summary of aforementioned considerations, a table was prepared devoted towards advantages and disadvantages of both presented methods of preservation, allowing simple and clear comparisons. Few criteria were established, basing on general role of past communication towards widespread public, these were: knowledge communication, educational value, preservation and conservational value, harmonization with urban structure of settlement unit, simplicity of introduction of nowadays safety conditions, people-architecture interaction, and attractiveness. A three step grading system was adopted: high – medium – low, however grades were shortly explained in brackets. This clarification was necessary, due to some subjectiveness of evaluation, which could not be omitted.

Table 1: A comparisons of advantages and disadvantages of heritage parks and contemporary adaptation of historic buildings. (elaboration J. Jablonska)

Future	***A heritage park (an open-air museum)***	***Adaptation of historic structure to nowadays, commercial functions***
Knowledge communication	*high*	*medium (changes introduced)*
Education value	*high*	*medium (changes introduced)*
Preservation and conservational value	*high*	*medium (changes introduced)*
Harmonization with urban structure of settlement unit	*low (an island form)*	*high (blended)*
Simplicity of introduction of nowadays safety conditions	*low to medium (a lot of objects, need for money submission)*	*high (need for fulfilment of conservation guidelines)*
People-architecture interaction	*medium*	*high*
Attractiveness	*medium*	*high (possibility to stay in historical building)*

6. Conclusions

This study may serve all subjects engaged in historic building preservation. Case study supported by presented literature research, will assist acknowledging both open-air museum and reuse of historic building structure, as well as learning about different approaches and existing implementation. Aforementioned comparison should reinforce the decision making process on selection for the suitable way of historic building treatment. Studies may be continued at the basis of included material.

As it was clearly proved both methods for vernacular buildings preservation and treatment are connected to positives and negatives, which may affect decision making process of governments and cultural institutions. It is obvious that museums, and in this case open-air museums, are necessary for preserving past and communicating it to widespread public and future generations. At the same time commercial approach, assuming refurbishment of old structures with their adaptation to nowadays needs, can become rescue for many buildings which cannot be overtaken by public programs. The private investor sector should be encouraged to seek attractive solutions on the basis of amazing vernacular architecture of central Europe, of course until the preservation and conservation will be respected. We hope, that by such approach a lot of precious wooden and timber-frame structures will be saved and will have chance to become a vibrant places, where past can be not only studied, but experienced. Moreover, historic buildings will be treated as a valid and equal element of urban fabric in contemporary cities.

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Work environment and communication of posted workers on a Swedish construction project

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Abstract

Procurement of foreign labour in Sweden has changed the once homogenous society to be a more multicultural. Influx of posted workers in Sweden is mainly due to shortage of skilled workers in certain trade and the ageing local workforce. However, this multicultural workforce in the local construction scenario is creating new problems. The main problem is poor health and safety knowledge and the difficulty to communicate when common language and common working culture is lacking. This communication difficulty together with poor health and safety knowledge contribute to the stigma that posted workers contribute to a poor health and safety at the workplace. Since this scenario will unlikely change, it is important that we gauge health and safety knowledge of posted workers and overcome communication barriers in order to have an insight of how to manage the problem.

Therefore, this study was aimed at examining the work environment and communication of posted workers (in this case, posted subcontractors) faced by main contractor on a construction project. The objectives were i) to analyse the recorded incidents concerning posted workers ii) to assess the work environment of posted workers and ii) to examine the communication between the main contractor and the posted subcontractors. A case study was adopted to achieve these objectives. Results demonstrated that despite a few barriers, the work environment functioned very well during the project execution due to the effective role of the Health and Safety Coordinator. Moreover, only 28 incidents were reported from June 2012 until June 2015 and of this only 4 cases involved posted subcontractors while 18 cases involved local subcontractors and 6 cases involved main contractor. The barriers identified were i) communication difficulties due language barrier which could easily results in misunderstandings, and ii) cultural differences regarding safety and health at work. No conclusions can be drawn whether or not posted workers caused more accidents compared with local workers.

Keywords: posted workers, health and safety, construction; multicultural communication

1. Introduction

With the expansion of the European Union and various new schemes providing opportunities to move across member states to work, the number of foreign workers have grown tremendously. Dramatic shifts of labour process in the construction industry can be observed when many labourers move from Eastern to Western Europe (Agapiou, 2005). According to a report by the labour organisation, 20 percent of the labour force comprises posted workers employed in the construction sector. Construction companies typically have large variations in employment and need different opportunities to generate resources for building projects. Generally, companies use mainly their own resources, but lately had begun to subcontract work packages, procured staff and in recent years also contracted personnel to cope with workload peaks and special solutions. The shortage of skilled labour and the ageing workforce in the construction industry are additional reasons for companies to look for workforce abroad

While foreign workers may bring much needed skills and meet labour demands in the industry, the existence of irregular workforce can have an impact on labour market conditions, public finances and health and safety measures (Nurul Azita Salleh, et al 2012). The use of foreign labour at construction sites has been identified as one of the major issues confronting employers and unions. Key issues include their health and safety knowledge, language of communication and working culture. Therefore, this study was aimed to examine the work environment and communication of posted workers (in this case posted subcontractors) faced by main contractor on a construction project. The objectives were i) to analyse recorded incidents concerning posted workers ii) to assess work environment of posted workers and ii) to examine the communication between the main contractor and the posted subcontractors. The paper will present discussions on posted workers in Sweden, the multicultural communication barriers, research method and findings.

2. Posted workers in Sweden

Posting of workers to Sweden is a topical and controversial issue. The Swedish Work Environment (SWEA) defined posted employee as a person who is sent by his or her employer to work in another country for a limited period. The employee shall provide cross border services. For the duration of the work, the employee is subject to certain provisions in the host country's legislation or collective bargaining agreements. Posted workers are guaranteed certain level of protection in accordance with provisions in the Posting of Workers Directive (Directive 1996/711). Some important areas covered by posted workers' rights are: working environment, minimum wages and holiday pay, regulations on working hours, workplace discrimination and parental leave. These rules will reflect the standards of local workers. This step will eliminate "social dumping" where foreign service providers can undercut local service providers because their labour standards are lower. In July 2013, SWEA has taken the initiative to impose a record on all posted workers, allowing the possibility to gain statistics on the exact number of posted workers in the country. From the posting records for the second half of 2013, approximately 2,800 posted workers work in the construction sector. This figure represents approximately 1.3 percent of the total number of construction workers in the country (Sveriges Byggindustrier

2013). There are three ways of how posted workers get engaged in Sweden, namely: i) when their company won a bid ii) hiring of individuals through outsourcing companies and iii) self-employment with F-tax. The record also revealed that most posted workers comes from Poland (more than 1200 workers), Lithuania (more than 600 workers), Denmark (around 600 workers) Germany, Latvia Finland, Slovenia and Ireland (below 400 workers). While Sweden used statutory means to ensure that the core employment conditions stipulated by the Directive are applied to posted workers, the tradition for statutory minimum wages is not applicable. Here, the foreign suppliers, by means of union pressure, enter collective agreement with the Union. The union for construction workers is ‘Byggnads’ the powerful union with more than 100,000 members. The critique here is whether the free movement of labour market can tolerate equality of arms for trade unions seeking to combat wage shopping on the part of employers.

Studies of the impact of the construction labour movement have suggested that foreign labour have high risk of occupational accidents compared with local workers (Agapiou, 2005; Rowlands, 2005). With low wages, foreign workers are willing to work in hazardous conditions and generally take jobs that are temporary, require less skill and are largely unattractive to local labour forces (Robert, 2004; Rowlands, 2005). Language diversity becomes a barrier in communication on site which often results in unsafe behaviours. This problem is evident in a study performed by Trajkobski & Loosemore (2006) where nearly half of the respondents admitted to have misunderstood work-based instructions as a result of their poor command of the native language while 67 percent acknowledge that they had made a mistake at some point as a result of this handicap. Lack of knowledge in the existing situation of foreign construction workers in Sweden, the scale and implications of their health and safety problems make it difficult to accurately demonstrate the extent of the problem.

3. Multicultural communication

Culture differences have a big influence on the performance of construction industry (Ambos and Schlegelmilch 2008). The management style in the west is different from that in the east: Swedish management style is approachable and open, while, the East European managers are highly hierarchical and dictatorial. For managers with low multi-lingual skills Loosemore and Lee (2002) claimed that this often meant that early warnings of foreseeable problems would not be forthcoming and that operatives would be more likely to ignore the problems or will tackle them independently without consulting the managers first. The consequences of mismanaging cultural diversity are serious and include increased stress among the workforce, confusion, frustration and conflict which translates into lower morale, productivity, quality problems and higher accident rates (Loosemore and Lee 2002).

Today, many different nationalities can be found on construction project sites and when they meet, all differences between them can potentially lead to misunderstanding. Many languages spoken on site and the use of English as the main medium of communication is confined to a relatively small group that can speak it fluently (Loosemore and Lee 2002). Examples of issues arising from this cross-cultural misunderstandings are: instructions would have to be issued repeatedly and that they had to be reinforced by especially close supervision; a lack of a common language is a significant source of frustration that reduces their effectiveness and productivity on site and it can lead to health and safety problems. In the construction industry in Australia, language factor had contributed towards high accidents rate (86 percent) due to foreign workers using a language other than English at the work place. Thus the challenges of converting health and safety systems to accommodate this multicultural workforce need to be addressed seriously (Trajkovski and Loosemore's 2006). In Sweden, posted workers from the Nordic countries are able to communicate using the local language thus minimising these barriers.

4. Research Method

To achieve the research aim, a case study which had posted subcontractors and local subcontractors on the project was chosen. This allowed possible access to information from both parties and the management. Once this project was identified, document analysis was conducted to gather data on the health and safety performance of workers on the project. The documents were mostly confidential, internal documents. The materials presented in this paper are with permission from the organisation concerned. The information gathered were from the digital database Construction Industry Information System (BIA) that was linked to the company. The categories of information extracted were types of accidents, causes of accidents, notes and reports on incidences.

The next phase was gathering information on health and safety experience of posted subcontractors on site. This was achieved through two sets of interviews. The first interview was an open interview (Interview A) involved the project management team to capture and examined i) health and safety of posted subcontractors and ii) communication with posted subcontractors. This was performed through face-to-face interviews with six persons from the main contractor. They were the production manager who also qualified as a safety coordinator (M1), two project supervisors (M2, M3), one main safety representative (M4), one logistic coordinator who is also qualified safety coordinator (M5) and one project safety coordinator (M6). The second interview (Interview B) was a semi-structured interview involved posted subcontractors. Since this study was performed at the end of the project, all posted workers had left the country. Therefore, ten posted subcontractors were contacted by email informing them about the aim of the study and the intended questions. Only four posted subcontractors responded and they were from Chez Republic (P1), Denmark (P2), Eastland (P3) and Lithuanian (P4). Although the sample size was small, reliability of the results were secured by critically examining all information obtained from the management side and posted subcontractors.

Notes are made after each interview. Transcripts are read through and notes made, throughout the reading, on general themes within the transcripts. From the reading, as many headings as necessary are written down to describe all aspects of the content. The ‘headings’ or ‘category system’ should account for almost all of the interview data. The method used to categorise and codify the interview transcripts was developed out of the literature on content analysis and out of other sources concerned with the analysis of qualitative data (Bryman 1988).

5. Results

Case study – Project KKH

Project KKH located in Malmö city centre started from June 2012 and was completed in May 2015. The project comprised the construction of a six sub-projects: a concert hall, a congress hall, a hotel, two apartment buildings and an office building. Each sub-project is managed by a project team. Common functions such as logistics coordination as well as health and safety are planned at the main level. Since the construction area is very limited, meticulous planning was required for logistics demanding high cooperation between the various sub-projects. A total of 1.6 million work hours were recorded for the entire project. Project KKH has a strict policy about personal protective equipment (PPE) that must be borne by all on site at all times. The compulsory five PPEs are safety helmet, safety shoes, safety glasses, high visibility jackets and safety gloves. The project has a strong health and safety organisation led by the main safety coordinator, main safety representative, safety representatives from each sub-project and managers with health and safety competence.

Posted workers on project KKH.

Of 4341 total workers registered with the project until 31 Maj 2015, 436 were posted workers. On average almost 350 workers were on site daily and the most 600 workers and only 70 were directly employed by the main contractor. Most of the posted workers were from Poland, Latvia, Lithuanian, Germany, Denmark and Czech Republic. Table 1 shows the distribution of posted workers on the project.

Table 1: Distribution of posted subcontractors according to trade at project KKH

COUNTRY	***TYPE OF WORK (number of workers in parentheses)***
Denmark	*Telephony (2), Blinds and curtains (6), Crane operator (3), Floor layer (27), Installation of concrete elements (9), Design Engineer (1)*
Estonia	*Production and assembly of steel and glass profiles (13)*
Finland	*Ventilation Work (3)*
Italy	*Bathroom modules(20)*
Latvia	*Frame mounting (57)*
Lithuanian	*Steel Designer and frame mounting (56)*
The Netherlands	*Floor layers (natural stone)*
Poland	*Framing contractor: Design and manufacture of precast element (13), Stone layer (7), Ventilation Work (9), Formwork, Concrete work, groundwork, wall, mounting plaster walls, steel construction (135)*

All workers including posted workers must undergo safety introduction before starting work on the project. For posted workers, the safety introduction was conducted in English or the native language. The main contractors have their own staff who are fluent in Germany and Polish but for other languages, the management sought help among the posted workers. The main reason for engaging posted workers on this project were either cost issue or skill shortage. In terms of cost, many Eastern European subcontractors quoted significantly lower price than the corresponding Swedish subcontractors. Even with additional cost for training posted workers in occupational health and safety, their quotation is still much lower. For this project, the main contractor engaged posted workers for concreting buildings due to shortage of local concretors. Additionally, posted subcontractors are also employed for certain specialist work. For example subcontractors from Czech Republic are competent in producing and assembling facade elements while those from Germany subcontractors specialise in design and construction of the concert hall.

Recorded incidents on project KKH

From the start of construction in June 2012 until 30 June 2015, a total of 28 cases of incidents (all workers) were reported and notably only 3 cases with absence from work. The distribution of accidents at project KKH (with absent from work in parenthesis) were as follows: main contractor – 9 (0); local subcontractor – 16 (2); and posted subcontractor – 3 (1). From the reported incidents, 16 were categorised as self-inflicted, meaning that injury was caused by improper use of equipment or facilities, incorrect working method, insufficient knowledge, carelessness or stress. Three incidents occurred because of both self-inflicted and technical deficiency, e.g. meaning lack of protective device or equipment, lack of supervision or control, disarray at the workplace or poor housekeeping and incorrect work performance or workmanship. Five incidents were caused by technical defects. Lastly, four incidents were caused due to negligence of co-workers which included lack of communication between the workers, incomplete work instructions and faulty methods.

Further examination of how the foreign workers contributed to the project statistic is necessary. The list below presents the cases involving posted workers (first three) while the fourth involved a foreign worker that was employed by a local subcontractor. Analysis of the underlying causes revealed that most the incidences were due to negligence, poor knowledge, stress, lack of working instruction, faulty equipment and poor supervision.

1. A posted worker used an unauthorised ladder during assembly of facade elements. When the worker climbed down the ladder it began to slide, causing to him to fall. The employee landed badly and broke one foot and a finger. However, no sick leave was taken, and instead alternative duties were allocated to him.
2. A posted worker was working on the roof top when a power cable reel came rolling down. The worker managed to catch the cable reel from falling down from the roof, but in doing so broke his little finger. No sick leave was taken.
3. A posted crane operator raised a hoisting drum without communicating with the ground crew and had no insight where to place the load. The operator lowered the drum too fast and hit a local worker in the head.

4. A foreign worker (not posted but employed by a local subcontractor) with very limited knowledge of Swedish and English illegally borrowed a rolling scaffold during cleaning work. The worker drove the scaffolding along a vent pipe while standing on the scaffold. His action caused the scaffolding to overturn and he fell about 2 meters down to the floor. He broke his wrist and ankle and was on sick leave for more than 14 days.

Results from interview A

How was the overall health and safety experience at project KKH?

In general, everyone agreed that there was good working environment and safety on project KKH. They stated that health and safety was always high on the company's agenda throughout the project. This was mainly due to the main contractor's strong health and safety organisation. On this project, the role of the safety coordinator was not borne by the project manager. Instead this role was allocated to an individual whose duty was solely to manage health and safety on the project. Generally, it is usual for project managers to have two roles both, i.e. as managers and safety coordinators. Separating the roles had worked well due to non-conflicting interests of the health and safety against productivity. When asked about the health and safety of posted workers, respondents claimed that posted workers standard of health and safety is much lower than the main contractor. The main hurdle is the communication difficulty which hindered progress of the project. These different standards resulted problems during the project as what is acceptable with one party was not so with the other. Respondent M6 agreed that was not easy to get everyone on board working with the company's work environment policies and their own workers were no different. However, all respondents agreed that the posted subcontractors were keen to work with the management and comply with the company's health and safety practices. There was not one particular trade group that caused more accidents than the other. However, respondent M3 claimed that certain posted workers performed work unsafely. Respondent M6 believed that it was luck that no serious incidents occurred on the project. In one incident, when the posted worker injured and broke his foot, report was made only after a week. Hence, it was not impossible if incidences involving posted workers (especially when they work late evenings and on weekends) went unreported. The management were aware of this possibility but found it difficult to overcome the issue especially when it involved working outside the ordinary working time (after 07.00 – 16.00; Monday till Friday). Even though the company is successful in educating its own workers (who were directly employed) to have high regard for health and safety, the same cannot be applied to local and posted subcontractors. The latter complained that the pressure on health and safety was costing them time and money. Many of the subcontractors' workers were having difficulty adapting at work and not used to the strong emphasis on health and safety at work.

How was the health and safety of posted subcontractors and their workers?

All respondents agreed that posted subcontractors were not at the front-end of health and safety compared with the main contractor. The subcontractors had a lot to learn about working safely and paying attention to risks. Majority agreed that the working culture among posted workers is prioritising productivity more than health and safety. They only performed safety precaution when required. Respondent M3 observed that apart from compulsory PPE, foreign workers never took extra initiatives regarding health and safety. For example during welding work on a higher storey, it was recommended to mark the floor below to notify of the activity above. None of the subcontractors took this extra initiative. Respondent M5 claimed that posted subcontractors had different levels of risk tolerance in comparison with local workers. Even though posted workers are required to abide by safety rules, they lacked planning and control capabilities. For example, they knowingly placed materials in spaces that should be free and unblocked. Both respondent M2 and M3 noticed that subcontractors in general and posted subcontractors specifically abide by safety rules to please the management and avoid being reprimanded or penalised. For example, in one case, workers from Lithuanian kept repeating the same mistakes such as using unapproved ladders, incomplete PPE, using safety and lifting equipment that were not inspected. The penalty were reminders and fines. On the contrary, the main contractor's own worker had to be sent home for using unapproved ladders after several warnings. The same rule were not applied to the subcontractors mainly because handling these issues took a lot of time and energy. Nevertheless, the management admitted that they must continue to champion for safer work environment. The respondents noticed that there was a positive difference in the understanding of health and safety among posted subcontractors upon completion of the contract. They had begun to embrace the company's health and safety rules and regulations and understood the reasons to observe them. The company was proud of this outcome and would continue to improve it.

How did the communication work between the posted subcontractors and main contractor?

Overall, communication worked fairly well. It was difficult in the beginning but it got better as the project progressed and the management learned how to manage this hurdle. Having at least one person in the group that could communicate either in English or Swedish was important to ensure safe work environment. Sometimes the respondents resorted to using hand movements or demonstration to get things done. In certain complicated and critical situations, the company was lucky to have one of the local subcontractor's worker who could speak Russian and managed to help out. One of the project supervisors spoke Polish and German, making communication with the respective subcontractors much easier and smoother. There was no problem communicating with the Danes. In the case for respondent M4, there was never a direct communication between him and posted workers. He usually conveyed his instructions through project supervisors who would then discuss them with the project manager. According to respondent M4 when the project manager was involved, posted workers took matters seriously. The disadvantage was that the chain of communication was long and time wasting. Additionally, respondent M4 felt intimidated using his broken English when communicating with foreign workers. Yet, communicating with posted subcontractors who spoke good English, made the job easier for respondent M5. This was evident with the subcontractor from Czech Republic where they performed well in the project. Unfortunately, in some subcontractor groups, only the group leaders can speak fairly good English. In such situation, all instructions or corrective measures had to be conveyed to the group leader and the management team had no idea what the group leader actually said to their workers. This sometimes led to situations where subcontractors kept repeating the same mistakes and no corrective measures were performed. A lot of time was wasted with fussing about performing the corrective measures. This is a common scenario every morning. As the project progressed, respondent M1 had learned how to communicate with limited English to the posted subcontractors. Whenever he needed to inform them about corrective measures, he ensured that then group leader informed all of his workers and not just the one involved with the corrective measures. This was successful in getting them to perform.

Results from interview B

How important was a safe and healthy work environment for you?

All four respondents agreed that safety and a good working environment are very important. Respondent P1 explained that since he was responsible for his workers, he had to prioritise their safety. Respondent P2 emphasised that both physical and psychological work is very important for himself and his colleagues. Together they worked constantly to create a good and safe working environment. For respondent P3 many factors were vital in ensuring the safety of the working environment including actions such as putting up barriers, signs, warning signs, light signals, etc. as he discovered how much they really needed to make a workplace safe. According to respondent P4, the main contractor achieved good working environment on project KKH due to regular control on health and safety.

How was your health and safety experience on project KKH?

Overall all four respondents agreed that they had very good experience and witnessed how safety was made a priority at project KKH. However, respondent P1 claimed that foreign subcontractors had stringent rules compared to local subcontractors when it came to health and safety issues. According to respondent P1, to ensure his own skilled workers to understand the importance of these issues, they had to keep a higher level of safety standard than the local subcontractors and this was the greatest difficulty. For respondents P2 and P4, the difficulty had been the obligation to wear PPE all the time regardless of the task performed. Respondent P2 would have preferred if the management had been more flexible as their work entailed a lot of working on the knees and the safety helmet contributed to an increased load on the neck. Similarly, the requirement of wearing gloves posed problems as it was difficult to use the fingers when working with bonding of wood flooring. His workers were photographed on several occasions for not wearing gloves or helmet while working. He felt that the management should have taken a more diplomatic approach and reminded his workers instead of photographing the offence as evidence. Respondent P3 emphasised that all safety restrictions and safe work could sometime lead to retaliation. He confessed that there was no strong distinction between the standards of safety at the Swedish construction sites to his home country but better implementation in Sweden.

How did the communication work between you (or your workers) with the main contractor?

Surprisingly, the respondents did not see language as a barrier. Mainly, English was used among all posted subcontractors except for the German and Danish subcontractors. Respondents P1, P3 and P4 used English to communicate. They admitted that while there were some mistakes when communicating, they were resolved quickly. They could make themselves understood well enough to exchange the amount of information that was required and necessary. Both management and subcontractors appreciated the open dialogue based on trust between them. They believed that their language skills were sufficient to perform their tasks. Everyone agreed that that it was very important to have good commination to ensure the smooth running of the project.

6. Analysis and discussions

Working with posted workers posed many challenges for the main contractor and its own workers. It is clear the foreign workers on the project lack health and safety knowledge and have higher risk tolerance in comparison with local workers. This concurs with studies performed by the SWEA (2012), Bergsten et al. (2014) and Jonsson and Larsson (2013) that there are a number of difficulties linked to the current global and free labour movement. People with a foreign background have a 36 percent higher chance of being involved in an accident than a person with Swedish background (SWEA 2014). The risk is also evident when people with different cultural backgrounds work together. The probability of an accident occurring has substantially been linked to linguistic misunderstandings and cultural differences at the workplace, which are different from what the foreign workers are accustomed to (Allwood 1985). In Australia, Loosemore and Andonakis (2007) discovered that the existing language problem among foreign workers usually affect compliance with health and safety, thus, effecting the implementation of healthier and safer work environment. Accidents have also been linked to outdated regulations: The Work Environment Act was written in the 1970s, a time before the EU's single market was established and when foreign companies on the Swedish workplaces was unusual. Today, many foreign workers see the free labour movement in the EU as an opportunity to earn better living outside their homeland (Jonsson and Larsson 2013) and construction is among the attractive trades. Construction workers often come from Eastern Europe, where wages are lower, social security is inferior or non-existent and unemployment has periodically been high. Posted workers were procured based on price and labour shortage. Nonetheless, their presence often create resentment from the local Union (Byggnads) as they not only for their poor health and safety knowledge but also the collective agreement with foreign workers working conditions and wages (Jonsson and Larsson 2013).

Results from interview A showed that there were divided opinions on how well communication worked with posted workers. Majority of respondents from the management team felt that their English skills were sufficient for satisfactory communication with the posted subcontractors. A few respondents had communication difficulties with posted workers. Certain respondents stated that since their language skills was limited, they had chosen not to communicate directly with the posted subcontractors. Another concern was that usually, the posted supervisory person was the only one who spoke English. Several respondents felt that this lead to the long chain of communication (Figure 1) which was troubling, and that information got lost in the trail. The long communication chain was time-consuming and problematic and can lead to security risk in emergency situations (Gustafsson and Hansson 2005).

Posted worker ⟺ Posted worker supervisor ⟺ Swedish supervisor ⟺ Swedish Manager

On the contrary, the posted subcontractors' response reflect a different picture. They claimed that communication worked well and there had not been any major misunderstandings despite the language barrier and their English skills were sufficient to get the work done. In cases where communications had worked well, it was often because the posted workers were fluent in English. There was also the contradiction of stricter rules when breaching the health and safety rules and regulation. The management team claimed (from interview A) that they impose stricter rules to their own workers i.e. like sending them home after several warnings. In a conflicting claim made by posted subcontractors (interview B), they felt that the main contractor had stringent rules imposed on them compared to local subcontractors i.e. photographed their worker when they failed to use full PPE.

7. Conclusions

The objectives of the study are i) to analyse recorded incidents concerning posted workers ii) to assess work environment of posted workers and ii) to examine the communication between the main contractor and the posted subcontractors. The objectives were achieved as follows: *objective i)* there is no evident linking foreign workers to occupational accidents. On the contrary, project KKH incident records showed the opposite; *objective ii)* the work environment with posted subcontractors are satisfactory. However, the posted subcontractors lack sufficient knowledge and understanding to be able to work safely which can be problematic. The main contractor had to put in extra time and resources to resolves these problems; objective iii) communication difficulties based on lack of language skills could easily lead to misunderstandings, cultural work differences in safety and work environment compounded job safety problems, and the presence of foreign workers from different countries (sharing no common language at the work site) accentuated job safety problems in the industry. Suggestions from this study are i) increase more simple and clear aids to communicate in multicultural workplace e.g. more visual communication, ii) clear emphasis on the contract on the requirement for language competence and health and safety competence when procuring posted workers iii) education about cultural differences must be performed; and iv) improve English and other common foreign language proficiencies of local workers. The over-reliance on labour-only subcontracting and more importantly, the use of foreign workers is a scenario that will be common in construction projects. Thus, the Swedish construction industry must embrace, accept and adjust to having a multicultural workforce.

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Part II: Constructing Commitment and acknowledging human experiences

3. Health and Safety
4. Organisations, Knowledge and Communications
5. Projects, Procurement and Performance
6. Users, Clients and Stakeholder Engagement

TAMPERE UNIVERSITY OF TECHNOLOGY

Revisiting the Relationship between Physical Strain and Task Productivity

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Abstract

Identifying human factors and job characteristics affecting performance is crucial for a sustainable management of the workforce in a labor-intensive industry, such as the construction industry. At the individual worker level, physiological status and environmental stressors are reported to influence workforce performance. Previous exploratory research reported a U-shaped curve between physical strain and productivity at the group level. This paper revisits those exploratory findings to validate the U-curve relationship between physical strain and productivity at the group level. It also evaluates the relationship at the individual level while controlling for personal demographic information and heat stress. This study builds upon the previous study by expanding the original dataset and conducting an identical experimental protocol. The subjects wore sensors to monitor their heart rate, which indirectly measured their physical strain. Cameras were used to record experimental activities. The correlations between physical strain and productivity were analyzed at both the individual and group levels. We divided each subject's four-hour experimental data into 5-minute intervals, assigned time variables, and generated panel data sets for each subject. Then, the time effect on the subjects was observed to reflect the effect of time on physical strain and productivity. To conduct the panel data regression analysis, individual physical differences such as age, gender and body mass index were defined as control variables; physical strain and time effect were set as independent variables; and productivity was defined as a dependent variable. Random-effect models of panel data analysis were used to investigate the relationship. Based on the above statistical analysis, we observed the U-curve relationship between physical strain and task-level productivity both in the group and individual level as the construction laborers' job characteristics. This research finding demonstrates how physical strain in a laborer involved in construction work is correlated to task productivity.

Keywords: Occupational Health and Safety, Labor Productivity, Work Physiology, Labor and Personal Issues, Human Resource Management

1. Introduction

Taylor (1911) initiated the modern journey into management theories. Still, the application of Taylor's findings, aka Taylorism has shown many shortcomings due to some of its assumptions. Whereas its major issues have been overcome by human relations and lean concepts, Taylor's premise is still powerful for its implied argument for sustainability that encompasses human resources, and provides a good introduction to this paper.

> We can see our forests vanishing, our water-powers going to waste, our soil being carried by floods into the sea; and the end of our coal and our iron is in sight. But our larger wastes of human effort, which go on every day through such of our acts as are blundering, ill-directed, or inefficient, […] are less visible, less tangible, and are but vaguely appreciated. We can see and feel the waste of material things. Awkward, inefficient, or ill-directed movements of men, however, leave nothing visible or tangible behind them. Their appreciation calls for […] an effort of the imagination. (Taylor, 1911, pp.iii).

When it comes to workforce, the construction industry in the United States is struggling with high fatalities and injury rates (CPWR 2013). Construction workers are suffering from several health issues such as obesity, cardiovascular diseases, and musculoskeletal disorders (BLS 2012). Workers' poor health conditions cause higher rates of presenteeism and absenteeism (Swanson et al. 2011), which eventually lead to labor productivity losses. Job characteristics in construction may be the reason why the construction labor productivity is stagnant or even decreasing compared to manufacturing over the past decades. Thus, identifying the human factors and job characteristics affecting construction labor performance is crucial for a sustainable management of the workforce in such a labor-intensive industry (Gatti et al. 2012).

The influence of physical strain on the productivity of construction workers was recently explored by Gatti et al. (2014) who performed a study to identify the relationship between physical strain and performance in the construction workforce by using wearable physiological status monitor (PSM) technology. Relying on literature using heart rate as a reliable indicator of physical strain level (Kirk & Sullman 2011; Ainslie et al. 2003), Gatti et al. (2014) reported a U-shaped curve between physical strain and productivity at the group level based on experiments with 9 subjects of age between 19 and 23. Results of this exploratory study were well discussed but carried limited external validity due to the small subject sample, and the narrow range of the subject ages. For the same limitations, individual factors, such as age, gender, body mass index (BMI), height, and weight could not be statistically controlled in the analysis of the relationship between physical strain and productivity. Also, Gatti et al (2014) did not evaluate if productivity would reduce according to an increase in their physiological strain or if their physiological strain would increase according to the effort input to increase productivity. Thus, this paper sought to revisit the U-curve found by Gatti et al. (2014) by investigating the causality between physiological strain and productivity. To this end, panel data were produced by reflecting the time variable in each subject data, and 5-minute interval panel data were produced.

2. Methods

2.1 Participants

Gatti et al. (2014) conducted 9 experiments with subjects with an age range from 19 to 23. We collected data from additional 11 experiments with an age range from 23 to 33. All subjects were recruited among university students and were instructed to perform simulated construction activities that did not require previous field experience. The participant sample is assumed to represent the population of workers entering the industry as apprentices. The study was approved by the Institutional Review Board (IRB) of the University of Washington.

2.2 Equipment and Experiment Protocol

All the procedures of the experiment followed the protocol of the initial exploratory study, and were conducted in the same lab using the same physical layout. The detailed protocol is described in Gatti et al. (2014), and only briefly described in this paper. Subjects simulated the construction task of installing a raised deck made of concrete pavers weighing 7kg on adjustable plastic supports. The distance from the storage area to the floor installation area was 2.2 meters. After completing the installation of a rectangular-shaped floor (seven rows by three concrete pavers), subjects moved on to an adjacent floor installation area. This task was repeated during four working periods consisting of approximately 50 minutes each with 10-minute breaks. The same instrumentation, the BioHarness BT (Zephyr Performance System, Annapolis, MD, USA) was used to collect heart rates. This device weighs 35g without fabric chest belt, and it collects electrocardiogram (ECG), breathing rate, skin temperature and 3-axial accelerometer data. As part of the approved IRB protocol, we monitored subject overexertion in real time using transmission of live data to the laboratory computer through a radio signal communication rather than logging data inside of the device's memory. Researchers monitored heart rate on the computer screen during the entire experiment. A heat-stress meter (Sper Scientific, Scottsdale, AZ, USA) measured wet-bulb globe temperature as the index of indoor heat-stress level. Figure 1 shows the devices that were used during the assigned raised concrete deck installation activity.

Figure 1. Experimental setting and equipment

The experiment participants were provided bottled water to rehydrate. This allowed assuming that the hydration status was maintained at a normal level homogenously among all participants, so that a participant's hydration level did not critically influenced her heart rate.

2.3 Heart Rate Index

The relative heart rate (RHR) was estimated as an indicator for assessing physical strain introduced by Rodahl (1989):

$RHR[\%] = (HR - HR_{rest})/(HR_{max} - HR_{rest}) \times 100$,

where 'HRmax' is predicted maximum heart rate and 'HRrest' is measured average heart rate while sitting on a chair for 15 minutes. Using RHR instead of absolute heart rate values allowed to normalize the individual characteristic such as the subject's age and resting heart rate.

There are several formulas to calculate the maximum heart rate. This study adapted the equation used in Gatti et al. (2014) introduced by Tanaka et al. (2001):

$HR_{max} = 208 - 0.7 \times Age$, where 'Age' is the age of subject.

2.4 Research Hypothesis

Since the study design does not provide production goals in the assigned time of the task, the subjects work at their own pace. This potentially means the productivity in time t is positively related with productivity in time t + Δt at the individual level. Between individuals, more productive workers will remain more productive than low-productive workers based on author's observations while monitoring experiments.

Research Hypothesis 1: This study hypothesizes that the worker's current production rate affects next production rate positively.

If the individual characteristics were not taken into account in the relationship between physical strain and productivity, the direction of the relationship is positive as found by Gatti et al. (2014). However, when we consider the individual factors such as age, gender and BMI by controlling for them in the regression model, the direction of the relationship could be linearly negative as discussed by other studies (Åstrand et al. 2003; Bernold & AbouRizk 2010). Thus, when the physical strain (i.e., RHR) increases, the productivity will be decreasing linearly.

Research Hypothesis 2: The direction of the relationship between individual physical strain at time t and productivity at time t + Δt is linearly negative while controlling for the effect of individual factors.

Gatti et al (2014) found that the scatter plot of physical strain versus productivity fits a convex parabolic regression model. However, based on the literature that discussed negative effect of physical strain on productivity (Åstrand et al. 2003; Bernold & AbouRizk 2010), we could hypothesize that the quadratic relationship between physical strain and productivity can be a concave parabolic shape (i.e. inverted U-shape) while controlling for individual factor variables. Thus, the productivity will increase with increasing RHR at certain points; however, the productivity will decrease when the worker has an overexertion status by exceeding an RHR turning point level.

Research Hypothesis 3: At the group level, the quadratic relationship between physical strain at time t and productivity at time t + Δt is a concave parabolic shape while controlling for individual factor variables.

2.5 Description of Variables

Based on the description on the research hypothesis of this study, the dependent variable is the productivity at the task level of construction activity. Since the data come from a panel data set including time factor, we lead the dependent variable by one 5-min period. The independent variables are RHR, and productivity is measured over the 5-min period.

Additionally, variations of circadian rhythms affect the physical strain of workers (Åstrand 2003; Folkard 2003). Thus, a categorical variable was added to control for the start time of each experiment: morning (before noon), afternoon (noon to 6 pm), and evening (after 6pm).

Table 1. Definition of variables

Variables	*Variable code*	*Description*	*Hypothesis*
Productivity in next 5 minutes	*LEADPRO*	*The explanatory variable collected every 5 minutes, which affects the productivity of the next 5 minutes (longitudinal) than the productivity during the same time period (cross-sectional).*	*Dependent variable*
Productivity in current 5 minutes	*PRO*	*The unit productivity measure by the number of panels installed was divided by 5 minutes. The unit of this variable is concrete panels installed per minute.*	+
Relative heart rate	*RHR*	*The normalized indicator of physical strain level was measured by heart rate, taking into account age and heart rate at rest.*	-
Squared relative heart	*RHRSQ*	*A squared term of relative heart rate was used for the quadratic regression model.*	-
Subject age	*AGE*	*The younger subject would be more productive than older subject while working in the labor-intensive task.*	*Control variable*
Gender of subject	*MALE*	*The male subject can be more productive in the given concrete-paver-installation activity (Female=0, Male =1).*	*Control variable*
Body mass index	*BMI*	*High obesity level or low body mass index can influence productivity level.*	*Control variable*
Resting heart rate	*HRINR*	*The index of physiological status measured by heart rate at rest.*	*Control variable*
Time for conducting experiment	*MORN, AFTER, EVEN*	*Dummy variable; the evening (omitted coefficient) is the baseline of the analysis. EVEN is the reference dummy variable in the regression model.*	*Control variable*

2.6 Data Analysis

Experiments were assigned a session code (e.g. A.M.4) for data analysis following the same convention as Gatti et al (2014). Data for two of the 2014 experiments were lost due to a technical failure (i.e. J.F.4 and U.M.4). After integrating data collected in 2010 and 2014, we had 20 experiments available for analysis. The Pearson product-moment correlation coefficient is used for individual level of correlation between physiological strain and productivity. The group level of distribution of the data points is analyzed by scatter plot with linear and quadratic fit lines. For each experimental session, time-series data were generated in 5-minute intervals for average heart rate and unit productivity resulting in multiple observations for each experimental session. Each time interval includes cross-sectional data for each subject's individual characteristics that can influence productivity, such as age, gender, BMI, resting heart rate, and time for conducting the experiment (Table 1). All subject time series and cross-sectional data were integrated on the panel dataset. Due to some missing data on specific subjects, the panel data is unbalanced, but there were no time gaps because the missing data was observed at the beginning of the experiment (i.e. the ECG patch of wearable sensor was not wet enough to transmit an ECG signal to the sensor module before the subjects were made sweaty by physical activity) or at the end of the experiment (i.e. the case where a subject elected to stop the experiment earlier than four hours of working). Heart rate outliers were detected and removed using the Grubbs test on an individual level. Removed heart rate values were counted as missing values and replaced with neighboring preceding non-missing values.

This study aimed at studying how the influence of physical strain measured by heart rate on productivity would change over time, so panel data analysis was employed. A random effects (RE) model was used rather than a fixed effects (FE) model because each subject's individual characteristics data were collected and used to estimate their effects on the dependent variable. The data analysis was conducted using STATA13 (College Station, TX, USA: StataCorp LP).

Muscle types and environmental conditions are known to affect heart rate. Since the subjects followed the same experimental protocol, it is reasonable to assume all the participants mostly used the same muscle types, and the unobserved effect of muscle type use had no relationship with the explanatory variable. We also controlled the effects of the observed difference of individual characteristics (i.e. age, gender, BMI, and resting heart rate) on their productivity. Moreover, for all the test participants, consumption of food and caffeinated beverages and smoking were banned 2-hour before the experiment.

3. Results

Demographic information of the 2010 and 2014 samples is summarized in Table 2 after excluding sessions with lost data (i.e. J.F.4 and U.M.4). With a 99% confidence level, there is not statistic difference in average age in subject and indoor WBGT measured by heat stress monitor between the 2010 and 2014 experiments. However, the range of subject ages is much wider for the 2014 group (SD=3.1) than for the 2010 group (SD=1.7). This was intended to overcome one of the stated limitations of the study by Gatti et al (2014) based on the 2010 sample. Thus, age was also included as control variables in the panel data analysis. The indoor wet-bulb globe temperatures (WBGT), measured at the time and day that the subjects conducted a task, were not significantly different. The indoor WBGT temperature measured are not varied between subjects as well as between data collected in 2010 and 2014. Thus, the variable of heat stress level eventually was removed from the regression model analysis. Last, a greater sample of people is expected to show a wider range of anthropometric measurements such as weight and height. Thus, this factor should be statistically controlled in the regression model for analyzing the relationship between physical strain and productivity model.

Table 2: Demographic information of subjects and indoor heat stress index

Variable	*Data Collection in 2010 (n=9)*	*Data Collection in 2014 (n=11)*	*p*
Age (years)	*20.7 (1.7)*	*25.5(3.1)*	*<.001*
Height (cm)	*173.3(5.3)*	*174.5(14.3)*	*.810*
Weight (kg)	*68.5(5.9)*	*68.0 (17.0)*	*.932*
BMI	*22.8(1.5)*	*22.1 (3.4)*	*.055*
Indoor WBGT (°C)	*14.1(1.1)*	*13.9(.9)*	*<.001*

One of the 2010 subjects participated twice in the experiment similarly to two 2014 subjects. Since the objective of this study is to understand the relationship between physical strain level measured by heart rate and productivity while controlling for effects from other factors, such as age, gender, and BMI, etc., we treated each experimental observation as a separate data point, which also increased the statistical power.

In the result of the correlation coefficient analysis with x-axis for RHR and y-axis for productivity, most subjects presented moderate and strong positive correlation relationship (Table 3). If the heart rate is an effective predictor of physical strain, the physical strain is positively correlated with task level of productivity in the concrete paver installation activity.

Table 3: Correlation coefficient between relative heart rate and productivity

Correlation coefficient	*-0.5 <= r <-0.2*	*-0.2 <= r <0*	*0< r <=0.2*	*0.2<r <=0.5*	*0.5<r <=0.8*
Direction and strength of correlation	*Moderately negative*	*Weakly negative*	*Weakly positive*	*Moderately positive*	*Strongly positive*
Subject	*(Q.F.4)*	*(D.F.4), (I.M.2), (L.M.4)*	*(F.F.4), (U.M.4)*	*(A.M.4), (B.M.4), (G.M.2), (K.M.4), (M.M.4), (T.M.4)*	*(C.M.4), (H.M.2), (E.F.4), (N.F.4), (O.M.4), (P.F.4), (R.M.4), (S.M.4)*

In Figure 2, the group-level scatter plot between RHR and productivity confirms the u-curve trend that was observed by Gatti et al (2014). Except for apparent outliers (i.e., subject in the right bottom in the plot), the observed data is clustered in three individual groups. In the first group, the subjects were productive while maintaining low RHR. In the second group, the subjects achieved low productivity while maintaining an average level of RHR. In the last group, the subjects were highly productive, but the physical strain level was also high based on the measured relative heart rate.

Before performing the panel data analysis, we looked at multicollinearity among the dependent variable and independent variables. After performing the variance inflation factors (VIF) measurement test with the dependent and independent variables except for the square term of relative heart rate, we found that none of the VIF values of variables exceeded 10, which indicates no multicollinearity among the variables (O'Brien 2007).

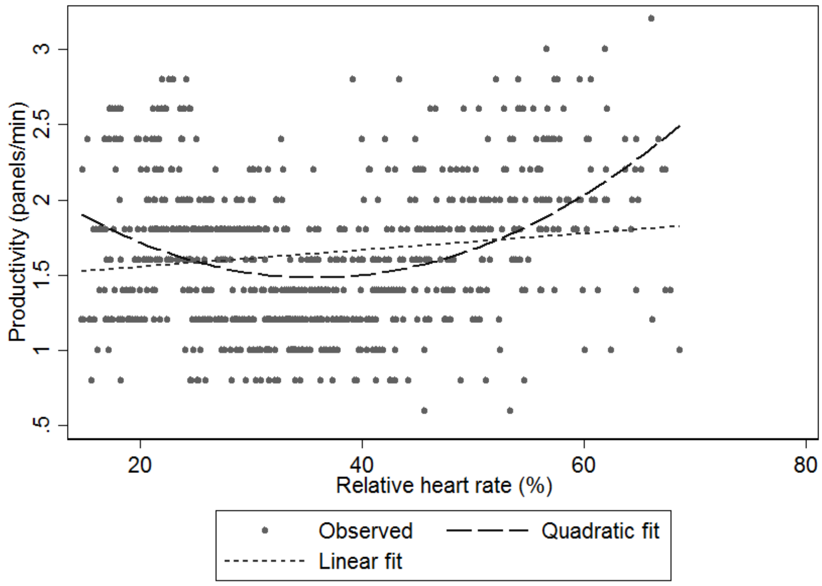

Figure 2. Scatter plot relative heart rate vs. productivity (time interval 5 min)

The results of panel analysis for RE models are summarized in Table 4. We initially analyzed data both with the RE model and FE model. Since there are no omitted time-invariant explanatory variables in the RE model while the FE model omitted control variables in the analysis, the RE model is better than the FE model (Allison 2009). Due to the omitted variables in the FE model, the Hausman test choosing between the FE model and RE model was not applicable. Also, the effects of time-invariant variables were estimated with small standard errors of the estimates; thus the RE model is appropriate to the collected data set.

The effect of explanatory variables on the dependent variable is identically applied to 'between groups' and 'within group' in the RE panel data regression model. In the RE model, the group variable is defined as the subject. Model 1 in Table 4 tested Research Hypothesis 1, that the subject's current production rate linearly affects positively the production rate in the next period. Therefore, assuming Subjects A and B had the same control variables (e.g., the same age, sex, BMI, resting HR, conducting task in the similar workday such as morning hour), if subject A was over-producing Subject B by 1 panel/minute at current time (t), it was found with 95% confidence level that Subject A would also over-produce Subject B by 0.8 panels/minute in the next 5 minutes ($p<0.01$). Model 2 in Table 4 tested Research Hypothesis 2, that the relationship between physical strain and productivity is linearly negative at the group level.

Since we confirmed the statistically significant effect of current productivity (i.e., Productivity t) to the next productivity rate (i.e., Productivity t+1), the variable PRO was also included in the model ($p<0.01$). A linear relationship between RHR and productivity was presumed in the hypothesis, but there was no significant linear effect of RHR variable on the dependent variable with 95% confidence level. The final Model 3 (i.e., Full model) tested Research Hypothesis 3, that the RHR variable is nonlinearly related to the dependent variable at the group level. We also added a PRO variable in Model 3 since the significant effect of it is estimated in Model 1 ($p<0.01$). Based on the analysis of Model 3, the coefficient of RHRSQ is a positive value ($p<0.05$), and the coefficient of RHR is negative ($p<0.05$), so the shape of the quadratic graph is a U-shape. The turning point of the U-shape is 30%, estimated at the coefficient on RHR over twice the absolute value of the coefficient on RHRSQ (i.e., $|-.012/(2\times.0002)|$). So, the turning point in the model where individual factors were controlled was lower than the turning point of scatter plot (i.e., around 40%) in Figure 2. Therefore, the result of analysis was unlike the Research Hypothesis3—workers' productivity will increase up to a certain level of RHR, and when RHR continuously increases over a certain turning point, productivity will decrease. Productivity keeps decreasing until the RHR of workers reached 30%, and when RHR has increased over 30%, productivity will increase along the U- shape curve with a 95% confidence level when the effect of other variables, including PRO, are constant.

Table 4: Panel data analyses

	Model 1	*Model 2*	*Model 3*
Variables	*LEADPRO*	*LEADPRO*	*LEADPRO*
Control Variables			
AGE	*.017**** *(.005)*	*.017**** *(.005)*	*.013**** *(.005)*
MALE	*.028* *(.026)*	*.028* *(.026)*	*.038* *(.026)*
BMI	*-.009*** *(.004)*	*-.009** *(.005)*	*-.009*** *(.005)*
HRINR	*-.003**** *(.001)*	*-.003*** *(.001)*	*-.003** *(.001)*
MORN	*-.114**** *(.036)*	*-.113**** *(.036)*	*-.095*** *(.036)*
AFTER	*-.118**** *(.040)*	*-.117**** *(.040)*	*-.067** *(.043)*
Explanatory Variables			
PRO	*.799**** *(.023)*	*.798**** *(.024)*	*.785**** *(.024)*
RHR		*.0001* *(.0001)*	*-.012*** *(.005)*
RHRSQ			*.0002*** *(.0001)*
N. of observations	*739*	*739*	*739*
Number of groups	*20*	*20*	*20*
F test	*1782.24****	*1779.90****	*1796.16****
R-squared (overall)	*.7091*	*.7092*	*.7113*

*Note 1. Significant levels; *** p<0.01, ** p<0.05, * p<0.1.*
Note 2. Standard errors in parentheses.

4. Discussion

The results of our data analysis led to a failure to reject the null hypothesis for research hypotheses 2 and 3. Therefore, we could not accept these research hypotheses on the relationship between physical strain (i.e., RHR) and productivity. On the other hand, we were able to reject the null hypothesis for research hypothesis 1. Therefore, we found that the prior productivity positively related with the following productivity in a 5-minute interval.

Taylor (1911) introduced scientific management by investigating the current production rate as a decreasing function of fatigue, in his time and motion observation studies. The recent development of precise and wearable sensors to monitor the physiological status of workers allows for a simpler and more scientific data collection and analysis for reevaluate Taylor's findings. The current study hypothesized that increasing physical strain will have a correlation with a significant decrease in future productivity from a certain inflection point (concave parabolic shape). However, the result was found to be the opposite (e.g., convex U-shape) suggesting that the higher physiological strain/cost was the result of higher production output. As an explanation of these results, we can envision that a subject who put more effort (higher strain) at the current time point would be more productive at the current time (cross-sectional) as found by Gatti et al (20104). However, a 5-minute lag does not seem enough to observe the expected negative relationship with increasing physical strain and decreasing production rate. The ongoing continuation of this study is expected to complement human scientific management by considering a control production schedule that reflects the expected time for production decreases based on the real-time physical strain of workers who perform repetitive construction activities. Thus, this study will predict and quantify the concept of human durability defined by Taylor—'The current rate of activity in a given muscle group is a decreasing unit of fatigue in that group' (March & Simon p.17) —to generalize it among the current construction workers in the apprenticeship level population aged from 19 to 29.

The heart rate index has a limitation to be used as a single index to measure workers' physical strain. Rather than physical strain, heart rate should be used as an index to measure physical workload objectively, or as a physiological cost, meaning how much physical effort was put in for a worker to conduct a task. Therefore, when the relationship between heart rate and productivity is positive, it should be interpreted that productivity is improved as long as the worker invests more physiological cost. In addition to this, any follow-up study should involve a task longer than 4 hours, and analyze how the efficiency of productivity (output) decreases in proportion to physical cost (input). In the U-shape that was drawn from this study, when data is added with RHR, which is measured higher than the observed level due to the 4-hour work period, the relationship between physical strain and productivity in the quadratic term can turn into a third-order term. That is, if RHR increases and stays at an excessive level, productivity can decrease again.

This study has found that individual workers' physical characteristics or other psychological factors influence their physiological strain or productivity. Therefore, follow-up research is needed to see what factors are involved in the process of physiological strain influencing productivity. Also, follow-up research should be done to figure out if there is any group of people that fails to fit themselves to the task given in terms of physiological aspects and how to train them to be a group of people that can adapt themselves to it properly. About the range of this training, it can be done with an on-the-job site, but it needs to be extended to change the workers' life quality and attitude, even off-duty as well. The following studies should involve additional explanatory variables about emotional and mental activities.

In this study, individual factors were control variables, as was presumed in the beginning, and coefficient and p-value of the model were not discussed. However, the effect of age and BMI on productivity was found to be significant. Therefore, the following experiments and studies should put these factors into consideration. Especially, the effect of time of experiment on dependent variables was significant.

5. Conclusions

By using panel data analyses, we found the U-curve relationship between physical strain and task- level productivity both in the group and on an individual level, as the construction laborers' job characteristics. This trend was found identically, regardless of the difference of physical characteristics among individuals. From a management perspective, there are many other factors influencing the worker's performance; for instance, social support, mental stress motivation and engagement, and so forth. However, when it comes to the construction industry, we believe that physical strain plays a significant role that has been somehow ignored by previous research on labor performance. Physical strain should be monitored by project and safety managers to sustainably manage construction workers so that they can achieve optimal performance. Therefore, to plan work assignments, it is needed to consider the characteristics of change in workers' physiological strain. We proposed the heart rate or relative heart rate needs to be understood as how much physical effort the subject consumed for production. Thus, the physiological cost significantly affects task productivity, and the efficiency of investing physiological effect on productivity is changing by time. This proposition should be studied with further investigations about the worker who has lower efficiency on their productivity per their physiological cost input. This contributes to managing the unveiled issues in the construction companies' organizational level to foster the low-performance of employees to maintain their careers more sustainably.

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Empowerment in construction: a qualitative analysis of subcontractors' quality assurance

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Abstract

Employee involvement has been a focus of attention for many years in various guises, such as participative decision-making and participative management, but more recently it has been extended through the concept of empowerment. Employee empowerment means that management provides employees with the tools and authority required to continuously improve their performance. Empowerment leads to better utilization of skills and innovative capabilities. Once empowerment is attained, the individual worker becomes an integral part of the project organization and will be willing to commit himself to project goals. Workers can offer different perspectives than foremen, and they may be able to offer a creative solution not otherwise considered. However, construction as a project-based industry characterized by variation and contract orientation sets challenges for empowerment.

The purpose of this study was set to determine how subcontracted employees are empowered during the preparation and implementation phases of quality assurance. In this study, we investigate how employees are empowered in quality assurance and how well the information of quality standards is getting to employees.

A qualitative approach was chosen to assess the empowerment practices in quality operations among subcontractors. The data is based on a set of 20 semi-structured interviews in the Helsinki metropolitan area with Finnish and Estonian speaking workers and supervisors.

The findings of the study indicate that subcontracted workers are often neglected in the quality assurance process by their nearest supervisors. Workers are not involved in formal planning of tasks or self-inspection in quality assurance. They need to recall spoken information, since written documents are not on hand. Further, workers rarely cited any particular quality standards during the interviews and perceived quality as 'the same as always' or 'what looks good'.

Keywords: employee empowerment, quality, quality assurance, subcontracting

1. Introduction

Definitions of empowerment abound (Honold, 1997). Conger and Kanungo (1988) argue that empowerment is often seen as a synonym for sharing power. In fact, in empowerment, power is shared to subordinates. To decide and act as empowered subordinates, the workforce needs the knowledge, skills, authority and desire to take responsibility (Juran and De Feo, 2010). The authors emphasize that empowering the workforce will lead to a culture of high performance or what is often called a quality culture. Empowerment has been collectively defined as: The process of giving employees the authority to take decisions, relating to their work processes and functions, and within the limits provided by management, but requiring them to assume full responsibility and risk for their actions (Holt et al., 2000). The authors add that empowerment is employees' perception that they believe in and control what happens to their work processes, and that they are capable of controlling those processes efficiently and effectively.

Empowerment is distinctively conceptualized as a structural concept and as a psychological concept. As a structural concept, empowerment is deeply rooted in job design and occurs through objective and formal organizational changes that grant individuals greater latitude to make decisions and exert influence regarding their work (Liden and Arad, 1996). The psychological perspective, on the other hand, proposes that empowerment is a constellation of experienced cognitions. Psychologically empowered individuals and teams 'see themselves as having freedom and discretion, as having a personal connection to the organization, as confident about their abilities, and as able to make a difference in the system in which they are embedded' (Tuuli and Rowlinson, 2010).

Many aspects of present construction management structures foster the lowering of individuals' feelings of self-efficacy and of belonging to the company and also to the project. Construction as a project based industry with changing teams and leaders sets barriers for strategic workforce empowerment (Greasley, 2005). That is, features of bureaucratic and authoritarian management systems breed powerlessness resulting from dependency, poor communication systems and poor recognition or reward structures (Greasley et al., 2003). Especially construction contractors are blamed to be too cost and revenue oriented. An excessive body of research argues that more attention should be paid to quality (e.g. Zantanidis and Tsiotras, 1998) and partnering (e.g. Wong and Fung, 1999; Särkilahti, 1995) because main contractors often outsource construction work to subcontractors and suppliers. High quality relationships with subcontractors benefit the performance of main contractors (Kale and Arditi, 2001). Subcontractors should be regarded as partners and provided all available information and steering possible (Haupt and Whiteman, 2004). Contract orientation in the industry has led to a situation where risk is allocated 'elsewhere'. Construction is also characterized by disputes and litigation of past problems and there are little resources for developing new strategies for improved performance (Holt, 2000).

People and processes are highly related. Every individual has the potential to improve not only one's own processes but others as well. Imperfect empowerment is unsuccessful because poor performance of one hampers the improvement of others (Nesan and Holt, 1999; cited by Holt

2000), especially in project environment where processes are highly connected to one another. Therefore, the concept of empowerment should be extended to project supply chains, not limited to organizational boundaries (Dainty et al., 2002).

Empowerment requires a holistic approach in reorganizing the way the business thinks and every individual in the organization should be part of it (Holt, 2000). The main benefits of employee empowerment are enhanced morale, more productivity, healthier coworker relationships, and creative thinking (Tuuli and Rowlinson, 2010; Mullins and Peacock, 1991). Involving employees in decisions that directly affect their jobs while also empowering employees to be more autonomous, greatly improves company morale at large. When employees are given independence and expected to be more self-sufficient, they eventually become more efficient as they learn to navigate their responsibilities with minimal interference. This allows foremen to allocate more resources to their other responsibilities and decreases micromanagement that minimizes productivity. Employee empowerment also fosters better relationships between employees and with their foremen, as employees who are given more independence tend to form better working relationships. Employees can offer different perspectives than foremen and they may be able to offer a creative solution not otherwise considered.

Empowerment is seen as an important characteristic of quality improvement (Juran and De Feo, 2000). Formal quality assurance procedures increase productivity in construction because they lead to more systematic overall management of work. Thus the management of resources, information, organization structure and people are enhanced leading to better utilization of site-based resources (Langford et al., 2000).

Construction can be characterized as a fragmented project industry, meaning that each project is unique in various degrees. Therefore, the construction industry lacks standardization. Attempts to standardize processes encounter obstacles in an environment where subcontracting prevails and project teams change. However, many processes (tasks) are recurrent from project to project, especially in industrialized housing construction, setting a fruitful soil for standardization. In the current study, the authors show that steering and monitoring practices of subcontracted work are emphasized by variation. In quality operations, it is essential that employees carrying out the work are fully aware of the quality standards set by the customer and designers. Furthermore, the project's management team should systematically run the quality assurance procedures that the subcontractor follows.

A cultural and behavioural shift in the mind-set of all participants in the construction process (Kanji and Wong, 1998), especially top or senior management, is necessary if the construction industry is to improve its performance and competitiveness. Participation in decision making (PDM) means that both supervisors and subordinates mutually have influence in organizations (Deming, 1982). Since the 1990s, the literature has emphasized e.g. Total Quality Management (TQM) and Lean to answer mainly the poor efficiency of construction. Both aim at satisfying the customer’s needs in an effective manner and feature workforce empowerment.

This paper describes the design and implementation of steering and controlling of subcontracted work. The data for this study were collected using semi-structured interviews in housing construction sites in the Helsinki metropolitan area in Finland. The present study fills a gap in the literature by systematically investigating the employee empowerment practises in quality operations, particularly in the involvement in task preparation and self-inspection. Furthermore, this paper discusses potential ways to increase employee empowerment.

2. Empowerment in Construction

In Finland, construction experienced a major change in production technology in the 1960s when industrialization started the still on-going urbanization, which affected the demand of affordable housing. Off-site building technology made it possible to build housing fast and cost-effectively compared to traditional bricks and mortar technology. Particularly prefabricated concrete units led to new demands for the management of construction. For example, the structural engineering of prefabricated concrete units started to require specialization. The Design-Bid-Build delivery is the traditional and still the most widely used delivery method in Finland in terms of the number of projects. In terms of contract sums, the most widely used delivery methods are forms of Construction management (CM). Therefore, the development of procurement and cooperation are important for construction companies since contractors' procurement accounts for 60–90 percent of their turnover and subcontracted works constitute over 50 percent of total works.

Furthermore, new project delivery models, such as Construction management (CM), caused fragmentation leading to the rise of subcontracting. Procurement and dealing with numerous parties started to play a larger role adding complexity to projects. In quality operations, subcontracted contractors are steered via separate contractual arrangements requiring subcontractors' own supervision of work. This partly outsources quality management to the subcontractor.

Wong and Fung (1999) argued that there are three reasons for subcontracting. First, the subcontractor is specialized and possesses certain skills. Secondly, the main contractor's skills are insufficient in a particular area. Thirdly, there are possibilities for cost savings as the main contractor is relieved from maintaining the in-house capability for the subcontracted work. Therefore, subcontractors should be seen as a strategic resource for main contractors (Kale and Arditi, 2001). Specializing and subcontracting seem to be a permanent phenomenon because technology is in a continuous progress increasing fragmentation.

Improvements in technology and the fragmentation of project management are not the only challenges human resources management faces in construction in the 2010s. A wide range of people with different backgrounds work in the construction sector, such as unskilled workmen, highly educated managers, and foreigners. Individuals coming from different working cultures need to work together and understand each other in a changing project-based environment. These different groups have both common and separate objectives that overlap but often they also are different. Further, on an individual level, objectives differ on how work is carried out (Loosemore et al., 2003).

Empowerment is the process of enabling workers to set their own work-related goals, make decisions, and solve problems within their sphere of responsibility and authority. Therefore empowering can be both simple and complex at the same time (Pheng and May, 1997). It is simple in that foremen need to stop 'bossing' people around and let them do their jobs. It is complex in that foremen and workers typically are not trained to do that and may therefore require training to facilitate the process of empowerment. This process of change is especially difficult in the competitive environment in which construction takes place and where the bottom line is still the primary motivation of construction companies.

Participative management is an important criterion in the implementation of TQM (e.g. Ho et al., 2000; Yong and Wilkinson, 2001). One of the important concepts of TQM is employee involvement and empowerment (Haupt and Whiteman, 2004). In the TQM initiative, workers are encouraged to use their expertise and knowledge to suggest methods for improvements in their work areas. These suggestions could be related to improvements in the job or the product. This is in contrast to conventional quality assurance practices where managers and foremen take all decisions and workers just follow them to accomplish their jobs.

Most of today's quality problems in construction do not have a technical origin but are rather a result of the motivations and attitudes of both managers and workers towards their work (Atkinson, 1997; Bennett, 2000) and thus constitute the main challenge and opportunity in project management. The attitudes of individuals towards work are developed through the influences of the organisational systems within which they function. Hierarchical management structures, top-down information systems and adversarial contracts are all integral parts of the operational framework of the construction industry and each has substantial negative consequences on the social and cultural aspects of the industry. For instance, Haupt and Whiteman (2004) used a survey to assess the most important factors underlying unsuccessful attempts to implement TQM. The authors identified subcontractors' reluctance to co-operate and low bid subcontracting among the most important factors for poor implementation of TQM.

Empowerment approaches aim at enhancing responsibility, increasing authority, and making jobs challenging and interesting to workers, based on their abilities and the needs of the project. This means that managers and foremen provide workers with the tools required to continuously improve their work and performance. From the employees' viewpoint, the nearest supervisor has a strong influence on how empowerment can be implemented (Greasley et al., 2005). Empowerment also means that all workers feel that they have the responsibility and authority to participate in planning, controlling and decision making in their own work. According to Juran and De Feo (2010), workers need to have common goals with the organization and particularly an understanding of other stakeholders and customers' needs. This shared agenda is linked to the need to feel that the work has a meaning, which leads to engagement. Empowerment increases trust and commitment in the workplace (Dainty et al., 2002).

Juran and De Feo (2010) argue that open communication is vital in building workforce empowerment and engagement. Workers need to be encouraged to use their existing knowledge and skills fully, as well as develop new skills. They need procedures to help them to do their job, rather than to be told how to do it. Foremen have to define quality goals clearly, for instance through structured checklists, and to empower workers to check their own work and sign off on correctly completed work. Workers are able to make day-to-day decisions correctly only if their needs for information are fulfilled. Juran and De Feo add that what was before thought to be 'not relevant information' is nowadays relevant. Subcontractors' workforce is easily neglected in the sharing of information because there are numerous steps from the customer to the subcontracted worker in information distribution (Figure 1). The effective management of the information flow sets a major cornerstone, not only for empowerment, but also for successful project execution. Therefore, contractors should consider subcontractors as partners, and managers should consult employees before making decisions affecting them (Kathuria and Davis, 2000). Further, Wong and Fung (1999) suggest that subcontractors should take part in the site's quality teams to improve performance and co-operation. Expanding the use of building information modelling (BIM) helps knowledge sharing and the communication relationships in projects. BIM has thus far mainly been used as a tool for designers but it has lately been extended to other processes of construction projects, such as construction management.

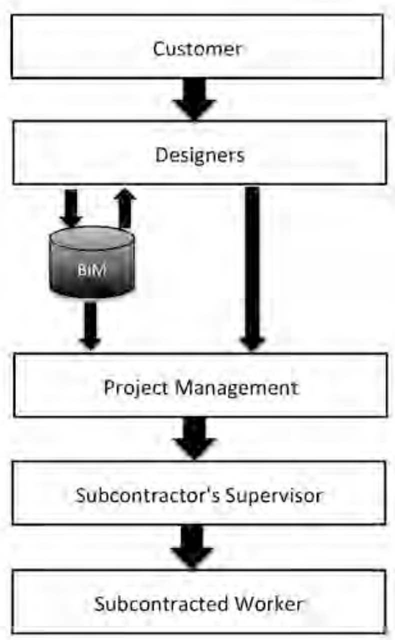

Figure 1: Information distribution from designers to a subcontracted worker

Unfortunately, there are many barriers to the empowerment of workers. There is still a widespread belief among managers that to empower workers is to lose one's own power and authority (Pheng and May, 1997). Empowerment also requires the management to take risks by turning over some control of the works to the workers (Ambad and Bahron, 2012). The management must appreciate that relinquishing control to the effective and skilled workers will result in a more productive organization with better teamwork and faster problem resolution. On the other hand, workers might be reluctant to take more responsibility for their work and quality assurance.

Project managers also encounter challenges in managing the empowerment of individuals or sub-teams outside their organization (Dainty et al., 2002). They need to make decisions concerning HRM under the pressure coming from the wider organization and the ongoing project (Loosemore et al., 2003). The implementation of HRM procedures and an empowerment policy encounters numerous difficulties because teams and leaders change from project to project. Every project is steered by its own management team, which is far from senior management by both its mentality and physical location (Greasley et al., 2005). Further, project objectives are short-term and company strategy is long-term. These two worlds conflict, for example, in staff training, which may not be beneficial for a project but for an organization in the long run.

3. Methodology and Data

The data for this study was collected in June 2015 in co-operation with four large Finnish main contractors. Subcontractors' supervisors and employees were interviewed in 5 new-built housing construction projects located in the Helsinki metropolitan area. The selected contractors were participating in a research project aimed at gaining better quality and performance through applying effective leadership tools for project management especially during the implementation phase. The selection of applicable projects followed the research projects' initial selection of case projects. Therefore, the selected projects are not a pure cross-section of on-going housing construction projects because in the cases, management personnel had received training and encouragement to enhance leadership practices on site. However, employee empowerment was not a topic of the received training and therefore, from the view of this paper, generalization of the results faces no hindrances arising from the selection of the surveyed projects.

Semi-structured interviews were chosen to allow a deeper insight into the quality assurance practices that the sites have applied in the steering of subcontracted work. The issues discussed concerned three main topics: task preparation, knowledge of quality specifications, and quality assurance. A pre-defined structure of questions was used in each interview, including follow-up questions when appropriate to complement answers. The interviews were conducted by two researchers so that one asked the questions and discussed the topics, and the other researcher simultaneously took notes. The duration of the interviews varied between 10 to 20 minutes and workers assigned to same tasks (max. 2 persons) were interviewed at once. The specific environment for the interviews was either the Project Management's office or on the site where the workers were working at the time.

Only Finnish speaking Finns and Estonians were included in the sample. A total of 20 interviews were conducted and documented with 26 participants (Table 1). The selection of respondents was made in co-operation with each project manager in advance or ad-hoc at the site, and the response rate reached 90 percent. However, taking into account these two different methods of selection, calculating an exact response rate rests solely on the ad-hoc selection, in which one group of electricians and one group of fitters of prefabricated units declined to take part in the study.

Table 1: Overview of the interviews

		Count	Percent
Position			
	Supervisor	6	23.1%
	Employee	20	76.9%
	TOTAL	26	
Trade/profession			
	Carpentry	6	23.1%
	Electricity	5	19.2%
	Plumbing or ventilation	4	15.4%
	Masonry	4	15.4%
	Plastering	2	7.7%
	Painting	2	7.7%
	Finishing	1	3.8%
	Handyman	2	7.7%
	TOTAL	26	
Nationality			
	Finnish	20	76.9%
	Estonian	6	23.1%
	TOTAL	26	

23.1 percent of the respondents were subcontractors' supervisors and the rest, 76.9 percent, were employees. The interviews represent a large variety of professions, including carpentry, electricity, plumbing or ventilation, and masonry. The qualitative data collected with the interviews were analysed to form a general impression of quality assurance practices, and partly transformed to quantitative data to present results in a condensed form.

4. Results: Empowerment in Subcontracted Work

On the workers' level, empowerment is not currently widely in use (Table 2). During the preparation phase of work, only 23.1 percent of workers had participated in a task specific starting meeting. During the starting meeting, the subcontractor and the project manager discuss the timetable and resources, quality requirements, and quality assurance etc. specific to the work. According to the interviews, typically a supervisor attends the meeting without workers, and in the cases when workers are involved, they are self-employed workers or 'heads of workers'. Task schemes are documents that are drawn up to prepare tasks for successful procurement and implementation. Only one worker had seen a task scheme for the current work, which indicates that task schemes are not in use at all or the information is not distributed to workers. Work was mostly guided on a day-to-day basis by supervisors.

Table 2: Documented employee empowerment practices

	Employee involvement			
	Yes count	Yes percent	No count	Total count
Task preparation knowledge of task specific quality requirements				
Orientation to site	26	100.0%	0	26
Official task specific starting meeting	6	23.1%	20	26
Documented task scheme	1	3.8%	25	26
Site specific standards and tolerances written down	0	0.0%	26	26
Quality supervision				
Documented self-inspection of the first section of tasks	1	3.8%	25	26
Drown stages of tasks self-inspected and documented[a]	3	11.5%	17	26
Tasks' documented self-inspection in the end or in stages	4	15.4%	22	26

Note a: Self-inspection of drown stages was not relevant in 6 cases, such as plastering.

Workers and their supervisors regarded quality typically as 'what looks good' or 'same as always', and no site specific written quality requirements were handed over to workers, as shown in Table 2. Tasks are recurrent from project to project especially in housing construction with little variation and the subcontractors had often co-operated with the main contractors in the past. Site-specific quality standards or tolerances did not exist or at least they were not written down and handed to the subcontractors. However, work was often guided by quality standards and working instructions coming from material suppliers.

In quality supervision, the project management team typically inspects the required first section with the subcontractor's supervisor possibly in co-operation with the customer's project representative or designer for preferred visual and functional outcome. Often self-inspection for a task is initially required by the project management, but rarely implemented. Self-inspection is understood almost solely as a supervisor's task, since only one worker executed documented self-inspection of the first section (Table 2). Drown stages were self-documented by 11.5 percent of the workers and the end of work by 15.4 percent. The documents were typically photographs and/or checklists.

5. Discussion and Conclusions

This paper argues that a greater emphasis should be laid on employee involvement and empowerment to increase productivity and quality in construction. The nature of project management in the industry changed already in the 20th century due to contract orientation, subcontracting, fragmentation, and complexity. The industry has put effort into increasing co-operation and decreasing confronting objectives via project management models, such as alliancing and IPD. Empowerment is embedded in mainstream management theories like TQM and Lean that have been applied by the industry. Important elements of TQM and Lean are training, development, and empowerment of employees. The principles of TQM should be applied beyond management levels and include workers on construction sites. Workers must be empowered, involved and trained in problem solving and quality assurance. However, main contractors' project management lacks a holistic approach to the development of empowerment, and subcontractors and their workers are often not considered to belong in projects' core organization. The benefits of empowerment are immense: a higher degree of morale, healthier co-worker relationships, enhanced productivity and innovativeness (Tuuli and Rowlinson, 2010).

The current study found that workers are not systematically involved in task preparation. A vast majority does not participate in the starting meetings of tasks, where information of how the work is carried out is discussed without go-betweens. Further, employees do not receive documents of specific quality requirements and task schemes, which raise knowledge of, not only the current task, but also preceding and subsequent tasks. The findings clearly indicate that there is a lack of understanding of how people-related issues may influence quality management systems within construction sites. Ironically, researchers have identified quality as being the most significant provider of competitive advantage (e.g. Zantanidis and Tsiotras, 1998). The obsession with the bottom line and viewing quality as merely an overhead might be contributory to this attitude. The exclusion of employees from quality assurance and quality improvement is a serious problem not only in Finland but also elsewhere (Haupt and Whiteman, 2004). Construction companies and main contractors clearly have not bought into this finding in their daily operations on site.

In Finnish housing construction, quality varies only limitedly, since it is strictly regulated by the National Building Code. A generally acknowledged mode for good building practise (e.g. tolerances for each task) is typically cited in contracts. In principle, common targets set a fruitful soil for the development of the standardization of quality processes. However, customer requirements steer quality from project to project, and therefore quality requirements should be cleared for workers. As presented in the results section above, subcontractors work with a ‘same as always’ and ‘what looks good’ mentality without specific project based quality standards.

For successful empowerment, all information should be shared with employees and there is no irrelevant information (Juran and De Feo 2000). Supervisors are not always present when workers make day-to-day decisions. Spoken information is useful but not always accessible and employees may change during construction work. To improve effective information distribution and to allow empowerment, more effort should be put into sharing information with workers. However, one should carefully consider the means of sharing written information so that workers can adapt it, meaning short and illustrative task schemes and a 'talk trough' of documents.

Another important finding was that subcontractors rarely systematically conduct documented self-inspection of quality, which is often initially required by project management. Moreover, workers are not empowered to self-inspection of their work. The nearest supervisor has a great influence over the success of empowerment (Greasley et al., 2005). Overall, the results of this paper indicate that empowerment is tackled by employees' nearest supervisors affected by the industry's prevailing culture of not supporting empowerment outside the core organization of projects.

Systematic quality assurance procedures lead to better utilization of site based resources (Langford et al., 2000). There is potential to increase empowerment in quality assurance, as the results show. Future research is needed to increase understanding of empowerment in subcontracted work.

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Emotional Intelligence: A Conceptual Model for Managing Productivity, Creativity and Performance

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Abstract

Analysis of the UK construction industry over the last 100 years has evidenced a number of performance-related issues; from productivity, through to quality, process management and challenges relating to innovation. Seminal literature and influential reports have directly garnered evidence from other sectors, citing specific exemplars of success which could quite easily be adopted for immediate impact. A recurrent theme from this literature suggests that 'soft skills' within organisations are increasingly being linked to performance improvement and profitability. These soft skills include "Emotional Intelligence" (EI), the underlying principle of which helps guide thinking and behaviour. This research examines the impact and pervasiveness of emotional intelligence in the UK construction industry, using construction project managers as the main sample set for investigation.

The research methodological approach adopted used literature from Construction and Applied Psychology to distil EI themes into a cogent set of priorities. The results help inform the next stage of this work, which engaged an explicit mixed methods approach as the primary data collection tool. Inferential analysis from 68 respondents helped to develop a conceptual engagement model for managing productivity, creativity and performance (with a construction setting).

Research findings identified a significant absence and understanding of EI in the sector. The conceptual model presented highlights a series of push-pull forces, which when combined together with different management tools (and the concepts of EI) can help increase productivity, creativity and performance. The conceptual model is considered beneficial across academia, training organisations, professional institutions and commercial organisations. Whilst this relatively small sample set is considered homogenous and 'representative', future work will include factors relating to scale, organisational maturity, and hierarchical trajectories.

Keywords: Project Management; Emotional Intelligence; Conceptual Model; Learning; Skills; Training.

1. Introduction

The construction industry has been criticised for its performance compared to other industrial sectors (Banwell, 1964; Latham, 1994; Egan, 1998). From a construction education and training perspective, emphasis has tended to focus upon "process" and "product"; and more recently, "environment" (Love and Wood, 2011). The increasing demands faced by project managers often resonate with understanding the need to increase the probability of project success. Process has historically been the focus of improvements across projects – the concepts and approaches of which are well-represented in various Project Management (PM) literature. However, whilst understanding process can assist in monitoring, correcting and reporting (on progress etc.), it is equally important to understand the underpinning 'glue'; as more often than not, this is reliant on people to ensure that success [process] is delivered. The importance of people [engaged in the process] is therefore exceptionally important, as this includes many issues, from initial recruitment, through to engagement, communication, motivation etc. Rothwell (1998), for example, identified the need to develop both 'hard' and 'soft' skills in construction graduates. However, sector-specific skills and the development of intellectual capital [in construction literature] seem to be somewhat underrepresented in extant literature. Acknowledging this paucity, there is an exigent need to understand the precise roles, traits and behaviours that form theses core skills sets (e.g. motivation, communication, conflict management, intuition etc.). These issues are examined in this paper, using the role of a project manager as the primary research lens.

2. Emotional Intelligence

Organisations often have to balance a range of skills and competence in order to meet business goals as "companies which are adept at using their skill base effectively are able to use and reuse…. these skills many times" (Andrews, 1987; Mintzberg and Quinn, 1991); Given this, over the last two decades in particular, various concepts on emotional intelligence (EI) have been published. The prominence and associated success of EI is now starting to be examined within the construction sector. EI is considered by some as a subset of Social Intelligence (Thorndike, 1904). It is comprised of four interrelated cognitive abilities which Salovey and Mayer (1990) summarise as:

- The ability to reason about a particular type of information;
- The ability to perceive accurately, appraise and express emotion;
- The ability to access or generate feelings when facilitating thought;
- The ability to understand emotion and emotional knowledge and to regulate emotions to promote emotional and intellectual growth.

3. Emotional Intelligence and the Project Manager

The role of a project manager is often demanding, complex and varied; the typical roles and traits of which are highlighted in the Project Management Body of Knowledge (PMBOK) Guide (PMI 2013). Thomas and Mengel (2008) highlight the importance of aligning learning to role complexity, and also competence to project management descriptors. Similarly, the need to focus on people management over "tools and techniques" was recognised by Ives (2005) and Winter et al. (2006). In addition, the influence of both internal and external environments when managing complex projects is also acknowledged, as the unpredictability (of events) often increases the complex nature of decision making particularly when multiple unknowns (variables) are present. This unpredictability places increased demands on the project manager beyond the typical process driven planning, managing and execution of tasks found within the taught linear skills documented in established text. Given this requirement for dealing with 'unknowns', within complex/chaotic environments, it requires personal attributes of: self-reference, an ability to thrive on change, to make informed decisions on the "fly", whilst also maintaining a motivated and focused team. Interpersonal skills are an important part of this, as recognised by the Project Management Institute (PMI, 2013); however, the methods to develop these within project managers are somewhat nondescript - in effect silent. Why is this void present when the criticality of these skills is openly acknowledged? This is especially so, as it is seen across other industries, that the engagement of soft skills can generate positive outcomes; where for example, the attributes of EI in chaotic/fluid environments have been applied successfully (Goleman (1996); Salovey and Grewel, 2005). Thus, whilst it is important to lead, guide, direct, motivate and steer the team through challenges [to deliver a specific goal], it is also important to appreciate the impact of EI on that process – especially to appreciate the impact this may have on project success. This poses a question: should EI be introduced to construction professionals so that an appreciation of interpersonal skills is understood, thereby facilitating an holistic approach to project delivery? Mayer and Salovey's (1997), definition of EI is particularly useful here, namely the ability to identify, understand, process and influence one's own emotions and those of others to guide feeling, thinking and actions present a clear direct path between the daily actions of the project manager and emotional intelligence.

4. Emotional Intelligence, Leadership and Project Teams

The Leadership within construction is ostensibly found in two main areas, charismatic and transformational (Love and Wood 2011). Bass, (1999), links transformational leadership with emotional intelligence; where, process was highlighted as the main focus across construction in improving effectiveness. EI however, is an essential method of expanding the model to further improve the probability of project success. Currently a project manager's EI abilities are not generally evaluated or assessed prior to appointment. The psychological attributes of project managers are however very important – and some would argue misunderstood. These include the process skills that assist in how "problems" are overcome, which reflects the thinking (and subsequently the behaviour) of the project manager. The PM's behaviour therefore has a direct correlation with leadership, the style adopted, impact across the team, and success of the project. Research by Leban and Zulauf (2004) support these findings specifically with reference to EI and its impact on leadership behaviour. The significance of 'good' leadership is especially important in complex projects, but more applied engagement is needed where cultural differences within the team are readily evident. The project manager's awareness of these social differences is paramount as this can influence thinking and behaviour (Goleman, 2001).

5. Research Methodology

This research stems from the need to gain understanding on why the construction industry fails to perform as effectively as other industrial sectors. The engagement of "soft skills" across other industrial sectors has generated positive results and associated increases in profitability. The engagement of "soft skills" within construction is loosely acknowledged within domain literature and this research aims to generate further understanding on how EI impacts on project management across the UK construction industry. Literature from the fields of Construction and Applied Psychology was first used to determine and distil EI themes into a cogent set of priorities. The results from this helped inform the next stage of this work, which engaged an explicit mixed methods approach as the primary data collection tool. To obtain appropriate data for this research, an on-line survey forum was deployed. The questionnaire was designed based on the findings from the literature review and associated priorities. This assessed the candidates' capacity to:

a. recognise their own emotions and those of others;

b. understand how best to motivate themselves;

c. become close to others;

d. manage their own feelings and those of others.

The questions were grouped in to three categories including the respondent's background, performance and leadership together with training and understanding of EI. The influencing factors for considering the research design included, but were not limited to:

(i) Being able to assess the present levels of emotional intelligence within a known sample size and background. An objective assessment promoting detached data.

(ii) Use of numeric data to link emotional intelligence with project success.

(iii) Highlight the nature and size of relationships between variables.

(iv) Engage statistics using closed questions and a five point Likert scale.

(v) Use of a finite timeframe.

(vi) The accessibility of primary data/methods of obtaining the data.

Data was gained from two industrial sectors (undertaking the same function). This promoted a more robust probability sample. The sample was determined by means of assessing the following criteria:

1. Is the sample appropriate to the objectives?
2. Is there sufficient time to capture data from the sample?
3. Is access to the sample possible?
4. Is the sample as good as possible?

The following steps were followed in compiling the primary data and concomitant analysis.

1. Sample Selection
2. Developing the questionnaire and piloting
3. Mode of delivery
4. Data collection
5. Response rate

6. Data & Discussion

An analytical survey was used to establish relationships and associations. These relate to defined attribute and objects introduced within the questionnaire. An example being the awareness of a project manager's EI and its relationship with general motivation on a given project. Inferential analysis from 68 respondents helped to develop a conceptual engagement model for managing productivity, creativity and performance (with a construction setting). Respondents were reviewed in terms of time spent within the construction sector and how long they held their current post/role. These were then reviewed against the perceived levels of EI. Research findings noted that there was a negative relationship r -0.19 (-1.188) from a sample of 68 or a degree of freedom at 66. The negative relationship communicates that as one variable increases (experience) the other decreases (EI). Whilst the demands from tomorrow's graduates highlight the increasing need on both hard and soft skills (Rothwell 1998), the legacy from both academia and commerce as reflected in this regard, suggests that EI is absent throughout, with younger professionals holding greater appreciation than experienced respondents. There is unfamiliarity surrounding EI, and whilst this may simply be a misunderstanding surrounding terminology, the data supports that it does however exists nonetheless.

This paper also examined how emotional intelligence affected a project manager's leadership and overall performance on projects. The data conveys 52% of the sample was not familiar with EI and a further 25% were a little familiar. The statistical significance of the levels of EI and the link with formal training surrounding EI suggests a slight positive relationship or p = 0.01 having a degree of freedom df of 63 and a two tail significance of 0.47. If the relationship p was 1.00 then a perfect association would be achieved. The upper and lower boundaries are +/- 1.00. As the correlation promotes 0.01, then this is close to a zero score. A zero score indicates that the sample are randomly scattered around any straight line drawn through the data. This suggests that EI has no effect on the samples leadership style and subsequently, project performance. Care is necessary here and is highlighted in the research by Crawford et al. (2006). Projects can be successful on process alone, specifically on low value/simplistic projects. 62% of the survey was completed by project managers who manage projects with values less than £1m. The importance of EI and transformational management increases in influence on complex projects. Love and Wood (2011), Mullar and Turner (2010), Turner and Mullar (2005), Zhang and Fan (2013), discuss the link between EI capabilities and project success with transformational leadership being highlighted as an influencing factor is steering the team through the changes and challenges faced.

The research confirms an insignificant relationship (0.47) between EI techniques engaged during projects and the formal training of the respondents thereby supporting current literature. Time Quality Cost (TQC) was used as a measure of success by 89% of the sample. Care on what this suggests needs to be taken as TQC is the outputs rather than how they were achieved. Given this, the data is clear in its assessment of EI and correlation with experience. A negative relationship exists, which suggests that 'soft' skills are not readily engaged. The research equally notes the absence of EI across CPD events and postgraduate education. There is an expectation that EI goes some considerable way to bridge the gap in knowledge and move towards a more holistic approach to project management. Only by adopting each and all avenues of improving project success will the performance levels within the construction sector be aligned with other industries. As the complexity of the project increases, the abilities and characteristics of the project manager becomes more influential over the teams, their performance and ultimately project success.

Clarke (2010), studied EI and its correlation with the behaviour of the project manager. Significant associations were found between teamwork and managing conflict, empathy and how this facilitated thinking and furthermore transformational leadership dynamics. The survey promoted data that initially failed to support this. EI was largely unknown. How the team was treated was regarded as significant by the data and influential in addressing motivation (95% - Q12/5). Whilst the treatment of the team is recognised in terms of the effect on motivation, the tools and behaviours employed by the project manager in influencing the magnitude of such motivation was not overtly appreciated or understood. Frequent interactions of a social nature positively influence performance (Ashmanasy and Dars, 2005). Whilst the lack of understanding surrounding EI was found within this study, a very high percentage (95%) confirmed that how they treated/managed/manipulated the team, directly influenced motivation.

The psychological aspects of a project manager need to be embraced and exploited in order to manage, motivate and drive the team. This self-awareness encapsulates social awareness and social management skills. Both link with EI but differ in that it does not manage "one's own and other's feeling to achieve a desired outcome." Ostensibly this may be considered to be manipulation however people tend to resist this. The perception of being a good manager may relate to the team members who believe that they are not being manipulated, are being listened to and wish to be associated with the team who delivers on a common goal. The challenge on most construction projects is the manner in which the team is created. Often teams are brought together based on their ability to provide a competitive quotation. A number of subcontractors often merge to create the 'construction team'. These subcontractors will invariably have their own identities, goals, objectives and drivers. The PM will therefore have to pull the group together to form an 'effective team' having its own identity and super-ordinate goal.

How team members behave with each other can directly influence how they perform within a project setting. The need to alter management style throughout the project, (Frame, 1987) shape the performance of the team. The ability to listen, learn, negotiate, analyse, persuade, influence and adapt are all flexible or persuasive attributes. Complex projects and how levels of emotional intelligence determine success levels on projects have been highlighted (Zhang and Fan, 2013). The next phase, team emotional intelligence is acknowledged. The Conceptual Skills Model, Figure 1, summarises the skills that influence one's own and other's emotions. Both process and people-centred management techniques need to be embraced. The Model reinforces the importance of motivation and the need to widen the project managers understanding beyond process. Engagement of different management tools to increase productivity, creativity and performance has a vastness that falls beyond the scope of this research. Process, EI and different management styles all combine and change throughout each project. The benefits experienced and lessons learned as suggested by Nonaka, (1994) are constantly being reviewed so that organisational knowledge continually evolves.

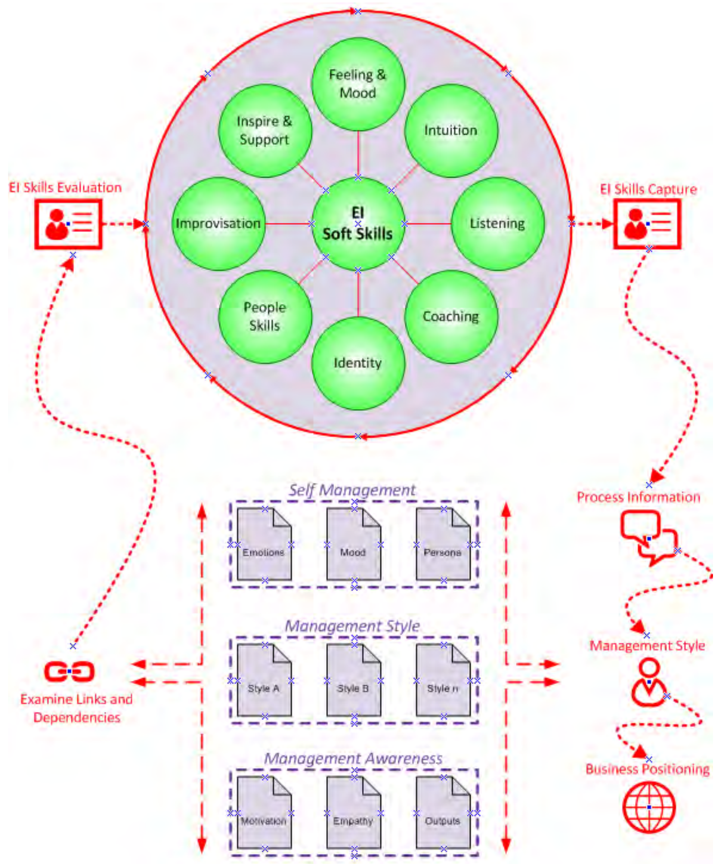

Figure 1. Soft Management Conceptual Skills Model

7. Conclusions

This research highlighted the need to engage 'soft skills' within organisations, particularly "Emotional Intelligence". The premise of which was that this understanding will help guide thinking and behaviour – leading to increased performance and project success. Given this, a Conceptual Skills Model for managing productivity, creativity and performance with a construction setting was developed from 68 respondents. This model helps identify how one manages one's own emotions, and how this impacts on the decisions taken and the effects of others. These "resilience factors" are essential for project managers. Whilst time, quality and cost elements continue to be used as indicator of project success, the foresight, consideration, objectivity, direction, support and leadership that the project manager eludes are not explicitly measured. Only the success/failures of the project manager's actions may be felt (albeit through the ubiquitous time, quality and cost assessments).

The 'Conceptual Skills Model' for Project Management aims to stimulate discussion within the world of project management on how improvements are able to be made with the associated increases in performance. The importance of these skills should not be underestimated. They have a proven benefit within other industrial sectors. The engagement of EI within the construction sector will, by default, need to engage and promote a step change. Arguably the need for such change, was highlighted as early as Banwell (1964), or indeed the Tavistock Institute (1966), reflecting the magnitude of the challenges faced. Critical reflection is therefore needed, not only to engage with areas that historically have been associated with other industrial sectors, but to begin to realise the true potential of these within the construction industry. The tacit skills of tomorrow's project managers need to embrace these findings. Similarly, process has consistently been the lens by which construction aimed to narrow performance gaps with other sectors. The research confirms the correlation between low value projects, the reliance on process and its relationship with successful outcomes. Furthermore the absence of EI within construction project managers is still evident.

Greater focus on the PM's ability to listen, learn, reflect, negotiate, analyse, persuade and influence the project team is therefore needed. This needs increased momentum, especially on challenging complex projects. The Conceptual Skills Model presents a clear 'interpersonal skills' definition, along with drivers and dependencies. This model offers stakeholders a conceptual stepwise solution. Whilst limited to the domain identified, additional work is now needed to expand the model, to encompass further 'soft skills' in order to create clear indicators of 'success'.

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Creativity and the Construction Project Manager: An Exploratory Study

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Abstract

This research examines how a special class of project managers – Creative Construction Project Managers (CCPMs) – are able to balance the inherent tension between pace, efficiency, productivity and quality to consistently achieve creative outcomes. This paper examines the cognition and action of CCPMs in response to the challenge posed by (1) the social needs of designers and other project stakeholders (2) a collaborative creative process and (3) the environmental press factors affecting designer's ability to be creative. A soft system methodology has been applied, whereby the challenge of creativity is considered a largely soft, fuzzy, wicked 'problem situation' – defined in the perceptions of project stakeholders; with CCPMs asked to describe their thinking and action in response to similar problem situations – and in doing so construct an approximation of their internal 'purposeful action model': their frame of reference when considering what action may be appropriate. The findings of this research draw parallels with previous research models, but are ultimately presented as an independent purposeful action model - focused on the specific challenges faced by project managers working on construction design projects. The proposed CCPM purposeful action model is recommended for application as a complementary overlay to project management best practice.

Keywords: Creativity, construction project manager, soft systems methodology

1. Introduction

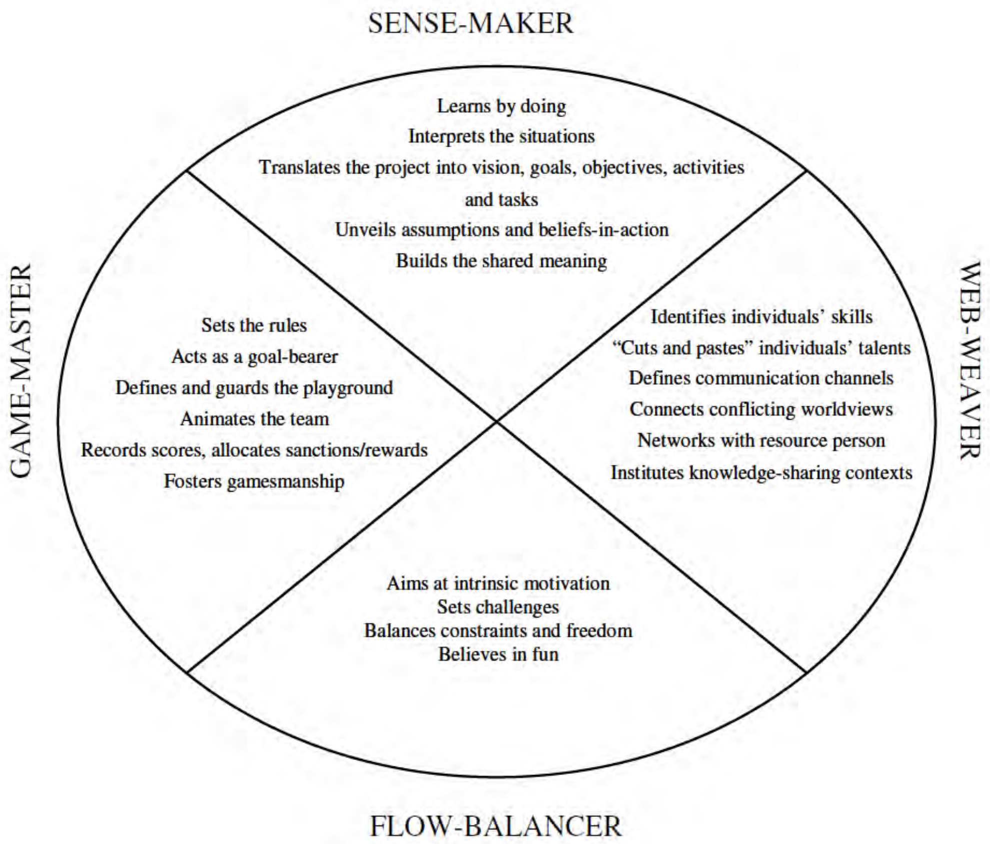
One of the most widely cited definitions of 'successful' project management is in taking appropriate action to balance conflicting objectives. When questioned on their function, most construction project managers – let's call them project management professionals (PMPs) - will tell you that they deliver projects 'on time, on budget and to the client's quality aspirations'. This comfortable mantra, is a poor reflection of the complex factors at play in building projects.

Anecdotal evidence suggests that PMP's rigid application of best practice methodologies has a tendency to introduce social disharmony and in doing so undermines the fertile environment needed for creativity to flourish. However, a different class of project manager also exists – referred to in this study as Creative Construction Project Managers (CCPMs). These CCPMs build happy and motivated teams, who consistently achieve creative outcomes. Due to the nature of the outcome, this approach may be considered as mitigating the 'problem situation' of creativity.

This research was borne out of a desire to uncover and document the approach of CCPMs in a format which PMPs would be likely to engage with; and in doing so build support for a paradigm shift in the dichotomisation of project objectives and the prioritisation of hard issues in mainstream project management practice (Lewis, Welsh, Dehler and Green, 2002; Gustavsson and Hallin, 2014).

One of the most significant challenges in this regard is the resistance of 'soft issues' to definition and 'engineering' in pursuit of an optimal, prescriptive response. Soft systems methodology offers a means of conceptualising the problem, as a 'problem situation' and engineering a solution, through the use of analogy through reference to 'purposeful action models'.

This research was inspired by Simon's exploratory study into creative project manager cognition and action. The model put forward in his 2006 journal article has been considered a purposeful action



model (see figure 1), which this research has sought to emulate.

Figure 1: Simon's model of creative project manager activities/actions

This research responds directly to Simon's call for further "direct observations and qualitative accounts of creative project manager (CPM) action, intuitive decision-making and rationale" (2006, p.125); recognising that Simon's model was not originally derived from, nor evaluated against project managers operating in the construction industry.

Throughout this paper, the term 'Creative Project Manager' ("CPM") has been used to describe the actions of project managers action as described in Simon's purposeful action model (2006) or as described in other academic literature; the term 'Creative Construction Project Manager' ("CCPM") has been used to describe the espoused action of the research population: Project managers whose projects have received peer recognition, awards or publication in the construction and architectural press.

2. Defining Creativity

Creativity is a highly subjective notion: What may be considered creative by one person may not be by another; creativity may be applied to any problem solving situation, not just the design of a product (Lindeman, 2010 in Taura and Nagai, 2011). The ambiguity of the term is reflected in the diversity of its definitions within the literature. Such varied definitions may be classified according to the perspective as to *where* creativity exists.

In 1961, Rhodes established four perspectives by which to locate creativity (in Lauer, 1994): Creativity in outcomes (product), as an attribute of people (person), as a type of cognitive process and as the conditions which facilitates creativity (press). In 2010, Gero identified seven perspectives and three strands of scientific creative research: cognitive behaviour, design process and interactions (in Taura and Nagai, 2011).

Since it was first published Rhodes 4-P's model has been cited in various seminal works on creativity. It is therefore perhaps unsurprising that parallels can be drawn between Rhodes' and Gero's definitions of creativity – as shown in table 1.

Table 1: Locating and defining creativity (adapted from Rhodes, 1961 in Lauer, 1994; Gero, 2010 in Taura and Nagai, 2011)

Academic field	*Perspective*	*Creativity existing…*	*Strand of research*
Psychology	Product	….in the design ….in the assessor of the design	
	Person	….in the designer	Cognitive behaviour
Psychology (Sociology)	Process	….in the design process	Design process (interactions)
Sociology	Press	….in the interaction between user & designer ….in the society in which the design sits ….in the interaction of all of the above	Interaction
	Rhodes (1961)	Gero (2010)	

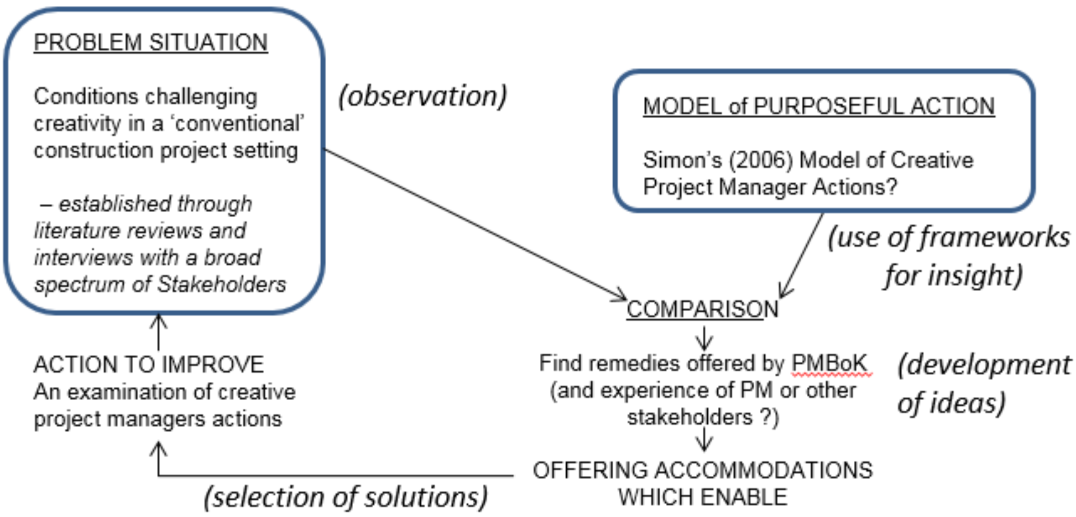
The comparison of Gero's and Rhodes' model demonstrates the integrity of Rhodes model and its continuing applicability as a framework for conceptualising creativity and focusing research. Gero's model is, however, useful in recognising the growing interest of research in collaborative design process, in favour of extended discussions of creative products or individuals.

This research is fundamentally concerned with building a holistic understanding of creativity; adopting a systems view of creativity which recognises the inter-dependencies between climatic, and cultural conditions, and the cognitive process and performance of creative individuals and teams. In the context of the CCPMs, we are concerned with the creative process of actualisation and not the creativity of building design.

3. The Methodology

A soft system methodology has been applied, whereby the challenge of creativity is considered a largely soft, fuzzy, wicked 'problem situation' – defined in the perceptions of project stakeholders.

Soft System Methodologies offer a means of "rationalising the cognitive process of addressing 'wicked', soft or fuzzy problems – defined as ill-defined problems which are messy… and whose solutions are not true or false, but better or worse" (Stanford Design School, 2014). In this context, problem-solving is an iterative process of examining aggregate stakeholder perceptions of the problems, taking action to improve, assessing the impact on the problem situation, and repeating the process. By doing so the 'problem solver' is, over time, able to engineer their thinking about a problem, building up an internal 'purposeful action model' based on actions which have helped to



improve the problem situation (see figure 2).

Figure 2: Soft systems and design thinking methodologies for problem finding and solving represented under an appreciative systems analogy (adopted from Checkland et al, 1999)

The problem situation has been initially been constructed from both academic literature and anecdotal evidence; this has then been briefly validated through discussions with construction industry professionals: stakeholders on award-winning projects.

Two rounds of semi-structured ethnographic interviews were held: The first sought to test and supplement the CCPM's perceptions of the problem situation. In the second round the CCPMs were asked to explain their actions in response to the problem situation. Three interviews were conducted in each round. The respondents were asked to reference their experiences on real projects of architectural merit on which they served as project managers. The findings of this research have been analysed in the context of Simon's (2006) creative project manager (CPM) purposeful action model.

A soft systems methodology has ultimately offered a framework for exploring Creative Construction Project Managers in a project context; but has also enabled the logic behind the action taken to be interpreted, and an approximation of the frame, or purposeful action model, informing CCPMs action to be constructed.

4. Discussion of Results

The matrix summarised in table 2 compares the key outcomes of the research findings against Simon's (2006) CPM purposeful action model. The results are discussed within the framework of the defined subsections within Simon's model and contrasted to four new core themes: (1) personal and professional relations (2) visioning (3) sense-making (4) guarding the design team and process derived from the second round of interviews.

Table 2: Research findings overview: matrix comparing research findings with Simon's (2006) model

	WEB WEAVING	Identifies individuals skills	Cuts and pastes individuals talents	Defines communication channels	Connects conflicting worldviews	Networks with resource person	Institutes knowledge-sharing contexts	SENSE-MAKER	Learns by doing	Interprets the situation	Translates the project into visions, goals, objectives…	… activities and tasks	Unveils assumptions and beliefs in action	Builds the shared meaning	GAME-MASTER	Sets the rules	Acts as a goal-bearer	Defines and guards the playground	Animates the team	Records scores, allocates sanctions	Fosters gamesmanship	FLOW-BALANCER	Aims at intrinsic motivation	Sets challenges	Balances constraints and freedom	Believes in fun
PERSONAL and PROFESSIONAL RELATIONS																										
Build personal relationships with Client																										
Build personal relationships with influential design team members																										
Channel or redirect people with a negative outlook																			✔							
Maintain personal relationships on an equal footing					✔																✔		✔			
VISIONING																										
Establish the project brief through conversation with Client											✔															
Build Team						✔																	✔			
Soft influence over brief implementation											✔															
Build design team ownership of project plan					✔						✔					✔										
Build respect and understanding of [concessions needed for] a creative design process																		✔			✔					
SENSE MAKING																										
Embeds themselves within the design team									✔									✔			✔					
Interpret, communicate and represent the design frame					✔					✔			✔	✔			✔		✔	✔	✔					
Interpret and relate design issues back to goals and objectives					✔					✔			✔	✔			✔									
Build support for creative ideas or solutions of merit																			✔	✔	✔					
Triangulate solutions							✔			✔			✔	✔							✔			✔		
Focusing or channel design team members towards a project objective or away from a wrong path										✔			✔	✔							✔					
Idea generation, development or refinement							✔																	✔		
GUARDING THE DESIGN TEAM and PROCESS																										
Hands off management: Secure commitment and results through political influence																										
Influence design through positive engagement with design team					✔		✔		✔					✔					✔				✔		✔	
Framing difficult decisions in the context of project goals, through reference to analogy or previous experience					✔				✔									✔								
Secure compromise from client to satisfy design team need for time and space					✔													✔								
Secure compromise from design team to satisfy client needs					✔													✔								
Intelligent monitoring of design process against project goals and programme																✔	✔									
Maintaining forward momentum																		✔		✔						

Web weaving - At a general level both CPMs and CCPMs seek influence over individuals within their teams to achieve results through 'web weaving' activities.

At a specific level Simon's web-weaving activities place the CPM in executive control of the design team: defining the structure of the team, the make-up of the team, the activities and tasks of individual team members, and the interactions between team members. The findings of this research suggest that CCPM do not seek this degree of executive *control*, favouring instead a hands-off style of management style aimed at *influence* rather than control. A CCPM preference for the use of political power, in favour of authority, depends upon a strong and broad power base. To this end, CCPMs describe how they build and maintain personal as well as professional relationships with both the client and design team right from the outset and how these relationships are used and maintained over the course of the project to influence both process and outcomes. This is not explicit in Simon's model.

CCPM actions such as being present, being open and transparent, being dependable and reliable etc. respond to behaviours needed to gain the trust and respect of the design team. This is not reflected in Simon's model, perhaps signifying a structural difference in the project organisation structure and/or the proximity of the client to the design team and process.

Simon's model describes a CPM who is embedded within the team, who is delegating activities and tasks to those within his team who are best capable of doing them. Research findings suggest that CCPMs employ a middle tier of management – described as Captains – who are then responsible for this operational level of management. In this context, the definition and role of the CPM and CCPM differ; it is therefore unsurprising that the approach therefore to engaging with, and managing, those actually doing the work and their activities differs.

Simon's model also recognises that CPMs must adopt a poly-centric perspective and sensitivity to bridge cultural misunderstandings. To this extent, CPMs engage in sense-making actions - unveiling assumptions and beliefs in action, and interpreting the situation – alongside web-weaving activity of 'connecting conflicting worldviews through translation'.

Research findings suggest that CCPMs act out of a similar concern for cultural misunderstandings, by engaging in dialogue with the design team to interpret, communicate and represent the design frame, channelling and redirecting the team where necessary through political influence, and where this fails through private conversations to more forcibly correct misunderstandings. Their behaviour as an equal member of the design team, sets a benchmark for appropriate behaviour on the project.

CCPMs collaborative approach to project planning also mirrors Simon's descriptions of CPMs efforts to connect conflicting worldviews through translation. In this context, CCPMs engage the design team in project planning to build a common understanding of risks and support for mitigation measures which otherwise could otherwise be viewed to compromise the conditions needed for creativity.

This same collaborative approach to compromise is adopted by CCPMs in to secure concessions in demands made by the design team. Research findings describe how, in this situation, CCPMs will engage the team in dialogue to draw design team members to the same conclusions as the CCPM or Client. In this way, they protect they force the design team to take ownership of these decisions by working to make people think that the alternative path is their idea.

Sense maker – At a general level both CPMs and CCPMs are embedded within the design teams they are mandated to manage, adopting a participatory role in the design process. From this position of influence both CPMs and CCPMS attempt to influence perceptions of the project context to focus on, and build a common understanding of, the issues in hand. This is covered in Simon's model as a web-weaving activity "connecting conflicting worldviews through translation".

These sense-making activities may be considered as 'problem definition' in the context of traditional problem solving; 'uniting stakeholder perceptions of the problem situation' in the context of soft systems methodologies; or 'framing' or 'building the decision making frame' in the context of Design Thinking.

Both CPMs and CCPMs recognise interpreting, communicating and representing the design frame as a core function of project management. Some CCPMs described best practice project management tools such as project briefs, plans of work, minutes of meetings and action trackers as a means of doing so.

Research findings reveal another strand of sense-making activities not explicitly covered in Simon's model of CPM action, which appear to be the reserve of older and more experienced CCPMs: Triangulating solutions.

Actions associated with 'triangulating solutions' see the CCPM actively engage the team in identifying solutions, by seeking synergy between ideas put forward by the team, and through reference to decisions taken in similar situations on previous projects.

This process of triangulation is also used to intuitively recognise ideas worth refining or developing, building support for these ideas through political influence, and encouraging their development in a collaborative format.

Game master – Both CPMs and CCPMs are concerned with fostering a project environment which focuses creative teams towards useful outcomes, and in doing so defines expectations and appropriate behaviours. Simon's model suggests that CPMs do this through setting rules, keeping scores and imposing sanctions on the team; whereas research findings suggests that CCPMs do this through framing, encouraging and building support for ideas. This indicates that CCPMs possess a fundamental softer management style than the CPMs described in Simon's model. Both CPM and CCPM take action to define the project plan – expressed in Simon's model as 'setting the rules'. Simon's model implies that this is defined by the project manager and imposed on the team. Research findings suggest that CCPMs do this in an inclusive collaborative way, building team design ownership over the plan, and reducing the need to actively implement, promote or police it.

Both CPM and CCPMs act as goal bearers, adopting and representing the goals and objectives of the project in their professional interactions with the team. Research findings offer greater insight into *how* this is achieved, than is exposed by Simon's model, describing how CCPMs may frame goals and objectives through reference to precedent and their previous professional experiences.

Both CPM and CCPMs act to 'define and guard the borders of the playground', to encourage divergent or innovative thinking, but also focus and orientate the teams ideas towards project goals. CCPMs achieve this by expressing a genuine interest in, and appreciation of designers and what they are doing. In doing so, they may express wonder, excitement and support for certain ideas, whilst questioning and interrogating the logic of others.

Both CPM and CCPMs actions in 'defining borders' to divergent creativity represents a pragmatic outlook which acknowledges that projects ultimately serve business needs: that the creative imperative must be balanced alongside the commercial and programmatic imperative.

Simon's model does not describe how these borders are defined. Much of the CCPM's discussion of 'visioning' actions focused on the formulation of an appropriate project brief – a best practice tool – in doing so. CCPMs described the danger of overly prescriptive project briefs and the need to focus on core goals and objectives – particularly in initial pre-concept and concept design stages.

CCPMs and CPMs also acting as a goal-bearer with an intuitive understanding of the project vision. In the context of a loosely defined brief, CCPMs actions as goal bearer allows them to focus the team and correct misunderstandings.

Research findings offer further insight into specific actions which CCPMs may take to focus or redirect the team towards project goals: Compromise is secured by interpreting, communicating and representing the design frame: framing difficult decisions – including those which may be perceived to constrain the team's creative freedoms - in the context of project goals through reference to analogy or previous experience.

Both CPMs and CCPMs attempt to animate the team through their social engagement with the team. The focus of Simon's model considers both the social dynamic of the team and the intrinsic motivation of individuals. Research findings suggest that CCPMs are less concerned with influencing the social dynamic of the team, but more concerned with influencing design through positive engagement with the team. This may again be a factor of the CCPMs delegation to design champions to manage the social intricacies of their teams; whereas under Simon's model this is a function of CPMs.

A further point of divergence between Simon's model and research findings relates to the response of CPMs to success and failure. Simon's model describes a culture of rewarding success and punishing failure; whereas research findings suggest that whilst CCPMs would build support and excitement around 'project successes' and treat the team at key project milestones, they would not punish failure nor undermine people's ideas in a group context.

Furthermore the language of Simon's model presents creative design as a game where people are motivated to win. Research findings suggest that internal competition is not conducive to creativity, and that creative design requires a tolerance of failure out of a respect and understanding the design process and concern for people and their intrinsic motivations.

Flow balancer - At a general level, CPMs and CCPMs are both concerned with maintaining the intrinsic motivation of individuals within their teams. Where research findings differ from the model is in the efforts made to adapt and adjust the design process and the division of work to appeal to design team member's interests and sensitivities.

Simon's model suggests that CPMs attempt to plan, monitor and organise the work in a way which responds to design team member's interests and sensibilities; whereas research findings suggest that although CCPMs will accommodate alternative ways of working where not detrimental to the project, they ultimately recognise personal goals are subservient to project goals. As such CCPMs focus less on appealing to intrinsic motivation, than acting to ensure that they do not undermine intrinsic motivation.

CCPMs actions aimed at not undermining intrinsic motivation are orientated around building design team ownership over project planning, the design process and project goals.

However, again it is necessary to bear in mind the structural differences in the creative teams studied and the professional culture of construction industry professionals: Simon's research considers small creative teams working on computer game design and advertising campaign projects; whereas this research considers large multi-disciplinary professional teams working on major engineering projects. The structure of the teams, and by extension the project managers mandate for micro-management of the work, is significantly different: Where Simon's CPMs set challenges to motivate the team, CCPMs revert to design champions to divide the work amongst their teams, manage egos and manage the social dynamic within their teams.

In this context, CCPMs are more process-orientated than their CPM counterparts, and their role is more concerned with guarding the design process, than it is managing the work itself. At a general level, actions relating to 'guarding the design process' reflect Simon's description of CPMs flow-balancing actions of 'balancing constraints and freedoms' and 'game-master' actions of 'setting the rules'; however under Simon's model, the focus of these actions is largely goal and objective orientated rather than process orientated.

Simon's model also refers to the culture that CPMs attempt to engender through reference to 'belief in fun' (a flow-balancing action), 'instituting knowledge sharing contexts' (a games-master action).

Research findings suggest that CCPMs are more likely to revert to professional culture, rather than attempt to engender a project organisation culture. They do however engage in activities aimed at ensuring they have a mechanism to influence the design process and design: Building a collaborative atmosphere where constructive criticism is welcomed. In doing so they are able to broaden the knowledge base of the team, as well as personally influencing the design team and the design process without undermining design team members intrinsic motivations.

5. Research Output

One of the most interesting outcomes of this research is what has not been said: The actions described by CCPMs do not contradict current project management best practice methodologies: They have not suggested that neither commercial nor programmatic objectives are not significant; nor that the tools nor processes need to achieve them be adapted, loosely implemented or otherwise compromised.

Indeed the research findings offer support for the "and/in-addition-to" attitude towards the management of social issues associated with creativity management, in parallel with the largely technical aspects of commercial and programmatic management (Lewis, Welsh, Dehler and Green, 2002; Gustavsson and Hallin, 2014); through the definitions of creativity as a function of quality, we ultimately recommend that the dichotomisation of time, cost and quality objectives – a paradigm accepted by the majority of construction project managers – be robustly challenged in future project management research.

In this context the proposed CCPM purposeful action model (see table 3) is recommended as a value-adding complementary "frame" for considering PM conduct and the application of project management best practice on building design projects.

Table 3: CCPM purposeful action model

PERSONAL-PROFESSIONAL RELATIONS	**VISIONING**
Build personal relationships with Client and influential team members; **B**e open and transparent and willing to engage in debate; **B**e dependable and reliable, success aligned with that of the team; **N**ever undermine people's contributions in a group setting; **C**hannel or redirect people with a negative outlook; **B**e Present; **B**ehave in a courteous and professional manner; **R**esolve disagreement and conflict amicably.	**B**uild an intuitive understanding of what the client is attempting to achieve; **F**ocus on goals and objectives, not prescriptive solutions; **C**ommunicate 'solutions' through reference to precedent or analogy; **A**dopt a transparent open book approach to financial and planning info; **B**uild respect and understanding of [concessions needed for] a creative design process; **E**ngage the team in risk identification and mitigation; **U**ncover goals and objectives; **S**elect partners with aligned vision.
Secure commitment and results through political influence **I**nfluence design through positive engagement with design team **F**rame difficult decisions in the context of project goals, through reference to analogy/ experience **I**ntelligent monitoring of design process against project goals and programme **M**aintain forward momentum	**F**acilitate direct interactions between design champions & the client **T**riangulate solutions: Focus & channel design team towards an objective or away from a wrong path **T**riangulate solutions: Encourage idea generation, development or refinement **I**nterpret & relate design issues to goals & objectives **B**uild support for creative ideas or solutions of merit **S**hare in success and failure of the design team
GUARDING DESIGN TEAM & PROCESS	**SENSE-MAKING**

6. Conclusion

This research proposal was borne from an observation of the dysfunctional and disruptive influence of mainstream project management practice on design team's motivation and output. The ultimate aim of this research was to examine and learn from the positive and integrative approach of CCPMs, and where possible promote and broaden the project management agenda. The proposed CCPM purposeful action model may be viewed as making a contribution to that agenda.

The theoretical claims of the proposed model are limited by sample size, the lack of effort to triangulate research findings, the skill and experience of the researcher in data collection under an ethnographic approach, and the analysis and categorisation of research findings at an appropriate level. As such, the proposed CCPM purposeful action model does not propose strong theoretical claims. As with Simon's (2006) model, further direct observations of CCPM action are needed to validate, challenge or supplement this model and secure greater insight into CCPM perception of the problem situation.

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Project Managers Skills Assessment in the AEC Industry

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Abstract

Construction project managers develop projects in changing, hostile and complex environments, where their skills determine their ability to make decisions. Usually, this decision-making process may be affected by deviations in human beings rationality associated with emotions, perceptions and personal interests. Therefore, it is important to determine and establish the most important skills required by a project manager in the Architecture, Engineering and Construction (AEC) industry, according to the particular needs of projects and specific characteristics of individuals.

This research aims to evaluate the perception of different industry stakeholders regarding required project managers skills in order to determine the most relevant ones. Similarly, differences between respondents' perceptions (if there are any) are identified as well as factors leading to these differences such as geographic location, gender, level of education, certifications acquired or methodological implementations, among others. Moreover, this study seeks to assess whether project managers technical skills are subordinated to primary emotions, since recent studies suggest that emotional skills are more important than technical skills.

Stakeholders' opinions were quantified through a survey sent to AEC companies in Colombia and to different people from this industry around the globe. Responses were analyzed using multiple regressions with dummy variables finding that technical skills are not subordinated to primary emotions, and that social skills are more influential to project management than technical skills.

Keywords: project managers, skills, perceptions, emotions, AEC industry.

1. Introduction

Construction projects are developed in complex environments requiring different skills from their managers to accomplish project goals. This is achieved by making accurate and effective decisions at the right timing. However, human beings may be affected by emotions, perceptions and personal interests. Therefore, it is important to determine and establish the most important skills required by a project manager. Authors have written about project managers' skills leading to the following findings.

Until 1980, though researchers considered that technical skills were essential for construction and engineering, personal features started to be relevant. Lippitt (1966) assigned great importance to skills in design, construction, management and operations for transportation developments in communist China associated to technical skills. Conversely, authors like Gaddis (1959) stated that, in addition to field experience, project managers should have a certain profile to develop their work, including their personal characteristics, determining individuals' behaviour on different situations. Martin (1976) proposed that effective project managers had personal characteristics and skills to perform their duties properly (e.g. leadership, honesty, integrity, as well as technical aspects such as planning and monitoring activities, quick thinking, search for information and decision making). Katz and Kahn (1978) assured that efficient communication and maintaining harmony and motivation between the working team was fundamental.

Between 1981 and 1990, in addition to project managers' achievement of objectives, authors like Allen et al. (1980) and Luthans (1988) identified personality traits to define key skills, where respect for others, confidence and vision (not only to anticipate situations but to conceive the project as a whole) were included. Stickney and Johnston (1983), besides using models composed of grouped skills, proposed that authority delegation and sharing promoted the commitment of all the people involved in development of projects. Certainly, authors from this period added more personal skills to project managers' profile.

Methodologies and project management processes played a key role in the 90s as they allowed companies to adapt and adopt practices (standardization), and develop new procedures to improve the efficiency of processes (Fisher, 2011; Wells, 2012). However, methodologies and certifications do not identify the skills that project managers require. Hence, Thomas and Mengel (2008) specified that this level of education does not prepare students to deal with the current projects environments. In fact, they confirmed that "trained" managers are afraid of change, do not adapt to unexpected situations, and avoid using strategies and new techniques. The latter definitely shows the gap between education and project needs.

In 1995, Goleman published Emotional Intelligence, a book referring to the importance of emotional intelligence for personal development. Goleman insisted on managing personal emotions, self-consciousness, and handling interactions with others, emphasizing on the fact that only intelligence is not the key. Self-awareness, tolerance and ability to work in teams began to play an important role on individuals' lives and in the perceptions of what is considered important in various fields. In project management some of these variables started to have relevance, to meet project needs.

Recently, a growing interest on skills and competencies has arisen and several authors continue to look for relevant skills in project managers, finding that, in addition to technical skills, there are key skills for the profession (Zhang et al., 2013). Moreover, the ability to recognize, interpret and manage emotions is critical in interpersonal relationships (Lopes, Salovey& Straus, 2003). In fact, El-Sabaa (2001) stated that social skills have more influence on project management than technical skills and Edum-Fotwe and McCaffer (2000) believed that the essence of relationships is social, not technical, and that relevant skills for managers of construction projects are leadership, communication, negotiation and problem solving. Zulch (2014) makes an interesting statement recognizing that "without emotional skills, interpersonal skills may not be used effectively, and without interpersonal skills, technical skills may be wasted".

Finally, Giraldo et al. (2013) conducted a study to characterize project managers' profiles in the construction sector in Bogota, Colombia. The authors stated that managers of successful projects require experience, educational background and a set of skills to respond in a more accurate and fast way to challenges and changes within the Colombian construction sector. They found that technical skills are the most representative skills for project managers, considering the other skills as complimentary. However, respondents belonging to professional associations, considered the interpersonal skills more important than other skills.

Figure 1 summarizes how the perception of important skills has changed over the years.

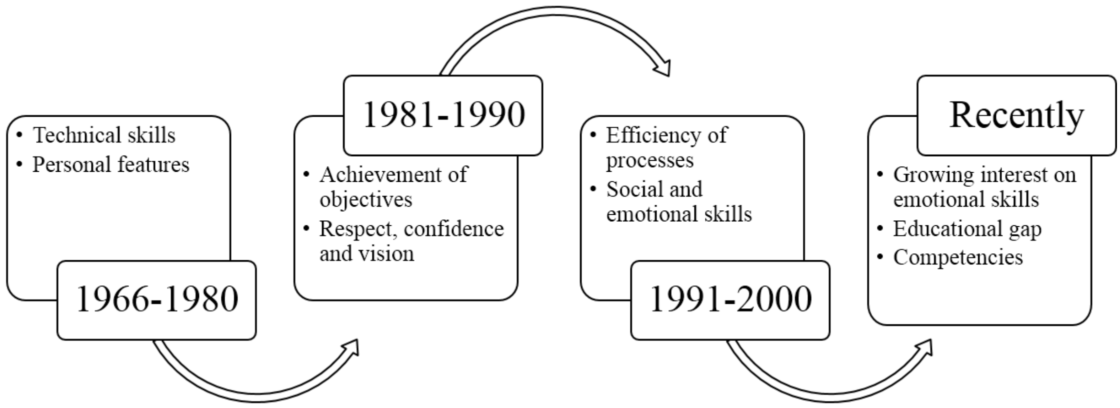

Figure 1: Important skills through time

This paper includes the methodological approach for developing a survey to assess project managers' skills, the results for each studied variable and the analysis done with multiple linear regressions. The final section contains conclusions based on our findings.

2. Research methodology

2.1 Preliminary stage

This stage included literature review, research hypotheses formulation and research strategy definition.

Literature review showed the opinions of different authors towards skills and served as a basis for classifying the skills and formulating the hypotheses. Our hypotheses are: 1) technical skills are subordinated to emotional skills, and 2) skills are independent from demographic conditions.

This research is framed in a mixed methodology which includes qualitative and quantitative approaches. According to Naoum (2007), the qualitative method considers an attitudinal approach to evaluate opinions; points of view or perceptions towards the skills that project managers require (variables). The quantitative method refers to the validation of the hypothesis through statistical analysis of the variables. The selected approach to data collection was fieldwork research, a primary data collection method that considers a survey approach with a postal questionnaire as a practical collecting technique.

2.2 Survey development

To develop the survey, first, a preliminary list of skills (variables) identified as relevant and common to different authors was completed. These variables were grouped into four broad categories, called factors: Cognitive (knowledge base); Technical (specific to a profession); Social (interactions with other people) and Emotional (personal knowledge and understanding, i.e. emotional awareness).

This first draft was checked several times, some variables were rewritten and those which were similar were pooled, reaching to a final definition of 31 variables: 4 cognitive, 5 technical, 12 social and 10 emotional. This distribution was used to develop an analytical survey, aiming to establish relationships and associations between answers and respondents to validate the hypotheses (Naoum, 2007). Table 1 shows all the variables included in the survey.

Authors considered that the most suitable technique for collecting data was the postal questionnaire. This instrument has been widely used to find out facts and opinions on specific themes. It is characterized for having closed-ended questions with specific answers or scales for factor or variable ranking (Naoum. 2007). Our postal questionnaire had opinion questions with quantifiers on a numerical rating scale from 1 to 9 for variables. The scale is odd to have a middle or neutral point. The quantifiers refer to:

- 9 = Extremely Important
- 5 = Important
- 1 = Extremely Unimportant

It also contains a ranking scale to indicate the factors importance or preference (4 - the most important and 1 - the least important). Vocabulary and questions were carefully examined to avoid bias and ensure their understanding. Two versions of the survey were made; one in Spanish and one in English, to enlarge the number of participants.

The survey had 6 sections: 1) Cognitive factors; 2) Technical factors; 3) Social factors; 4) Emotional factors; 5) Factor ranking; and 6) Demographic information. Last section had questions to characterize the sample such as gender, age, years of experience, working geographical area, sector, industry, use of methodologies/certifications acquired.

Survey sample was a selective sample of people related to the AEC field, considering teachers, contractors, and members of groups or associations worldwide. Respondents database was built from public information mainly from companies. Some participants were contacted through emails and social networks (LinkedIn and academia.edu). An introductory letter confirming anonymity of the respondents and the link to the survey were sent. The questionnaire was developed with Google Docs.

Before final data collection, a pilot study was done to test the survey with some experts. Their feedback was used to improve or modify questions. This questionnaire included a closed-ended question section regarding the survey length, the scale used, the instructions provided, the layout of the questionnaire and a space for additional comments.

2.3 Data analysis

After gathering respondents' opinions, the chosen method for data analysis was multiple linear regressions with dummy variables. These variables take the value of 0 or 1 to indicate the presence or absence of characteristics that may modify the outcome. Multiple linear regression models take the form:

$$y_i = \beta_0 + \beta_1 \cdot x_{1i} + \beta_2 \cdot x_{2i} + \cdots + \beta_n \cdot x_{ni} + u_i$$

Where: y_i =dependent variable, $\beta_0, \ldots, \beta_n$ =regression coefficient, x_{ni} =independent variables and u_i =error term.

Obtaining regression coefficients and their significance to examine the relationship between the independent and the dependent variables was possible due to the use of specialized software in data analysis (Stata/SE 12.1). Significance was verified with the following statements: 1) The null hypothesis states that $\beta_n = 0$ and 2) The alternative hypothesis considers that $\beta_n \neq 0$

Each coefficient has a P-value and a significance level of 5% (as the test chosen value). When the P-value is higher than the significance level, the null hypothesis is not rejected and the coefficients are not significant for the model, hence, the variables are independent. On the other hand, when the P-value is lower than the significance level, the null hypothesis is rejected and it is concluded that the coefficient is significant for the model and that the variables are dependent (i.e. the independent variable affect the dependent variable).

The results allowed validating or rejecting the research hypotheses mentioned above.

3. Results

3.1 Pilot study

For the pilot study 23 experts from different countries (e.g. Brazil, Chile, Colombia, Germany, Mexico, New Zealand, Spain, UK, and USA) were contacted, 12 experts (a response rate of 52.17%) participated in the survey and send their comments. Their feedback helped to introduce adjustments such as the scale modification and addition and removal of variables and questions.

3.2 Respondents

The questionnaire was sent to professionals related to project management in the AEC industry worldwide. There were 139 responses, however, a conventional response rate was not calculated due to the social network approach to sampling. The link to the survey was published online, making it almost possible for everybody to answer it and preventing authors of knowing the factual number of respondents. All replies were validated to include only the people related to AEC industry.

Sample demographic information showed that 79% were male and 21%female; 39% were from Spain, 28% from Colombia, 20% from America (North and South), 4% from Europe, 4% from Middle East, 3% were from Africa and 2% from Oceania. Due to the number of respondents in Colombia and Spain, both countries were excluded from America and Europe, respectively. Age distribution revealed that 15% were between 46 and 50 years old; 14% between 41 and 45; 14% between 31 and 35; 13% between 26 and 30; 12% between 36 and 40; 9% between 51 and 55; 9% were between 21 and 25; 7% between 56 and 60; 5% between 61 and 65; and 2% older than 65 years old.

Educationally, 75% had advanced studies (graduate), 23% had bachelor's degree, 1% were technicians and the remaining 1% were high school graduates. 77% worked in the private sector and 23% in the public sector. Respondents roles were classified under the categories 1) academy (professor, researcher and student), 2) business (investor, manager, owner, developer), 3) designer (architect, designer) and 4) production (project manager, resident engineer, construction work supervision and contactor. The occupation distribution is 51% production, 19% business, 18% designer and 12% academy.

Respondents also indicated that 24% relate to the Project Management Institute (PMI), 22% use lean construction, 19% apply LEED, ISO (International Organization for Standardization) or IPMA (International Project Management Association) and 35% do not use methodologies or have acquired certifications of any kind. The sample geographical working areas are 29% in Spain, 26% in Colombia, 21% in North and South America, 9% in Europe, 5% in the Middle East, 5% other regions, 4% in Africa, and 1% in Oceania.

3.3 Cognitive factor (CF)

Results show that the average importance rating and the ranking of the most and the least important variables are consistent (i.e. the variable perceived as most important is the one that has higher average and the one considered less important has the lowest average). The most important variable is *1.3 Evaluate different alternatives and their consequences* with a mean of 8.09, and the least important variable is *1.1 Search and collect information from different sources* with 7.09.

As it was mentioned before, the coefficients affect the model when their P-values are below 5%. Consequently, results define that the independent variable *sex* affects the dependent variable *1.1 Search and collect information from different sources,* which is also affected by those working in *Africa.* The variables that affect *1.2 Identify opportunities and challenges* are *nationality* and *geographical working area,* excluding *Middle East* in both of them. *Education* and the *Middle East* in *geographical working area* are significant variables for *1.3 Evaluate different alternatives and their consequences. Production* and the following geographical areas *America, Colombia and Africa* affect *1.4 Develop creative, innovative and original ideas*.

The only variable that influences every dependent variable of the cognitive factors is *geographical working area* in contrast to *sector* and *methodologies/certifications,* both insignificant for the cognitive skills.

3.4 Technical factor (TF)

The most important variable is *2.5 Design, plan, organize and control* with an average of 8.50, and the least important variable is *2.1 Use of specialized tools* (mean=6.37). The ranking of variables is congruent with the rating. Variable *2.1* is the only dependent variable that is not affected by any of the independent variables. *African nationality, education* and *other regions* in *geographical working areas* influence variable *2.2 English proficiency*. *Graduate degrees, academics, private sector* and *other regions* in *geographical working areas* have an impact on *2.3 Budget development and management. Bachelor's degree* and *geographical working area* are the independent variables that affect *2.4 Efficient resource management*. Finally, the use of anything related to *PMI* and *other regions* have an effect in variable *2.5*.

Results for technical factors show that none of the dependent variables is affected by *sex* and that *geographical working area* and *education* are the most affecting variables, therefore, workplace and education are crucial to assign the degree of importance for technical variables.

3.5 Social factor (SF)

The most important variable of the emotional factor is *3.7 Teamwork* (mean=8.32) and the least important variable is *3.4 Availability for others* (mean=6.80). The variable ranked as most important is also the rated most important variable (*3.7*). However, the variable ranked as least important, is not the one that has the lower average. Thus, this factor is incongruent in rating and ranking (i.e. the respondents assigned a slightly higher importance to the least important variable). Only considering the ranking, the least important variable is *3.6 Build long-term relationships*.

The independent variables that are more influential to the dependent variables are *education* and *geographical working area*, meanwhile *sector* and *methodologies/certifications* do not affect any variable. *Sex* is the only variable that influences *3.8 Effective oral and written communication*; therefore, being male or female alters the degree of importance given to the variable. *Nationalities* such as *Colombian, European* and *African* affect *3.1 Encourage others' participation, 3.2 Provide constructive feedback, 3.10 Encourage others' development* and *3.11 Promote learning*. The latter shows that people from developed and developing countries have an impact on the variables that concern about the progress of others. Similarly, *Colombia* and *Africa (geographical working areas)* affect variables that seek for the progress, motivation, development and consideration for the others. In addition, *education* also influences variables that relate to the efforts that a manager can do for them.

3.6 Emotional factor (EF)

4.2 Leadership is the most important variable of the factor with a rating of 8.32 and the least important variable is *4.6 Aware of own feelings* with an average of 6.57. The ranking of variables for this factor is consistent with the rating. *Geographical working area* influences the rating of variable *4.2*, whereas *Africa* is the only area affecting *4.6*. Furthermore, the *working area* is the most affecting variable for the emotional factor. *Occupation* and *sector* do not influence any dependent variable.

Males affect the rating of variable *4.7 Stress management*, causing that males assign less degree of importance to it. *Not having certifications or implement methodologies* is significant for variable *4.5 Adapt to changing situations*, however the rating does not change substantially. *Colombians, education,* and *Colombia* and *Africa (working places)* affect *4.10 Failure-tolerant*, a variable that was included due to the opinion of an expert who participated in the pilot study. The same independent variables are significant to*4.3 Proactivity*, nonetheless, all nationalities except *Middle East*, and only *Colombia* are the influencing classes.

Geographical working area affects four dependent variables. However, the only variable that is affected by all of them is *4.9 Recognize own strengths and weaknesses*. For the remaining variables: *Middle East* and *others* do not influence *4.1 Self-confidence*, *Colombia* is the only area that affects 4.*4 Being visionary* while only *Africa* impacts*4.6 Aware of own feelings.*

3.7 Ranking of variables according to their average

Table 1 shows all the variables ranked according to the degree of importance given to them. Some of the variables have an asterisk (*) on the side of the factor, that represents remarkable variables for the authors. For instance, *2.2 English proficiency* is relevant because some job offers in our country (Colombia) require proficiency in this language. Another example relates to variable *4.2 Leadership*, which is also considered important for many authors (Giraldo et al 2013). Some of these variables have a high average rating (*3.7 Teamwork, 4.2 Leadership*), though *2.2 English proficiency* and *4.7*

Stress management are in unappealing positions, indicating that those skills are not as relevant for project managers.

Other variables have a plus sign (+) denoting they were ranked the most important variables of its factor and others have a minus sign (-) representing the least important variables of each group. Variables considered as most important are in the top 6 and have averages between 8.50 and 8.09, whereas the least important variables are in the bottom positions with averages between 7.19 and 6.37. Besides, the degree of importance assigned to all variables is in the 6 to 9 range, suggesting that all the studied skills are important and extremely important.

2.5 Design, plan, organize and control is the most important variable (8.50), it belongs to the technical factor. On second place are *3.7 Teamwork* and *4.2 Leadership* both with the same degree of importance (an average of 8.32). The difference between the first and the second position is 2.11%. Consequently, the most important skill for project managers in the industry of Architecture, Engineering and Construction is the technical ability to *design, plan, organize and control*.

2.1 Use of specialized tools is the least important variable with a rating of 6.37. Even though in the numeric scale this average indicates that the variable is important, it demonstrates that the AEC sector is very conservative and averse to the use of technology. Nowadays countless tools exist to contribute to the planning, development and project control. However, there is still the idea that technology is inadequate to perform the tasks of a construction project manager (ESSEC, 1997).

Moreover, Table 1 shows that in the top 10 variables there are 2cognitive, 2technical, 3social and 3 emotional variables. This is consistent with the findings of Pettersen (1991) and Zhang et al. (2013) who suggest that a project manager must have skills such as planning, monitoring and supervision, leadership and group management. Similarly, Giraldo et al. (2013) claimed for the need of additional skills to the technical ones.

Conclusively, technical skills are still considered very important and emotional skills, despite having close degrees of importance, do not overcome them yet. These results are alike to the findings of Giraldo et al. (2013) for respondents who do not belong to professional associations. Nevertheless, we considered the AEC sector worldwide instead of project managers for a specific city, as they did in their research.

Table 1: Ranking of variables by mean

No.	*Factor*	*Variable*	*Mean*
1	*TF*	*2.5 Design, plan, organize and control (+)*	*8.50*
2	*SF**	*3.7 Teamwork (+)*	*8.32*
3	*EF**	*4.2 Leadership (+)*	*8.32*
4	*TF**	*2.4 Efficient resource management*	*8.22*
5	*EF*	*4.5 Adapt to changing situations*	*8.12*
6	*CF*	*1.3 Evaluate different alternatives and their consequences (+)*	*8.09*
7	*EF*	*4.3 Proactivity*	*8.04*

No.	Factor	Variable	Mean
8	CF	1.2 Identify opportunities and challenges	8
9	SF*	3.8 Effective oral and written communication	7.88
10	SF	3.9 Delegate responsibilities	7.86
11	EF	4.1 Self-confidence	7.80
12	EF*	4.9 Recognize own strengths and weaknesses	7.80
13	SF	3.3 Listen carefully to others	7.73
14	EF	4.8 Acknowledge own mistakes	7.66
15	SF*	3.5 Inspire people	7.60
16	CF*	1.4 Develop creative, innovative and original ideas	7.56
17	SF	3.11 Promote learning	7.50
18	TF	2.3 Budget development and management	7.48
19	SF*	3.1 Encourage others' participation	7.45
20	EF*	4.7 Stress management	7.45
21	EF	4.10 Failure-tolerant	7.36
22	SF	3.12 View from others' perspective	7.32
23	SF	3.10 Encourage others' development	7.29
24	SF	3.2 Provide constructive feedback	7.24
25	EF	4.4 Being visionary	7.22
26	SF	3.6 Build long-term relationships (-)	7.19
27	CF	1.1 Search and collect information from different sources (-)	7.09
28	SF	3.4 Availability for others	6.80
29	TF*	2.2 English proficiency	6.74
30	EF	4.6 Aware of own feelings (-)	6.57
31	TF	2.1 Use of specialized tools (-)	6.37

3.8 Ranking of factors

Table 2 presents the respondents' average preference for factors, ranking them from 1 to 4. It also shows that only *nationality* and *education* affect them. However, the technical factor is not influenced by any independent variable. The most important factor is social with an average of 3.23 and emotional factor is the least important (21% below).

Table 2: Ranking of factors

Factor	Average	Nationality	Education
Social	3.23	African Colombian Spaniard	
Technical	3.12		
Cognitive	3.07		Bachelor's Graduate
Emotional	2.55	All	Bachelor's Graduate

These results indicate that project managers primarily require skills to interact with others, while technical and cognitive skills are complementary. Emotional skills are somehow irrelevant as they are in the last position. El-Sabaa (2001), Edum-Fotwe and McCaffer (2000), and Zulch (2014) identified that social abilities are more influential to project management than technical skills.

4. Conclusions

This study shows that technical skills are not subordinated to emotional skills and that variables such as sex, education, geographical working area, certifications acquired or methodological implementations, and nationality affect skills. In fact, significant variables are *nationality*, *education* and *geographical working area* for almost all factors. Therefore, both research hypotheses were refused.

All variables are important or extremely important according to their average rating. Social and technical skills have similar degrees of importance, showing that project managers require social abilities to interact with others, while technical and cognitive skills are complementary. Emotional skills are overlooked. Consequently, social skills are more influential to project management than technical skills, as several authors have explained.

However, technical skills still occupy an important position among the skills required by project managers in the AEC industry. This demonstrates the conservative results-oriented approach of the sector prevailing since 1981. The indifference to technological uses shows that there is still the idea that technology is inadequate for construction project managers. Hence, the AEC industry seems to be a parallel, archaic world where current global trends oppose to its philosophies.

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Transparency and accountability as antecedents of value for money in construction

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Abstract

Public-sector projects are intended to result in improvements in the quality of life of the citizenry. However, studies show that a proportion of the funds intended for investment in public-sector projects is lost through corruption. This results in sub-standard buildings and infrastructure which are expensive to operate and maintain, and which can also lead to structural failure and loss of lives.

In many countries, the populace, community groups and non-governmental organisations are calling for, and often, taking measure to attain, clean government and accountable public service. These have led to initiatives which have resulted actions in some countries, including the review and strengthening of the procurement process; streamlining of contract administration procedures; and formation or strengthening of anti-corruption agencies. However, the incidence of corruption, malpractice and mismanagement in construction persists. Much effort is being made at the global, national, company and project levels to address the situation. One of these is the Construction Sector Transparency Initiative (CoST), which is being implemented in many countries. This study extends knowledge on how to deal with corruption in construction by exploring the merits of transparency in these regards. It considers the potential of CoST to enable the realisation of value for money in construction.

The literature on corruption, its impacts, its common occurrence in construction and the consequences, together with the underlying reasons, are reviewed. Meta-analysis of data from 216 projects in eight countries obtained in the pilot of the CoST initiative forms the other main plank of the study. It is found that previous approaches, such as legislation and procurement reform, have not been sufficient to address mismanagement on projects. It is shown that CoST has yielded tangible benefits, including avoidance of overdesign, cancellation of contract awards with possible corruption, and disciplining of miscreants. Many authors also support CoST and highlight its merits. It is concluded that project governance should receive emphasis. Given the large number of stakeholders on any sizeable construction project, it is proposed that a multi-stakeholder approach such as CoST would be most appropriate. Suggestions on how CoST can be instituted are made, with a focus on education.

Keywords: corruption, infrastructure projects, governance, disclosure, quality of life

1. Introduction

Transparency International (2005, 2008) suggests that 10% to 30% of investment in construction globally is lost through corruption. Mismanagement, malpractice and inefficiency account for a similar level of losses. Research shows that no country is immune from this. American Society of Civil Engineers (ASCE) (undated) considers corruption in construction globally a huge burden of some US$500 billion annually which occurs in every country. Public-funded construction works form 30% of most governments' budgets (OECD, 2002; CoST, 2013a). The leakage and wastage adversely affect the rate and quality of development. There is a demand around the world for probity and accountability in public office. Laws, institutions and project-based procedures appear unable to deal with the situation. Thus, there is a search for solutions. It is argued here that the Construction Sector Transparency Initiative (CoST) could be an effective response.

The aim of the study is to present CoST as a solution to problems of mismanagement and corruption on public construction projects. The objectives are to: (a) consider the nature and impact of corruption, and how and why it occurs in construction; (b) discuss solutions to corruption and mismanagement on public construction projects; and (c) explore key aspects of CoST. The study is based on a review of the literature on corruption in general and in construction and the consequences, together with the underlying reasons. Meta-analysis of data from 216 projects in eight countries obtained in the pilot of the CoST initiative forms the other main plank of the study.

2. Corruption, its effects and manifestation in construction

2.1 What is corruption, how extensive is it and what is its impact?

A definition of corruption agreed by the multi-lateral banks is (World Bank Office of Suspension and Debarment, 2014): "the offering, giving, receiving or soliciting, directly or indirectly, of anything of value to influence improperly the action of another party". United Nations Development Programme (UNDP) (2008) and Transparency International (undated) define it as: "the misuse of entrusted power for private gain" (p. 6). Corrupt acts take many forms including (GIZ, 2012; Ofori, 2012; Serious Fraud Office, 2014): bribery, extortion, fraud, nepotism, graft, kickbacks, theft, misappropriation, falsification of records, influence peddling, deception, coercive action, cartel price-rigging, illicit enrichment, commission/fee and dishonestly exercising official functions.

Studies show that corrupt practices exist in all countries; and that they are particularly common in construction. For example, in the Transparency International (2014) Corruption Perception Index, 69% of the 175 countries scored below 50 out of 100 ("indicating a serious corruption problem", p. 4). None of the 23 European countries studied by Transparency International (2012b) had a perfect record regarding anti-corruption systems and measures: "All countries in Europe, even …the 'cleanest of the clean', have some deficits in their anti-corruption frameworks" (p. 9). In the Bribe Payers Survey of Transparency International which studies the extent to which firms from 28 largest, industrialised economies pay bribes when doing business abroad, the "public works and construction" sector consistently performs worst. Transparency International (2012a: p. 3) noted: "Bribery is perceived to occur in all business sectors, but is seen as most common in …public works contracts and construction".

Corruption has wide ramifications. UNDP (2008) notes that it weakens national institutions, and leads to inequitable social services, economic inefficiency and unchecked environmental exploitation. It hits the poor hardest and undermines development. It corrodes the ideals of public service. Corruption erodes the rule of law; and harms the reputation of, and trust in, the state (World Bank, 2011b). Corruption deters investment, and distorts public investment decisions. It introduces further risk into business and influences the costs of transactions; it works against professionalism.

Some suggest that corruption can be useful to society as it (Ofori, 2012): facilitates and expedites procedures; and reduces business costs because, for example, expediting approval can reduce financing costs. It is also argued that corruption is part of human nature, and it is impossible to eradicate it; it is the way of doing business in some countries.

2.2 Corruption in construction

Corruption is common in construction. World Bank (2011a) reports that 25% of over 500 projects with a Bank-funded roads component approved in 1999 to 2009 drew fraud, corruption or collusion allegations. On 25 projects, allegations were confirmed, resulting in 29 cases of misconduct including collusion among bidders; fraud in implementation; and false documents and imposed sanctions in Bangladesh, Cambodia, India, Indonesia, Kenya, Philippines and Senegal. Kenny (2007) found a relationship between average unit cost for upgrading a road with a bitumen surface and the country's Corruption Perceptions Index. World Bank (2011a) reports these estimated cartel overcharges on road contracts: Florida, 8%; South Korea, 15%; Tanzania 15-60%; Philippines 20-60%. For a sample of 29 developing countries, the overcharge was 40 percent. Moreover, for all construction contracts, the overcharge in the Netherlands was up to 20%; in Japan, it was 30-50%; and for all cartels, it was 25%. European Investment Bank Group (2014) notes that direct costs of corruption in public procurement in five sectors (road and rail; water and waste; urban/utility construction; training; and research and development) in eight member states ranged between €1.4 billion and €2.2 billion. The probability that certain types of infrastructure would be affected by fraud and corruption ranged from 11% in road works to 27% on waste water plants. K&L Gates (2014) presents corruption cases around the world including Nigeria, Russia, UK, and US. Firms from Canada, France, Japan, UK and US have been fined for paying bribes while working abroad.

2.3 Why is there much corruption in construction?

Several studies highlight how corruption occurs on construction projects (Ofori, 2012); it is evident at all stages. Authors give many reasons why construction projects are prone to corruption and malpractice (Stansbury, 2005; Ofori, 2012; Hawkins, 2014). First, they are large and expensive, making corruption attractive and perhaps easier to conceal. Second, they take a long time to complete and involve many agencies so there is a temptation to influence approval processes. Third, constructed items are geographically dispersed and difficult to control administratively. Fourth, constructed items are technically complex, and it requires knowledge to detect malpractice. As each project is unique, there are no suitable comparators. Fifth, many portions of the built item (such as foundations, floor slabs, beams, roof structure and walls) are covered, making it possible to conceal poor quality of work. Sixth, avoiding responsibility is part of the industry's culture (Ofori, 2012).

PriceWaterhouseCoopers (2009) notes that engineering and construction companies "have a business model that exposes them to a more of the recognised corruption risks than those in almost any other sector. This is because they are involved in one-off long-term contracts, …using complex supply chains" (p. 3). The industry has a culture of using gifts, hospitality, entertainment and so on which might cross the line between good manners, and attempts to influence decision makers.

2.4 What are the effects of corruption on construction projects

FIDIC (undated) suggests that corruption lowers the quality of public infrastructure by diverting resources, and allowing avoidance of codes and standards. It is always unfair; is often criminal; breeds cynicism; and demeans individuals involved. Corruption can lead to unnecessary or wrong items being built; it leads to more capital projects which provide rent-seeking opportunities. It promotes impunity among public officials, practitioners and business leaders, and keeps out good firms from the industry as the playing field is not level. It entrenches inequality in business and in society. Hawkins (2013) notes that the impact of corruption is greater on small and medium-sized enterprises (SMEs) than on large firms. For example, the former are less able to withstand delays in payment. They work for a few clients, and are less able to stop bidding for certain clients. Corruption increases the costs of infrastructure; and raises environmental, health and safety issues. It leads to further deprivation of the poor as the items intended to improve the quality of their lives are sub-optimal in performance including on quality, durability, longevity, and service delivery.

Transparency International (undated) notes that corruption results in projects which are unreliable, dangerous and over-priced. This can lead to loss of life, poverty, economic damage and lack of development. For firms, it results in tendering uncertainty, wasted tender expenses, higher project costs, reduced work opportunities, criminal prosecutions, fines, blacklisting, and reputational risk. It damages individuals, resulting in soiled reputation, criminal prosecution, fines and imprisonment.

3. Efforts to fight corruption in construction

3.1 Anti-corruption initiatives in construction

Several national and international anti-corruption initiatives in construction are presented in the literature. Examples are (Ofori, 2012): UK Anti-Corruption Forum; U4 Anti-Corruption Resource Centre; Construction Industry Ethics and Compliance Initiative; Global Infrastructure Anti-Corruption Centre (GIACC); Transparency International; Water Integrity Network (WIN); World Economic Forum – Partnering against Corruption Initiative; United Nations Global Compact; International Federation of Consulting Engineers (FIDIC); World Federation of Engineering Organisations (WFEO) Committee on Anti-Corruption; Global Anti-Corruption Education and Training Project; Open Government Partnership; Open Partnership Initiative; and CoST.

Le et al. (2014) categorises anti-corruption strategies into: (a) transparency mechanisms – provide the public access to information on projects so that processes can be monitored, and decision makers can be held accountable; (b) ethical codes – seek to attain discipline and probity in professionals; (c) project governance – includes selecting leaders, assigning responsibilities, offering of rewards and imposing sanctions; and (d) audit and information technology – include technical audits; integrity pacts; and on-line procurement.

Some institutions have their programmes. World Bank's (2011a) controls to reduce misconduct on projects include procurement process reviews; financial audits; and field supervision. GIACC provides resources to assist in understanding, identification and prevention of corruption. ASCE (undated) is raising awareness of the real costs of corruption and being a catalyst for co-operation and action by engineers worldwide. It asks engineers around the world to sign "An Engineer's Charter: Combating Corruption in Engineering and Construction". FIDIC's Business Integrity Management System and Government Procurement Integrity Management System are often referred to as an effective set of measures. Transparency International (undated) believes that corruption on construction projects can only be eliminated if all project participants co-operate in developing and implementing actions addressing the supply and demand sides of corruption. It has formulated business tools, reports, actions and information to help actors to do this. In 2007, it developed the Project Anti-Corruption System comprising standards with GIACC which recommend anti-corruption measures on projects; and templates providing the tools by which measures in the standards may be implemented.

To Hawkins (2013), 'tools' to help identify and mitigate the risks of corruption on projects are: (a) Audits - can improve the fiduciary standard of a sectoral programme and help prevent poor quality assets; (b) CoST; (c) Community Monitoring - used where there is a gap in accountability in the project cycle; (d) Red Flags - provide alert indicators which help to identify and track vulnerabilities to corruption; (e) Integrity pacts - address corrupt behaviour of officials and bidders; (f) Project Anti-Corruption System; and (g) Citizen report cards - provide feedback from users of services.

3.2 Transparency as anti-corruption tool

Kenny (2007) notes that transparency, enforcement and focus on outcomes of poor construction are likely to have greater impact than regulation. Other useful tools are output-based and community-driven approaches, complimented by interventions including publication of procurement documents, independent and community oversight, physical audit and public-private anti-corruption partnerships. Kenny (2011) notes that evidence shows that transparency and oversight are powerful tools to reduce corruption. Regular publication of project details: improves transparency; provides public intellectual capital which reduces legal costs of contracting and helps spread best practices.

Hawkins (2013) suggests these components of an anti-corruption strategy in an infrastructure programme: (a) Promote transparency by giving stakeholders access to information; (b) Develop accountability mechanisms that empower civil society; (c) Improve the capacity of government and procuring entities to apply robust policies and regulations; (d) Create trust between procuring entities and potential suppliers; (e) Provide an incentive structure that rewards actors for complying with rules and penalises them when they do not comply; and (f) Identify political leadership to lead a co-ordinated set of actions.

4. Case study: CoST

4.1 What are the origins of CoST?

CoST is a multi-stakeholder initiative focused on public-sector construction projects which "…seeks to help participating countries improve the value for money spent on the construction of public infrastructure …to achieve the delivery of good quality infrastructure projects at lower cost, with increased predictability of outcomes" (CoST, 2013b). The objectives are to: promote transparency and accountability in public infrastructure; develop systems and procedures to collect, verify, interpret and disclose key project information; and reduce mismanagement and corruption and improve value for money in infrastructure investment.

Under CoST, governments, industry and civil society work together to disclose reliable information on public construction projects. Multi-Stakeholder Groups (MSGs) oversee the validation and interpretation of the information and build the capacity of the target audiences to understand the information. With this understanding, stakeholders (citizens, media, parliament, oversight agencies) can raise challenges over poor performance, perceived mismanagement, or corruption. Government responds to concerns raised by commissioning audits into specific projects or wider reviews into the performance of an agency or in a sector. The information facilitates the investigation, and action can be taken to sanction staff or prosecute offenders.

CoST was piloted in eight countries between April 2008 and December 2010. The countries were Ethiopia, Guatemala, the Philippines, Malawi, Tanzania, UK, Vietnam and Zambia. It was funded by the UK Department for International Development (DFID); and the countries. The World Bank hels an advisory position. Similar international multi-stakeholder transparency programmes are Extractive Industries Transparency Initiative (EITI), for the oil and gas industry; and Medicines Transparency Alliance (META). The pilot countries realised many benefits from it, including cost savings, regulatory reforms and institutional building. Examples are given below. After a critical review, the CoST international programme was launched in October 2012.

4.2 What were the results of the pilot phase?

During the pilot phase of CoST, information on 216 projects of many types (schools, housing, government buildings, hospitals, roads, airports, harbours, irrigation, flood control) across 29 procuring entities in the eight countries was collected, verified and disclosed. The meta-analysis of the data revealed significant levels of inefficiency and mismanagement in all the countries. Major causes for concern were unjustifiable time (10-120%) and cost (8-58%) overruns; and low levels of competitive bidding. Examples of shortcomings on projects included: (a) on average, only half of the information required by law in the countries to be disclosed was actually disclosed; (b) even where information was disclosed, the coverage was limited (in most cases, only information on tendering was disclosed); (c) the disclosed information was complex and opaque; (d) access to disclosed information was poor; and (e) stakeholders' involvement in projects was limited. A positive sign was that procurement reform had been effected in all the pilot countries.

4.3 What is the current CoST programme?

CoST is a global programme registered in the UK as a not-for-profit organisation, with a Board of Directors and a UK-based International Secretariat. There are now CoST programmes in 14 nations: Afghanistan, El Salvador, Ethiopia, Guatemala, Honduras, Malawi, Philippines, United Kingdom, Vietnam, Tanzania, Thailand, Uganda, Ukraine and Zambia. Over ten countries have expressed interest in joining CoST including Botswana, Colombia, Costa Rica, Indonesia, and Mexico.

After the pilot, CoST has been funded from a World Bank grant; the government of the Netherlands; resources from the government; and country offices of bilateral donors and regional development banks (for country programmes). Currently, much of the funds are from DfID.

The mission of CoST is: "Improved quality of life for all as a result of better infrastructure." The vision is: "To improve the value for money spent on public infrastructure, by increasing transparency and accountability in the delivery of construction projects."

A National Secretariat, under the direction of the MSG, administers the CoST programme. That secretariat is located in a Host Organisation which can employ personnel, and enter into contracts. Its tasks include: (i) providing administrative and management support to the MSG; (ii) procuring and administering necessary consultant services; (iii) facilitating necessary technical support, capacity building and related events; (iv) implementing the communications strategy of the MSG; and (v) maintaining liaison with the International Secretariat. Countries might establish an independent legal entity (usually a non-governmental organisation) to manage the functions of the MSG and the National Secretariat. A CoST Champion provides guidance to the national programme, and facilitates access to government leaders, and sources of project information. Champions have been ministers or prominent members of the society with a reputation for probity.

The International Secretariat provides technical guidance, support, start-up funds, and exchange of international best practice. The overall CoST programme is overseen by the International Board which includes representatives elected by each stakeholder group.

4.4 Disclosure of information

How does CoST work? Government departments or statutory agencies which procure public-sector construction projects (procuring entities (PEs)) are responsible for disclosing information on their projects proactively using the framework in the CoST Infrastructure Data Standard in Table 1. If such information is not legally required to be disclosed, an Interim Disclosure Requirement can be established. Eventually, the government should establish a Formal Disclosure Requirement (FDR). In Ethiopia, the FDR was established through a series of proclamations, regulations and directives, requiring PEs to disclose information on the website of Public Procurement and Property Administrator Agency (PPPAA). The FDR in Guatemala was set up through the 2014 Regulations of the Organic Law of the National Budget. In Malawi, CoST disclosure requirements will be part of the new Procurement Act.

Information is also disclosed reactively (i.e., on request by stakeholders). Items include the project brief, feasibility study, budget, project officials and roles, contract agreement, and list of variations and changes. PEs would respond to questions from stakeholders on the information which has been disclosed. There are differences in the disclosure process adopted in the CoST member countries.

The International Secretariat has produced several "guidance notes" on CoST (CoST, 2013c). These includes directions on how a country can join CoST and templates aspiring CoST countries can use.

4.5 What are the benefits and possible misgivings of CoST

CoST would lead to a reduction in fraud, corruption and mismanagement on public projects, resulting in improved quality of life for nations' citizens. For governments, it leads to greater efficiency in managing public investment and expenditure; enhanced value for money on public projects; improvements in the quality of public services and durability of built items; and reduction in risks to public safety from poor building practices. The government can provide credible information on its projects to citizens, leading to greater public awareness and confidence.

For the private sector, CoST would transform the business climate, with a level playing field, predictability and fair competition. CoST can create new markets overseas. There would be improved relationships between businesses and the communities they operate in. Reduction of risk and uncertainty would lead to improved access to finance for firms. Fairer opportunity to compete for work would foster the development of companies and professionals. Transparency of project information will make practitioners seek to improve their operations and performance. For civil society, CoST gives it a voice in relevant aspects of decision making on projects. For citizens, there would be better value for money and improved service delivery on infrastructure items.

Table 1 CoST Infrastructure Data Standard

PROJECT PHASE	*PROJECT INFORMATION*	*CONTRACT PHASE*	*CONTRACT OR PACKAGE INFORMATION*
Project Identification (6 items)	*Project owner*	***Procurement (13 items)***	*Procuring entity*
	Sector, subsector		*Procuring entity contact details*
	Project name		*Procurement process*
	Project location		*Contract type*
	Purpose		*Contract status (current)*
	Project description		*Number of firms tendering for the project*
Project Preparation (7 items)	*Project scope (main output)*		*Cost estimate*
	Environmental impact		*Contract administration entity*
	Land and settlement impact		*Contract title*
	Contact details		*Contract firm(s)*
	Funding sources		*Contract price*
	Project budget		*Contract scope of work*
	Project budget approval date		*Contract start date and duration*
Project Completion (6 items)	*Project status (current)*	***Implementation (6 items)***	*Variation to contract price*
	Completion cost (projected)		*Escalation of contract price*
	Completion date (projected)		*Variation to contract duration*
	Scope at completion (projected)		*Variation to contract scope*
	Reasons for project changes		*Reasons for price changes*
	Reference to audit and evaluation reports		*Reasons for scope and duration changes*

Advantages of multi-stakeholder working include the ability to pool knowledge to pursue common interests, and give more weight to decisions, but it can be time-consuming and difficult. Calland (2014) notes these concerns: bogus representation by government or industry; marginalisation of some stakeholders; self-selection by civil society groups; harassment or coercion; and uneven access to information. Thus, forming the MSG and building trust among constituents requires effort.

CoST does not impose any additional burdens on business. Disclosing project information can help firms to identify efficiency savings. Many top firms have endorsed CoST; they include Skanska (Sweden), Balfour Beatty (UK), Bechtel (US), Ramboll (Denmark), Halcrow (UK), Strabag (Austria) and NCC (Sweden). Institutions include European International Contractors and FIDIC. Some PEs fear that CoST involves additional work for them. However, under CoST, PEs release information, already available information in a standard format which is useful to PEs in monitoring projects. The CoST programme in Uganda was initiated by one PE, the National Roads Authority.

4.6 What is the impact of CoST?

Implementation of CoST has led to significant achievements. Examples are: (i) changes in government procurement and administration procedures which resulted in greater openness and accountability in Malawi, Tanzania and Ethiopia; (ii) improvements in human and financial management practices in procuring entities in Tanzania and Malawi; (iii) improvements in government policy on data management in UK; and (iv) enhanced scrutiny of contracting parties.

4.7 Endorsement of CoST in the literature

Several authors recommend the adoption of CoST as an effective anti-corruption programmes and measures in construction (see FATF, 2012; Runde et al., 2014). Hawkins and McKittrick (2012) explain why CoST is important to governments, firms and professionals globally. An Independent Joint Anti-Corruption Monitoring and Evaluation Committee expressed "serious concerns" over impunity in some of Afghanistan's "high-profile corruption cases". Among its recommendations was the setting up of CoST "which provides for multi-stakeholder monitoring and oversight of construction projects" (UNAMA, 2014). CoST was highlighted as recommended good practice by a UK parliamentary committee. In the UK's National Infrastructure Plan (HM Treasury, 2011), the government indicated that it would use the CoST template as a tool in managing its projects. B20 Panel of Six International Accounting Networks (2014) reproduced an extract from the CoST factsheet on the benefits of the initiative to the private sector. CoST was endorsed by the G20 group of countries in 2011. The G20 (2013) noted that, in October 2011, the Multi-lateral Development Banks Action Plan of G20 recommended the scaling up of CoST. In a letter to leaders of the G8, in January 2013, British Prime Minister, Mr David Cameron, identified transparency as a priority for the G8 during the UK Presidency. He referred to CoST as a programme that should be supported.

5. Recommendations and conclusion

Corruption is almost uniquitous in construction. It is pernicious and corrosive. There is need for 'proactiveness' to deal with this cancer and improve the image of the industry while contributing more for society by providing value for money on projects. All construction stakeholders should invest effort to deal with this challenge. Among initiatives at global, national, institutional, company and project levels to reduce corruption and mismanagement, CoST has proved effective, leading to enhanced value for money from projects. The multi-stakeholder disclosure process is a viable component of project governance systems in all countries. Governments, construction firms and practitioners, and civil society should collaborate to introduce CoST in all countries.

CoST disclosure requirements and related provisions should be authorised in national statutes and incorporated into governance systems, with a high degree of compliance and effectiveness. Modules should be introduced in tertiary educational institutions to build awareness and knowledge of students of corruption in construction and possible solutions such as CoST.

Professional institutions could include coverage of anti-corruption initiatives such as CoST in continuing professional development programmes and highlight transparency on projects in codes of conduct and other ethics codes. CoST can be a valuable source of data on infrastructure projects which can be used for research and decision making by governments and investors. This study adds to knowledge on ways of addressing corruption in construction by showing the merits of transparency.

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Improving alliance projects through facilitation

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Abstract

Alliance and other collaborative project delivery models such as integrated project delivery (IPD) represent a solution to decrease the fragmentation in the construction industry. New technology such as building information modelling (BIM) is also claimed to introduce more integration into the design and construction processes. However, an intensified collaboration is required for successful alliancing and BIM processes. The intensified collaboration does not seem to occur automatically after committing to a contract, but might often require help in the daily project activities. Facilitation is an activity used in other industries to help in accomplishing tasks by concentrating on the social processes of groups performing the activities. Currently, very little is known about the facilitation in the context of construction projects. Facilitation literature suggests that facilitation can support collaborative task performance with three elements: 1) the management of group process, 2) the management of content, and 3) facilitator's substantive expertise. With a qualitative case study approach, we studied what kind of facilitation occurs in a Finnish alliance project and how current facilitation methods meet the project needs. The results suggest the presence of all the three facilitation elements, but also suggest possibilities for improvement. The results connect facilitation literature to collaborative construction projects. The empirical analysis also offers practical suggestions on how to apply facilitation in construction projects efficiently.

Keywords: Facilitation, alliance, construction, management, collaboration

1. Introduction

Alliance and other collaborative project delivery models such as integrated project delivery (IPD) represent a solution to decrease the fragmentation in the construction industry (Lahdenperä, 2012). Furthermore, new technology such as building information modelling (BIM) is claimed to introduce more integration into the design and construction processes (Succar, 2009). However, successful alliancing and BIM processes require intensified collaboration (Alhava et al., 2015). Collaboration has been studied as an essential element of construction projects (e.g. Cicmil and Marshall, 2005) but it does not occur automatically after signing a contract, it is rather created in daily practices (Smits and van Marrewijk, 2012). Meetings are key events in a project where the representatives of the stakeholders perform collaboration. This collaboration can be enhanced with facilitation. Facilitation is scarcely studied in the construction project context, even when it is known that facilitation can help meetings to be more efficient (Vivacqua et al., 2011). The existing literature does not describe what kind of facilitation is performed in construction projects.

Within this study, we ask what kind of facilitation activities are performed in the meetings of an alliance project and how current facilitation methods meet the project needs. We observed two meetings, a formal design meeting and an informal designer collaboration meeting, of an alliance project in Finland to understand the various facilitation activities. The findings help us understand the role of facilitation in inter-organizational collaboration in alliance projects. The paper is structured as follows, the relevant literature on the construction sector and facilitation are presented. Then we describe the empirical case and methods. This is followed by presenting the results and the discussion based on results. We conclude by discussing the potential of facilitation in the context of inter-organizational construction project management meetings.

2. Facilitation of Collaboration

2.1 Facilitation of Collaboration in an Alliance Construction Project

Collaboration between construction project parties is crucial in order to design and construct buildings that meet the quality needs of customers. Unfortunately, collaboration in construction projects is often hindered by traditional design-bid-build contracts and silo-based working methods. Relational contracting, such as alliance contracting is a promising way to improve collaboration in construction projects. Alliance contracts usually include two or more parties who decide to cooperate throughout the project, based on ‘shared risk and shared reward’ thinking. In Finland, alliance contracts have been mainly used in infrastructure projects that include lots of uncertainty and complexity (Lahdenperä, 2011). Relational contracting has been considered to facilitate collaboration because it steers the project parties towards shared objectives. However, the relational contract alone does not suffice as a facilitative mechanism, but also, organizational mechanisms are needed (Lavikka et al., 2015).

Alliance projects can use several organizational mechanisms, such as a joint management and decision-making structure, early involvement of key project parties, alliancing workshops, co-location of teams, transparent financials, and lean principles of design, construction and operation (Lahdenperä, 2012). Jefferies et al. (2014) have also found that alliance projects can benefit from the facilitation of workshops that include both office and site personnel. (Jefferies et al., 2014) However, facilitation is not a trivial task and it requires facilitation skills (Hogan, 2002).

Research on facilitation in the construction project context is still scarce. Few studies exist such as Pala et al.'s (2014) work on ICT as a facilitator of a collaboration process. They found that ICT-enabled inter-organizational information exchange (Pala et al., 2014). Another study about facilitation in the construction sector context discusses intensive big room as a facilitator that enables value co-creation with the customers (Alhava et al., 2015). However, in this paper, we focus on facilitation that takes place in project meetings and where a facilitator is a person. Davis and Love (2011) and Rowlinson et al. (2005) studied alliance contracting and found that trust, commitment and open communication need to be maintained throughout the alliance relationship. Constant facilitation was found important to build open communication between project parties. According to Lahdenperä (2009:31), a facilitator "can be used to promote team formation and evaluate workshop performance." Professional, external facilitators seem to be used in alliance projects (Rowlinson et al., 2005) but to our knowledge, the practices and success of internal facilitators in construction project meetings is an unexplored research area.

2.2 Facilitation of collaboration in group situations

Facilitation aims to aid accomplishing tasks (Keltner, 1989). It has been studied in different circumstances such as a mode of management performance (Raelin, 2012), as enhancing collaboration in meetings (Cooren et al., 2006) and as helping group problem solving (Keltner, 1989). A great part of the literature on facilitation concerns group situations such as meetings and workshops. Earlier literature affirms that facilitation can help meetings to be more efficient (Vivacqua et al., 2011). Apart from efficiency, facilitation has also been suggested to have some positive effect on the satisfaction of the participants as well as the consensus of the group, at least in cases where facilitation is not too rigid (Vreede et al., 2002). These positive effects are welcomed as meetings can be unproductive, costly and dissatisfying (Romano and Nunamaker, 2001).

As facilitation aids to accomplish tasks, it also intervenes in the process and activities of a meeting. Concerning this, a facilitator needs to decide how strongly he or she should intervene in the meeting. If facilitation is too strong, the participation might reduce when a participant becomes more passive and leans on a facilitator (see Miranada and Bostrom, 1999). The facilitator can also be an outsider of group tasks (Hogan, 2002). In this case, the facilitator does not have his or her own interest involved in the meeting outcomes (Huxham and Cropper, 1994). Scholars such as Griffith et al. (1998) argue that facilitator should be neutral and not comment on the context of the meeting. However, the facilitator working also with the group tasks might have a better understanding of the relevance of the outcomes. As technology can be applied to aid facilitation (Vivacqua et al., 2011), technology or other artefacts can have a great role in a group process (Cooren et al., 2006).

The activities of group facilitation can be divided by the way they contribute to the task performance of the group. Earlier literature suggests the facilitation activities can be divided based on if they influence the content of the meeting or group process (Eden, 1990). Later Huxham and Cropper (1994) extended these ideas of facilitation and included a third category as influencing the decisions with expertise. The first facilitation area, the *content* of the meeting, means that a facilitator can manage the content of the meeting, by collecting information on the problem, leading the thinking and discussion of the group (Huxham and Copper, 1994). The activities found by Clawson and Bostrom (1996), can also be considered here as relating to the content. These are clarifying and integrating knowledge, encouraging multiple perspectives, presenting information to the group and keeping group outcome-focused. The second category concerns activities in which the facilitator can influence the *group process*. This category can include managing group interaction, managing meeting-design, managing the relationships between individuals, and tracking and responding to the needs of the group (Huxham and Copper, 1994). The following activities found by Clawson and Bostrom (1996) can also be considered as relating to group process; creating a participative environment, applying well-suited technology, managing conflict and negative emotions, managing flexible considering evolvement of the situation. The third category is the group's decision making that facilitator can give *input with expertise* (Huxham and Cropper, 1994). In this case, the facilitator has some expert knowledge concerning the substance of a decision. In facilitation situation, these three areas of facilitation relate to each other.

3. Research Approach and Methods

3.1 The Case Study of an Office Building Alliance Project

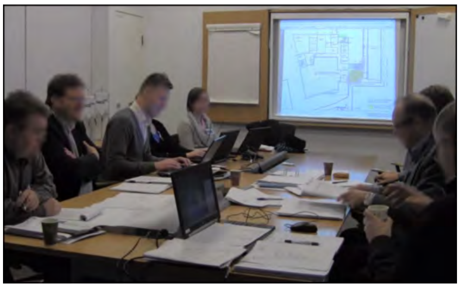
We conducted a qualitative case study of an alliance project in Finland. A case study strategy allows the investigation of a contemporary phenomenon that is difficult to separate from its context (Yin, 1989). Thus, the case study method enabled the investigation of facilitative activities in the alliance project. The aim of the €12 million alliance project was to build a 6-story, 6000 square meter office building on a tight lot in the middle of an operational campus area in Southern Finland. The project started in 2012, the construction phase started in the fall 2013 and the project was finished in 2015. The alliance contract was made between an owner and a general contractor but an architect and design engineers joined the alliance project with cost reimbursable contracts later on. The owner was also represented by the end user organization and a construction management company in project meetings.

3.2 Data Collection

Our overall data consists of six initial interviews in 2013 and seven follow-up interviews in 2014 with key representatives of participating organizations. In addition, we collected video data during 2012 and 2013 from 12 different meetings on different organizational decision-making levels. The meetings on higher decision-making level were an alliance executive group meeting, an alliance project group meeting, and an official design meeting. Additionally, the meetings on lower decision-making level were an unofficial designer collaboration meeting and a BIM clash detection meeting.

For this study, we chose two meetings, which we compared to understand the similarities and differences in the facilitation activities (Table 1). The two meetings were chosen because they represented typical formal and informal meetings in the project. A representative from the general contractor facilitated both meetings. By comparing these two meetings, we gained understanding from two different facilitation events within a single project.

Table 1: The characteristics of the meetings

Meeting / ***Characteristics***	***Formal meeting (Official Design Meeting)***	***Informal meeting (Designer Collaboration Meeting)***
Date	*January $8^{th,}$ 2013*	*January $8^{th,}$ 2013*
Duration	*2.25 hours*	*1.5 hours*
Usual occurrence	*Bi-weekly*	*When needed by any of the participants, but often once or twice a week.*
Participants	*13 participants: HVAC engineer, owner, electric designer, end-user, project engineers, structural engineer, architect, geoplanning, and construction management consultant.*	*6 participants: General contractor, architect, structural engineer, geoplanning, electrical engineer, and end-user.*
Facilitator	*General contractor (project manager)*	*General contractor (project engineer)*
Topics discussed	*Safety, clearance, planning requirements, cost effects of plans, and BIM modelling.*	*This time excavation work and the bypass of a tunnel, but usually topics concern the design of the facility or plot.*
Setting		

3.3 Data Analysis Process

The data analysis proceeded in five phases. First, we (three researchers) watched the two meeting videos and discussed them to agree on how to proceed with the data analysis. Second, each researcher watched the videos again on their own and searched for facilitation activities taking place in the videos. Third, each researcher grouped the found facilitation activities following the category of Huxman and Cropper (1994): 1) managing content, 2) managing group process and 3) taking part to a decision with expertise knowledge. 1) *Managing content* meant the activities when the facilitator manages what is discussed and for how long. 2) *Managing group process* referred to managing the ways the issues were dealt with. 3) *Taking part to content by managing with facilitator's expertise* referred to activities where the facilitator's own expertise was used to take part in making decisions. Fourth, to understand the three categories more profoundly we used Clawson and Bostrom's (1996) findings on facilitation activities as described in the theory section. Using these facilitation activities, we performed further analysis round as collating original categorization to more detailed sub-activity level. Finally, we compared the two meetings to identify which of the facilitation activities were emphasized in each meeting. The overall analysis process followed deductive video analysis approach by Derry et al. 2010. The results are presented in the following section.

4. Results

The observed meetings differed both by the nature of the meeting and the facilitation activities found in the meeting. Table 2 presents the facilitation activities found in each of the meetings. Activities are categorized into three areas of contribution by Huxham and Cropper (1994) and further classified under sub-activities found in the literature.

Table 2: Comparison of facilitator roles between the formal and informal meeting

Area of contribution	***Sub-activity***	***Formal meeting facilitation***	***Informal meeting facilitation***
Facilitating content	*Leading the thinking and discussion*	*Facilitator (project manager, GC) guides the conversation with a predefined agenda (security risk assessment excel, meeting minutes document)* *... ends a conversation as irrelevant in the meeting* *... tells that we do not need to discuss this because it is written how it should be done*	*Facilitator (project engineer, GC) states the topic of the meeting (excavation work and renovation of the tunnel)* *... takes the discussion to the next topic when needed* *... interrupts a "wild" discussion by increasing the tone and says it will be continued later on*
	Collecting information on problem	*... asks further questions concerning the project*	*... asks further questions* *... goes through questions from the list*
	Encouraging multiple perspectives	*... makes sure everything is said concerning an issue by asking if anyone has anything to add*	*... asks if new knowledge is still needed on an issue*
	Presenting information to the group	*... uses materials to elaborate the understanding (brochure and material of the façade, 2D drawing)*	*... uses materials to elaborate the understanding (2D drawings on screen and paper, photos)*
	Clarifying and integrating knowledge		*... synthesizes the talk and takes notes* *... asks if the knowledge is certain* *... clarifies the distribution of work*
	COMPARISON	*Emphasis on leading the thinking and discussion*	*Emphasis on clarifying and integrating knowledge*
Facilitating group process	*Managing group interaction*	*Facilitator (project manager, GC) was called formally as "Chairman" by others* *... sounded tough and formal when addressing participants*	*Facilitator (project engineer, GC) lets others talk freely and think together*

	Creating participative environment	*... asks everyone to share their key points one at a time but not reading from the document (as "everyone knows how to read")*	*... appoints one participant to start with the status update* *... asks if someone wants to say something*
	Tracking and responding to the needs of the group	*... says no need to repeat things that were said earlier in the meeting* *... asks if an issue should be written down (project engineer takes notes)*	*... is friendly and calm, confirms often* *... asks if the information can be sent via email to another designer*
	Managing conflict and negative emotions	*... makes no jokes (formal and serious atmosphere)*	*... makes few jokes (less formal atmosphere, some laughing in the beginning)*
	Applying well-suited technology	*... uses projector to show relevant documents*	*... uses a projector to show relevant documents* *... uses laser pointer to point out relevant areas on the screen*
	COMPARISON	*Emphasis on managing group interaction*	*Emphasis on creating participative environment and applying well-suited technology*
Taking part to content by facilitating with expertise	*Giving input with own expertise*	*Facilitator (project manager, GC) answers questions by CM consultant (about design review, maintenance manual, site fences)* *... defines that the tunnel is more acute issue* *... comments risks in the security risk assessment document*	*Facilitator (project engineer, GC) says this is important knowledge on a matter* *... interrupts to say that energy company will not give permission and asks further details*
	COMPARISON	*More input with expertise*	*Less input with expertise*

The formal meeting was an official design meeting held bi-weekly and facilitated by the project manager from the general contractor. The meeting had a predefined agenda in the form of meeting minutes and the facilitator's role was to make sure that all topics on the agenda were covered during the meeting. The nature of the discussion was more expressive rather than conversational as the participants mostly shared their own status updates under each topic. In *facilitating content*, the emphasis was on leading the thinking and discussion. The facilitator guided the conversation with the predefined agenda and ended irrelevant topics fast to keep the discussion on track and on time. Regarding *facilitating group process*, the emphasis was on managing group interaction. The interaction was formal and even tough at times; some participants called the facilitator formally as "Chairman" when addressing the meeting. Finally with *taking part to content by facilitating with expertise*, the facilitator gave more input with her own expertise when compared to the facilitator of the informal meeting.

The informal meeting was a designer collaboration meeting for designers on an as-needed basis and facilitated by the project engineer from the general contractor. The meeting had a predefined topic but the nature of the discussion was casual and interactive. The participants could bring various issues to the conversation and often used paper drawings or 3D models on the screen to elaborate the understanding. Regarding *facilitating content*, the emphasis was on clarifying and integrating knowledge. The facilitator synthesized the talk, took notes and clarified the distribution of work between the designers. In *facilitating group process*, the emphasis was on creating a participative environment and applying well-suited technology. The facilitator appointed participants to share their perspectives and often asked if someone wanted to say something on an issue. He also used a laser pointer to point out relevant areas on screen as 2D drawings and 3D models were often difficult to interpret. Finally, with *taking part to content by facilitating expertise*, the facilitator gave little input with his own expertise but rather let the participants think freely and in collaboration.

In addition to the facilitation activities described by Huxham and Cropper's (1994) categories, we also observed some other elements that influenced the interaction in the meetings. Both meetings were rather long and did not have any breaks to energize the participants. The formal meeting used some methods to build rapport among the participants. First, they had a rule that the person, who comes late to the meeting, will bring some pastry for others to the next meeting. This seemed to work as a nice icebreaker to start the meeting. Second, the client assessed the project team with Plus/Delta at the end of the meeting. This gave the client an opportunity to articulate to others what they appreciated the most (plusses) and what they thought needed improvement (deltas) in the project. The informal meeting did not use any specific methods for rapport building but there was more joking and laughing at least in the beginning of the meeting.

5. Discussion

Huxham and Cropper's (1994) categories are based on single client consultancy situations. In a case of collaboration between organizations, facilitation might be even more important because individuals from different companies and professions might have different communication practices. The findings show that facilitating the *content* in the meetings was mostly about leading the conversation, clarifying and integrating knowledge. This area of facilitation concerns what is discussed in the meeting (Huxham and Cropper, 1994). When the facilitator decides which topics are to be discussed, s/he exercises her/his power. To create a collaborative meeting, the facilitator should make sure that the discussed topics include important issues from the viewpoints of all stakeholders. Integrating knowledge potentially also aids collaboration as it can enhance common understanding.

Our findings on facilitating *group process* were mostly about managing group interaction and creating a participative environment as well as applying technology. Facilitating group process can create better relationships and trust among the participants by managing, for example, how interaction is performed. Good collaboration usually demands to create trust and relationships between individuals, especially in inter-organisational context (Batt and Purchase, 2004). Facilitation can enhance relations by managing active and pleasant interaction. Thus, facilitation of group process in collaborative projects should emphasize active interaction between individuals. The facilitator can also emphasize the relationships by offering open and friendly atmosphere.

Finally, our findings on facilitation *with expertise* show that the facilitator as a representative of the general contractor had expert knowledge and could intervene with this expertise to decisions. When one of the company representatives acts as a facilitator, there is a danger that her/his perspective is highlighted more than other companies' perspectives. An outsider should act as a facilitator if this danger needs to be avoided. In the studied meetings, the general contractor as a facilitator seemed to work without significant problems.

Overall, facilitator seemed to help to create more effective meetings. Also, facilitation seemed to influence the aspects of collaboration and trust which are valued in the specific project. The facilitator role should be given to a person who is skilled in enhancing collaborative practices that are structured socially. This could be especially important in projects where deep collaboration is needed on different levels. The analysis of the results reveals differences between these two meetings. The meetings can be arranged and performed in different ways. It is good to reflect what kind of facilitation would be suitable for the objectives of the meeting and purposes of the project. The findings suggest that facilitation methods depend on the purpose and context of the meeting.

6. Conclusions

Our study presents the performed facilitation practices in two types of meetings and compares them. Facilitation has been studied in different contexts, but few studies have considered facilitation as an important part of construction project management. At its best, facilitation in an alliance construction project helps the project parties to make better decisions and design solutions. However, based on the study it can be concluded that the full potential of facilitation is not always used. When the facilitation was creating effectiveness in the meetings, it could have been used more reflectively to create collaborative and efficient meetings. The facilitators in the studied project were not trained professionally for facilitation practices. Training on facilitation skills and methods could create more purposeful and useful facilitation. Additionally, reflection and planning concerning facilitation can create purposeful facilitation for the specific meeting or project, instead of only following general facilitation guidelines.

For practitioners, our results suggest that facilitation might bring benefits in inter-organizational meetings. The facilitation should be in line with the objectives and values of the specific meeting and overall project. In alliance projects, collaborative decision making can be enhanced by facilitation. In a meeting, practical issues such as breaks, working technology and the functionality of space also play a significant role and should be taken into account as part of the facilitator's role. Future research could measure what kind of financial benefits the facilitation could offer in the alliance project. Also, more research is needed to understand which kind of facilitation techniques and activities could enhance collaboration in construction projects. In addition to the facilitation activities, it would be useful to identify critical project events where facilitation can enhance project performance.

This paper is an important start for the discussion on the benefits and drawbacks of facilitation in the construction project context. The full potential of facilitation is not yet known, but it seems that collaborative work and relational projects are becoming more common in the construction sector. The use of building information modelling requires even more intensive collaboration between construction project parties. The sector is characterized by fragmentation and this has not been a fruitful platform for learning collaboration skills. As facilitation is a way to promote good collaborative work practices between construction project parties, the use of facilitators and training facilitation methods will probably grow within the construction sector in the future.

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Is it faster and is that measurable?
A Quantitative Research Into The Time Effects Of Integrated Contract Forms In Development Processes

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Abstract

Integrated contract forms are seen as a solution to various problems in the construction industry. Some studies found that building projects delivered with integrated contract forms show better performances on time, cost and quality. Other studies state that projects developed with integrated contract forms do not perform better on time, cost or quality when compared to projects developed with traditional contract forms. Conclusions from the studies analyzed vary and these studies have their shortcomings. This study reflects critically on these previous studies in order to promote better research and to reveal a small piece of the puzzle called 'integrated contract forms'. Empirical findings from a case control study of thirty secondary schools indicate that the use of integrated contract forms do not provide the expected benefits to time performance when compared to traditional contract forms. The data was collected from project managers via online questionnaires. However, when there is above average time pressure during the development process, parties tend to choose for integrated contracts because they assume that projects developed in this way have faster processes than projects developed with traditional contracts.

Keywords: integrated contract forms, time effects, empirical study, case control study, statistical analysis.

1. Introduction

Cost- and time overruns are unfortunately very common in the construction industry (Flyvbjerg, 2011). As a result there is high pressure from society to better control budgets and time schedules. At the same time, governments and the construction industry strongly steer on cost and time savings, as well as higher quality for buildings (Meng, 2012; Visscher, 2011). Other than traditional contract forms are thought to better enable control of budgets and schedules and therefore enhance quality. In the traditional contract form, which is still commonly used, the design phase and execution phase are procured to different parties (Masterman, 2002). The most common integrated contract form is the Design & Build contract form wherein the design phase and construction phase are procured in one procurement to one party or to a consortium. Over the last years Design, Build & Maintenance and Design, Build, Maintenance & Operate contract forms are emerging. In these contract forms maintenance and operation actions are also included in the contract which makes the contracting party also responsible for the exploitation of the building and the reward is a performance- related pay (Masterman, 2002).

Many studies have analyzed the effects of integrated contract forms in construction, all with different outcomes. Some of these studies found that the use of integrated contract forms leads to lower cost buildings, a faster development process and higher quality results (Bennett, Pothecary, & Robinson, 1996; Hale, Shrestha, Gibson, & Migliaccio, 2009; Konchar & Sanvido, 1998). While another study found that projects delivered with integrated contract forms have faster processes, but were not always cheaper (Vasters et al., 2010). In contrast, Ibbs found that projects developed with integrated contract forms do not perform significantly better on time and cost aspects compared to projects delivered with traditional contract forms (Ibbs, Kwak, Ng, & Odabasi, 2003). Conclusions from these studies vary, which may be partly due to their methodological weaknesses. Even in studies where the methodology is strong, results cannot be compared with each other because of the different definitions of measures used. As a result, the effects of integrated contract forms are unclear. Different definitions for time and cost are used in different studies, hence studies have different conclusions and outcomes of studies cannot be compared with each other. Weak methodology of studies is caused by different factors. First, the used samples are often too small or too heterogeneous and there was selection bias present in the sample. Secondly, studies are often based on expert judgements, resulting in socially desirable answers. Last, it can be mentioned the description of the methodology used often is weak.

According to Nyström (2007) studies comparing different contract forms must meet three requirements. First, the study must be based on project data and not on expert judgments. Secondly, the study must be based on comparative analyses. Finally, the study must address project variables other than contract form, potentially influencing the outcome. Since one of the flaws in previous studies concerns the too large heterogeneity of the data, this study focusses on secondary schools in the Netherlands. These schools are assumed a homogenous building type due to their similar appearance, purpose and funding. In the Netherlands, the (re)construction of secondary schools is publicly funded. This homogeneity makes them the better research sample for this study. The aim of this paper is to gain better insights into the effect of the process contract form, on the build outcome, in terms of time, by reducing weaknesses of previous studies. Specifically, the study elaborates on the research question: *"Do projects with integrated contract forms perform better on time aspects than projects with traditional contract forms?"*

The study's focus is on time aspects as the other outcomes, appearance, purpose and funding, are similar for secondary schools. To answer the research question a literature review was conducted followed by a case control study. Data was collected by online questionnaires completed by thirty project managers who were involved in the development of thirty secondary schools in the Netherlands. In the questionnaire project managers were asked to share project data only, the questionnaire did not elaborate on their expert opinion. The literature review provided input for the questionnaire that was developed as part of this study. The data was analyzed statistically to answer the research question. After that, findings were discussed in relation to prior literature, followed by conclusions and discussion of theoretical contributions.

2. Literature Review

Construction projects use a variety of contract forms to control project outcomes, some of which evolved over the last few decades. Research methods have varied across studies from project specific case studies, through opinion surveys, to empirical studies. Results of the most important empirical studies, which analyzed the relation between process and product, are reviewed here.

Bennett studied 332 projects and found that the construction speed (m^2 built per month) of D&B projects is 12% higher compared to traditional projects. The total project time, including design and construction, is 30% shorter for D&B projects than for projects with a traditional contract form. He found that 75% of D&B projects were delivered with a maximum budget overrun of 5%. While 63% of the traditional projects were delivered with a maximum budget overrun of 5%. D&B projects were at least 13% cheaper than traditional projects (Bennett et al., 1996).

Vasters partly disagreed with Bennett. He studied cost and time efficiency of six projects. He found that projects with a D&C contract show better time efficiency but not better cost efficiency (Vasters et al., 2010).

Hale is partly contrasting with Vasters. Hale's focus was on 77 military barracks of the US Navy. His conclusion was that projects with D&B contracts have shorter project times compared to projects with traditional contracts. He also concluded that projects with D&B contracts have less cost and time overruns than projects with traditional contracts (Hale et al., 2009).

Ibbs findings were partly inconsistent with Hale's. From his research Ibbs concluded that projects delivered with D&B contracts did not perform significantly better than projects delivered with traditional contracts. D&B projects have slightly less time overruns, not significant less, compared to projects with a traditional contract. And no cost savings were measured for D&B (Ibbs et al., 2003).

Konchar and Sanvido studied 351 building projects and concluded that projects delivered with D&B contracts performed better than projects with traditional contracts (Konchar & Sanvido, 1998).

By evaluating previous studies it became clear that different definitions for the variable 'time' were used. As summarized in table 1, the studies measured 'time' as building speed, total project time, delivery speed, time efficiency and schedule growth (Bennett et al., 1996; Hale et al., 2009; Ibbs et al., 2003; Konchar & Sanvido, 1998; Vasters et al., 2010). The studies also defined some variables differently.

Definition of the variable time (Time performance).	Explanation	Conclusion
Speed (m^2/time) (Bennett et al., 1996; Konchar & Sanvido, 1998).	**Construction speed=** [(net floor space/end date construction phase – start date construction phase)/30] in (m^2/month) **Delivery speed=** net floor space / (total actual project time/30) in (m^2/month)	The construction speed of D&B projects is 12% less than traditional projects (Bennett et al., 1996). The construction speed of D&B projects is at least 12% less compared to traditional projects (Konchar & Sanvido, 1998).
Time efficiency (Vasters et al., 2009).	**Time efficiency=** standard project time / total actual project time	D&C projects demonstrate a 52% higher time efficiency than traditional projects (Vasters et al., 2010).
Project time (Bennett et al., 1996; Hale et al., 2009; Konchar & Sanvido, 1998).	**Total actual project time=** date of project completion – date of the first contract action	D&B projects have shorter project times than traditional projects (Hale et al., 2009). The total project time of a project, design and construction time included, is 30% faster by D&B projects compared to traditional projects (Bennett et al., 1996). D&B projects are at least 33,5% faster delivered than traditional projects (Konchar & Sanvido, 1998).
Time schedule versus real project time (Bennett et al., 1996; Hale et al., 2009; Ibbs et al., 2003; Konchar & Sanvido, 1998).	**Change in total schedule (%)** = [(total actual project time – total as- planned project time) / total as- planned project time] * 100 **Change in design schedule** (%) = [(total design time – total as- planned design time) / total as- planned design time] * 100 **Change in construction schedule (%)** = [(total construction time – total as- planned construction time) / total as- planned construction time] * 100	It is 50% more likely that D&B projects are delivered on time compared to traditional projects (Bennett et al., 1996). D&B projects have less schedule growth than traditional projects (Hale et al., 2009). In absolute terms, D&B projects have 7,7% schedule growth compared to the planned schedule. Traditional projects have 8,4% schedule growth compared to the planned schedule. In relative terms, D&B projects have 4,1% schedule growth compared to the planned schedule. Traditional projects have 6,5% schedule growth compared to the planned schedule. These are no significant results. (Ibbs et al., 2003). D&B projects have at least 11,37% less schedule growth compared to traditional projects (Konchar & Sanvido, 1998)

Table 1: Used definitions of variables and conclusions of previous studies

In this paragraph some critical remarks on the used methodology of previous studies as listed in table 1, are identified and it is described how these issues are addressed.

In Bennett et al, (1996) report it is not clear how the sample is composed. A very big heterogeneous sample is used, but the report does not describe if smaller homogenous samples are used for the analysis. It is not possible to perform the same study, which makes this study less reliable. Also, the sample is composed with projects from the database of the Glenigan Group. From the report it is not possible to determine whether there was a selection bias. These two shortcomings are diminished in this study by composing a homogenous sample, also the way data is collected is described very precise and in a way that could be repeated. The sample used in Vasters study (Vasters et al., 2010) is too small (N=6). A bigger sample is composed in

this study which makes statistical analyses more meaningful. The variable ‘time efficiency’ as used by Vasters is time consuming to calculate, therefore in this study the variable ‘time efficiency’ is not used. Ibbs’s et al. (2003) sample exists of different building types from different countries, as a result the sample is very heterogeneous. The focus of this study is on the variable ‘as planned project time versus real project time’ which makes it not absolutely necessary to have a homogenous sample. But different countries have different views on schedules and contract forms, which makes the differences between countries too big. Therefore, projects in this study’s sample were built in one country and over a short time span.
Konchar and Sanvido’s study (Konchar and Sanvido, 1998) consists of 351 projects and more than 100 variables are used to compare project performances. Due to the large number of variables (+100) there might be the danger of data dredging. The process of data dredging is the use of a single sample by exhaustively searching for combinations of variables that might show correlation (Field, 2009). In this study fewer variables were used to minimize the chance of data dredging.
Last, Hale’s study (Hale et al., 2009) is evaluated, no shortcomings were identified in this study.

3. Research Methods

When collecting and analyzing data from development processes, a case control study is especially appropriate to measure the performance of processes. In the study two types of contract forms are compared with each other, on the one hand projects with traditional contracts on the other hand projects with integrated contracts. By identifying gaps and modifying prior work, this study aims to extend and elaborate on existing literature for performance measurement of different contract forms.

Forty six secondary school projects were selected through random sampling. The purpose of random sampling is to select projects completely randomly. Constraints for these projects are the eligibility criteria. Schools included in the sample must meet eligibility criteria to give greater confidence that results are caused by the intervention between process and outcome and not by other factors. Three eligibility criteria were specified; one building houses one school; the buildings were delivered between January 2008 and January 2015; the buildings are newly constructed buildings, renovation or transformation projects or an expansion of the existing building. If the building was a renovation, transformation or expansion project then the renovated, transformed or expanded floor space has to be 50% or more of the existing total floor space.

Data was collected through online questionnaires filled in by project managers hired by the client. Furthermore, the outcomes of processes in project management are measured in terms of cost, time and quality, these three control aspects form a triangle (Winch, 2010). The idea behind the triangle is that change in one of the control aspects has influence on the other control aspects. If, for example a project has to be completed in a shorter period of time, the costs are higher. Or, if the costs are lower, the quality is also lower. For clarity, cost, time and quality are interdependent. When the theory behind the triangle is applied to this study, the focus is limited to time aspects. This limitation is the reason secondary schools are chosen as the study subjects.

As mentioned earlier, secondary schools in the Netherlands receive the same funding for buildings; as a result the control aspects of 'cost' and 'quality' are more or less constant among this building type, which makes it possible to measure performance by time aspects. Therefore this study focused on the 'time' variable.

As mentioned, the outcome variables are the time performances. In the literature review four time performances are identified, namely 'Speed' (m^2/time), 'Time Efficiency', 'Project Time' and 'Time Schedule versus Real Project Time' (Bennett et al., 1996; Hale et al., 2009; Ibbs et al., 2003; Konchar & Sanvido, 1998; Vasters et al., 2010). 'Time efficiency' as used by Vasters is ignored in this study due to the time and effort needed to calculate this variable. 'Speed' and 'Project Time', as used by Bennett, Konchar and Hale, are not very reliable variables to measure project performance. These variables are project dependent; their outcome depends strongly on the construction type and circumstances of the project. As a result, the most appropriate variable to measure process performance is by comparing the planned schedule with the real project time. To calculate this variable a range of questions were asked to determine what the planned schedule for different phases was, and what the real project time for the same phases was. Nevertheless 'Speed' and 'Project Time' are also measured to have a complete picture.
The comprehensive online questionnaire included questions about a large number of subjects, namely:

- General questions about the project (m^2, project type, construction type, lay out of the plan and involved parties).
- Procurement method and contract form - Which procurement method and contract form were used and why? On the basis of which specifications was the project procured?
- Time schedule - What was the planned schedule for the different phases within the development process?
- Actual time spent - What was the actual time spent on the different phases of the development process?
- Additional information about the budget, delays, causes of delays, unforeseen circumstances, the role of the architect after the procurement, etc.

In addition to the process parameters and outcome variables, explanatory variables were set up. It is assumed that the contract form has an effect on the explanatory variables. Many explanatory variables were included in this study. The most important explanatory variables are:

- The presence or absence of above average time pressure on the development process.
- The number of parties involved during the preparation, design and execution phase.
- Reasons for choosing the contract form.
- If there is a presumption by the respondent about the kind of contract form and the speed of the development process, then the following question was asked: Was the choice for the contract form partly determined by the desired speed for the development process?

- Is the respondent willing to use the contract form also in the future for projects like the questioned project?
- Questions about the planned schedule, namely; the phase wherein the schedule was set up, how many times the schedule was changed during the development process, the aim of the schedule and commitment to the schedule.

Projectmanagers involved in the development process filled in the questionnaires with only project data (how long, how much, when, what, why etc.). Therefore expert opinions and measuring client/ projectmanager satisfaction were avoided.
To ensure the questionnaire focused on the correct variables, process parameters and outcome variables were set up. These parameters and variables were translated into questions in the questionnaires. Process parameters are the mechanisms which may influence the process performance of projects. This study focused on the influence of the contract form on the process performance of the project: the process parameter is the contract form and the outcome variables are the process performances on time.

For the contract form nine options are distinguished, namely the traditional contract form, the building team, the Design & Build or Design & Construct contract form (these are equivalents in the Netherlands), the Engineer & Build or Engineer & Construct contract form, the Design, Build & Maintain contract form, the Design, Build, Finance & Maintain contract form, the Design, Build, Maintain & Operate contract form and the Design, Build, Finance, Maintain & Operate contract form.
For analysis of the results the contract form is reclassified into two options: integrated contract form and not integrated contract form (which is the traditional contract form). This classification is based on whether the design and execution phase are procured within one contract to one party or to a consortium or are procured with two contracts, one for design and one for execution, to two different parties. The new classification categorizes 'the traditional contract form' and 'the building team' as 'traditional contract form/ not integrated contract form', the other contract forms form the category 'integrated contract form'.

Collected data was analyzed by statistical models with SPSS version 22. Exploratory univariate analyses were followed by multivariate linear regression models with bootstrapping. Univariate analysis of variables gave a global insight into the relationship between variables (Field, 2009). This analysis tested if the relationship found between variables is significant or based on coincidence.

This study applied a significance level of 95% ($p \leq 0.05$), which means that the probability that the observed values would be found without a relationship between the variables is smaller than 5% (Field, 2009). For logistic regression modelling the selection of potential variables occurred using the approach recommended by Hosmer and Lemeshow. Their approach is a purposeful selection process which begins by univariate analyses of each variable. Any variable having a significant univariate test at some arbitrary level is selected as a candidate for the logistic

regression model, any variable with a p-value lower than 0,3 is eligible for inclusion in the model (Hosmer, Lemeshow, & Sturdivant, 2013). Logistic regression models were developed to explain multivariate comparisons between contract forms. The logistic regression model predicts the outcome of the process parameter based on one or more outcome variables. These outcome variables are the variables from the 'significant group' and the 'hopeful group'. Bootstrapping is an efficient way to ensure that logistic regression models are reliable and will produce accurate results.
By resampling with replacements from the original data sample thousands of alternative versions of the data set were created. This made the results more reliable and accurate, also the impact of outliers was reduced which helps to ensure the stability and reliability of models (Field, 2009). In this study bootstrapping was applied because of the small sample size (N=30). The sample size was small but large enough for univariate logistic regression analysis. By applying the bootstrap method for the logistic regression model the results from this study became more reliable and accurate compared to not using the bootstrap method.

4. Results

Forty six questionnaires were sent to project managers. Thirty questionnaires were filled in and returned, which is a net response rate of 65%. Prior to sending out the questionnaires the respondents were asked if they would agree to collaborate, hence the high response rate.

Of the thirty projects surveyed, 53.3% were developed using traditional contract forms and 46.7% were developed using integrated contract forms (Design & Build, Design & Construct, Engineer & Build, Engineer & Construct and Design, Build & Maintain). The projects have a good spread across the Netherlands. 86.7% of the projects were completely new constructed buildings, while 13.3% of the surveyed projects were renovation, expansion or transformation projects. The majority of the projects (82%) were delivered between 2010 and 2013. Projects ranged in size from 1.518 m^2 to 26.500 m^2 . The mean of the project size is 9.130 m^2 with a standard deviation of 5.535 m^2. Unit costs (€/m^2) ranged from € 874 /m^2 to € 2153 /m^2. The mean of the unit cost is € 1447/m^2 with a standard deviation of € 367/m^2.
As mentioned earlier, the logistic regression model explains the contract form from differences in outcome variables.
Final modelling turned out to be difficult, as many of the questions are to be considered as describing the type of contract used. Any attempts to explain differences in time related outcomes were not distinguishing;

- Projects with integrated contract forms do not have significantly faster construction and delivery speed compared to projects delivered with traditional contract forms.
- Projects with integrated contract forms do not have significantly shorter project times.
- Projects with integrated contract forms do not meet planned schedules significantly more often compared to projects with traditional contract forms.

As a result, it can be concluded that projects with integrated contract forms do not perform better on time aspects compared to projects with traditional contract forms.

Thereafter a model was fitted using the presence of above average time pressure in the development process as an outcome. It then turned out that time pressure differs between processes covered by traditional and integrated contracts. More particularly, the presence of above average time pressure was found to be differing according to:

Variable	**P-value**
The choice for the contract form is influenced by the desired speed for the development process.	0.00
The presence of the contractor during the initiative, definition and design phase.	0.00
The kind of specification documents.	0.00
The contract form.	0.00
Procured on the basis of Lowest Price or MEAT (Most Economically Advantageous Tender).	0.03
The number of involved parties during the initiative and definition phase.	0.09
Control the capacity of the involved parties and commit to the schedule.	0.10
The phase in which the schedule is drawn up.	0.10
The number of involved parties during the design phase.	0.20
The kind of procurement procedure.	0.25
Adjusting the time schedule during the process.	0.26
The number of involved parties during the construction phase.	0.27

Table 2: Univariate analysis which were used as input in the logistic regression model with 'the presence of above average tim pressure in the development process'.

The final model was shaped by stepwise omitting variables that were not related to time pressure in addition to variables which were more significant related to time pressure, and starting with the one with the highest p- value (the number of parties involved during the construction phase, p- value: 0.27). Table 3 summarizes the final model, whereas table 4 shows the most eligible variables for inclusion in the final model. Since the question addresses the whole development process, time pressure concerns the initiative, design and construction phase.

Output of the bootstrapped logistic regression model for the variable 'the presence of above average time pressure on the development process'.						
Variable	**B**	**Odds ratio**	**S.E.**	**Sig.**	**Lower**	**Upper**
The choice for the contract form is influenced by the desired speed for the development process.	2.972	19.531	18.154	0.007	-18.777	56.127
The presence of the contractor during the initiative, definition and design phase.	1.966	7.142	16.040	0.014	-19.411	38.560
The kind of procurement procedure.	-1.852	0.157	16.631	0.017	-52.136	17.579
Constant	0.890	2.435	8.384	0.068	-8.503	26.349

Table 3: Final logistic regression model with process parameter: the presence of above average time pressure on the development process.

Univariate analyses	P-value
The choice for integrated contract forms is also influenced by the desired speed for the development process.	0,003
There is more often above average time pressure during the development process when projects are delivered with integrated contract forms.	0,035

Table 4. Outcome of the most relevant univariate analyses in addition to the final model.

5. Discussion and Conclusions

The purpose of this study was to get more precise insights into the effects of the contract form on the outcome in terms of cost, time and quality. By narrowing down the scope of this study on time aspects the research question became: *"Do projects with integrated contract forms perform better on time aspects than projects with traditional contract forms?"*

This study has shown that projects delivered with integrated contract forms do not perform significantly better on time aspects compared to projects delivered with traditional contract forms. This means that projects with integrated contract forms:
(i) were not developed significantly faster than projects with traditional contract forms.
(ii) did not meet planned schedules significantly more often than projects developed with traditional contract forms.
However, the study has shown that when there is above average time pressure on development processes, parties choose for integrated contract forms significantly more often (p- value: 0.035) because involved parties assume that projects developed with integrated contract forms are faster developed than projects developed with traditional contract forms (p- value: 0.007). But based on this study, the assumption that integrated projects are faster developed or enable greater control over time schedules is not supported.

There was the assumption that the results may be biased by renovation, expansion and transformation projects (13.3% of the data sample). To exclude doubts about the results, all analyses were also conducted for only the newly constructed projects, without the renovation, expansion and transformation projects, but these results did not differ significantly compared to the results from the original data sample.
Nevertheless, the results should be discussed in relation to the different penalty clauses on time overruns for traditional and integrated contract forms, because this may provide new insights.
In the Netherlands the UAC- 2012 (Uniform Administrative Conditions for the Execution of Works and Technical Installation Works 2012) regulates the contractual relationship between the client and contractor in a building process for traditional contract forms. Normally the client and contractor include project specific fines for time overruns in the contract documents. In absence of such project specific fines the UAC- 2012 describes a fine for time overruns which is € 60,- for each day overrun. The UAC- IC- 2005 (Uniform Administrative Conditions for Integrated Contracts 2005) is the same kind of regulation as the UAC- 2012, but for integrated contract forms. But the UAC-IC-2005 does not include any prescribed fines for time overruns. The client and the contractor have to include fines for time overruns in the contract documents.

Scope creep, i.e. extra works added, does not occur significantly more often by projects with traditional contract forms. Therefore it is not expected that projects with traditional contract forms do not meet planned time schedules compared to projects with integrated contract forms.
Almost always project specific fines in contract documents for both, integrated and traditional, contract forms are much more than the described € 60,- per day because the losses for the client are almost always more than € 60,- per day. Fines in the range of € 1000,- per day are not uncommon. But fines have to be proportionate with the actual damage suffered by the client and the reasonable ability of the contractor to pay.

To sum up, the size of fines is highly project specific, but as found in this study, parties choose significantly more often for integrated contract forms when there is above average time pressure on the development process and they assume that integrated processes have time savings. As a result it's more likely that integrated projects have higher fines when time overruns occur. This is an important issue as it shows the possibility of bias being present in studies using contract form as a sampling criterion: when time overruns are stricter penalized in integrated contract forms it makes sense that they will occur less when compared to using traditional contract forms, because contractors will make more effort to ensure that no time overruns occur.
However this study did not find less time overruns when using integrated contract forms. In contrast, almost all previous studies found that time overruns occur less frequently when using integrated contract forms. This argue may lie in the presence of penalty clauses rather than in the characteristics of the process of integrated contract forms. The topic of penalty clauses is not related to time overruns and contract forms in other studies. Further research is needed to get better insights about penalty clauses within different contract forms and time overruns.

Almost all studies discussed in the literature review did show better performances on time for integrated contract forms compared to traditional contract forms. The results of this study align with Ibbs' (2013) findings; projects developed with integrated contract forms do not perform significantly better on time aspects compared to projects developed with traditional contract forms. One argument for this great difference between findings is that previous studies are conducted between 1996 and 2009. Construction processes of buildings became more and more complex over the past decade due to the presence of more stakeholders, more and stricter building requirements and more and stricter regulations for procurement procedures. As a result construction processes from the '90 and early 00's vary a lot compared to processes nowadays and it is not so plausible to compare these studies with recent studies. In this line of reasoning it is legitimate that time savings found in 'older' studies cannot be found in recent construction processes, due to the more complex circumstances involved when developing buildings. This complexity makes that time savings became negligible and therefore are not measured.

This paper offered a performance-based, empirical study of two groups of contract forms. The study achieved several milestones in the field of research methodology and added state of the art findings to the body of knowledge of integrated contract forms.
This study was able to diminish shortcomings of previous research, which resulted in a more reliable study when compared to previous studies.
First, a homogenous data sample with objective data that was not biased by the selection of the

projects and expert opinions was composed. Second, transparency regarding the research methodology and the data collection process increases the reliability of this study. Last, this study's reliability is also enhanced by using the bootstrap method for the logistic regression model, which generates more reliable results.

Nevertheless, this study also has its shortcomings. There was the assumption that due to the similiar public funding for secondary schools, the sample is homogenous on the aspect of cost per m2. But analyses show a wide spread in costs per m2, this is caused due to extra funding available for schools by municipalities and school boards. Therefore the sample is less homogenous on the aspect of cost per m2 , but still homogenous due to similar appearance and purpose. Furthermore, this study's purpose was to study time aspects of development processes from the start of the initiative phase up to the end of the construction phase, but this was not possible due to the limited involvement of respondents during the initiative and definition phase (together the preparation phase) of projects.
Almost all respondents were only involved during the design and construction phase and not during the preparation phase. As a result no data is collected about the preparation phase. But when studying time aspects, and therefore time savings, it is essential to collect data about the preparation phase, because there is the widely shared presumption that integrated projects have a significant longer preparation phase and a significant shorter design and construction phase compared to traditional projects. This study was not able to study this presumption comprehensive, though a part of this presumption was subject of this study.

To conclude, this study measured performance as only being time aspects and found no significant better performances for integrated contract forms. This contradicts with many assumptions and statements.

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Equipment Productivity in Infrastructure Projects in GCC Countries

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Abstract

Good site management in construction must continually pursue the efficient utilization and allocation of labour, material and equipment. These elements are all essential in the pursuit of the Gulf Cooperation Council's (GCC's) vision for the future. Improvement of equipment productivity should be a considerable concern for control of infrastructure projects. In GCC countries, whilst the direct unit cost of equipment per hour in terms of cost rates paid may not be significantly high, findings indicate indirect costs are significant include hiring, transporting, storage, technical support, supervision and insurances.

Productivity in construction in analytical methods is defined as unit output per hour. It is important to note that equipment productivity is a measure of the overall effectiveness of organisation systems in utilizing labour, equipment and capital to convert labour efforts into useful output, and is not a measure of the capabilities of labour alone. Efficiency and effectiveness of organisation systems in utilizing resources will lead to minimizing construction waste. The selection of the appropriate type and size of construction equipment often affects the required amount of time and effort and thus productivity.

Research findings indicate that construction equipment is used to perform essentially repetitive operations, and can be classified according to its functions into: (a) that requiring operators such as cranes and graders which stay within the confines of construction sites, and (b) haulers such as dump trucks and ready mixed vehicles which transport materials to and from sites.

The aim of this paper is to identify and analyse major and common factors affecting equipment productivity on construction projects. A comprehensive literature review and factors recommended by authors from previous studies will be the foundation of the paper. The method for the study was a quantitative questionnaire supported by exploratory qualitative interviews with industry practitioners in GCC countries, and the survey findings indicates the major factor impacting equipment productivity is rework due to external factors like design changes or/and scope change.

Keywords: Construction, Productivity, Equipment, Factors

1. Introduction

Productivity in construction is often broadly defined as output per labour/equipment hour. Since labour/equipment constitutes a large part of construction cost and the quantity of labour/equipment hours in performing tasks in construction is more susceptible to the influence of management than are materials or capital, this productivity measure is often referred to as 'labour/equipment productivity'. However, it is important to note that labour/equipment productivity is a measure of the overall effectiveness of organization systems in utilizing its resource and capital to convert into useful output, and is not a measure of the capabilities of labour alone. For example, by investing in new equipment to perform certain tasks in construction, output may be increased for the same number of labour hours, thus resulting in higher labour productivity. An increase in productivity was noted prior to the mid-1960s in the construction industry (Stall, 1983). Later, a decline in productivity became an issue of great concern in the construction all over the world. In 1968, the Construction Roundtable was established due to concern about the increased cost of construction resulting from an increase in inflation and a significant decline in construction productivity (Thomas and Kramer, 1988). It was necessary to implement, as far as possible, industry-wide principles of production throughout the construction process. It was argued that careful adaptation would be required, to implement knowledge and experience gained in manufacturing to construction (Alarcon and Borcherding, 1991).

Past studies and research show that a number of factors affect productivity, but there are still unidentified factors that need to be further studied even in developed countries (Makulsawatudom and Emsley, 2002). A study by Polta and Arditi (2005) stated that policies to raise productivity are not always similar in each country. Their study identified different factors affecting labour productivity and grouped them according to their characteristics such as design, execution plan, material, equipment, labour, health and safety, supervision, working time, project factors, quality, leadership and coordination, organization, owner/consultants, and external factors. Adrian (1987) classified the factors causing low productivity as industry-related factors, labour-related factors, and management-related factors. Industry-related factors, essentially, are the characteristics of the construction industry, such as the uniqueness of construction projects, varied locations, adverse and unpredictable weather, and seasonality. Labour-related factors included lack of training and learning for labour, and lack of motivation. Management-related factors usually refer to a lack of management, and inappropriate use of tools and techniques. Olomolaiye et al. (1998) classified productivity factors into two categories: external factors are outside the control of organization management and internal factors relate to productivity issues originating within the organization. Thomas and Sakarcan (1994) developed ideas to describe factors affecting labour productivity. One study suggested that scheduled overtime always leads to efficiency losses because of the inability to deliver materials, tools, equipment, and information at an accelerated rate (Ginther, 1993). Productivity in the construction industry is not only influenced by labour, materials and equipment. However, most researchers and construction practice to date has primarily concentrated on labour productivity, as though labourers' performance is the sole contributor to increased construction productivity (Alwi, 1995). Investigation conducted by (Alwi, 2002) concluded that there was now concern over the high level of non-value adding activities within the construction industry. The activities, known as construction waste (disposals), have been identified as major factors affecting construction productivity. The foundation for this paper is built upon the work of Abdelaal et al, (2014) which examined labour productivity in GCC countries.

2. Literature Review

Productivity is the outcome of several interrelated factors. Discussed below are various factors affecting construction productivity and are reviewed from past studies.

2.1. Site working time:

During construction projects, working overtime initially results in increased production rates, but continuing overtime may lead to increased costs and reduced productivity (Hinze, 1999). Alinaitwe *et al* (2005) found that employees in the field only work effectively for 3.5 hours of an 8-hour shift and spend only 20% of time on direct value-adding activities.

2.2. Managing site equipment:

The Construction Industry Institute states that material and equipment currently comprise 50-60% of construction project costs (Materials Management Task Force, 2007). In addition, lack of suitable equipment is considered one of the major causes of construction delays. Good equipment management begins at the time the equipment is purchased/hired. Purchasing/hiring the proper equipment that matches the need of assigned tasks, while achieving the lowest costs, is necessary to attain suitable equipment management. Proper record keeping provides information for planning maintenance/ replacement, ensuring that they occur at the proper time. Managing equipment includes preventative maintenance, planning maintenance, and replacement activities (O'Brien et al 2007).

2.3. Communication:

Good communication is necessary to efficiently complete a project. Some of the more commonly used forms of work site communication include two-way radios, mobile phones and mobile wireless internet. Lack of communication can cause delays due to mistakes causing rework, lack of information causing downtime, and misinterpretation. Other common problems associated with communication on construction projects include understanding the chain of command and continuously communicating about the project and foreseeing potential problems in the future. This can be avoided by holding regular project management team meetings (Cingoranelli, 2007). As stated in the Project Management Institute's Standard (PMI, 2009), about 90% of project manager time is spent in communication.

2.4. Work schedules:

When there are early delays in projects, compression of the overall time frame for later activities is often used to compensate interruptions and to complete assigned tasks on schedule. From a professional scheduling perspective, schedule compression may be possible without accelerating individual work activities by utilizing float in project schedules; however in many projects, schedules are not fully resource loaded. As a consequence, an updated schedule reflecting delays may show the project finishing on time without shortening individual activities (National Electrical Contractors Association, 1983).

2.5. Working tasks types:

To accomplish acceptable productivity, every member of a crew requires adequate space to perform tasks without being affected by other crew members (space constraint). When more labourers are allotted to perform particular tasks, in a fixed amount of space, it is probable that interference may occur, thus decreasing productivity. Additionally, when multiple trades are assigned to work in the same area, the probability of interference rises and productivity may be reduced. Interference among the various crews and labourers is due to mismanagement on construction sites. For example, a steel-fixing crew has to wait before fixing reinforcement bars if the carpenter's formwork is incomplete. Types of activities and construction methods also influence labour productivity (Sanders and Thomas, 1991).

2.6. Safety measures:

Accidents have high impact on labour productivity. Various accident types occur at sites, and some may cause fatal injuries and result in total work stoppage for a number of days. An accident that causes an injured person to be hospitalized results in a work decrease of the crew for which the injured employee worked. Small accidents resulting from protruding nails and steel wires can stop work and, thus, decrease productivity (Sanders and Thomas, 1991).

2.7. Quality control:

Inefficiency of equipment, unskilled labourers and poor quality of raw material are factors which cause low productivity. The productivity rate of inefficient equipment is low. Old equipment is subject to a great number of breakdowns, and it takes a long time for labourers to complete the work, thus reducing productivity. Poor-quality material used for work is another reason for reducing productivity; also unskilled labourers causing rework, which leads to low productivity.

2.8. Managerial factors:

Project manager skills and attitudes influence construction productivity. In many organizations, productivity is low even though the latest technology and trained labour are made available. Low productivity is often because of inefficient and immature management. Advanced technology requires knowledgeable labourers who work under professionally capable leaders.

2.9. Skilled labourers:

A lack of labour experience is the factor which negatively affects labour productivity and proves that, to achieve good productivity, labour plays a significant role. Contractors should have sufficiently skilled labourers employed to be productive. If skilled labour is unavailable and a contractor is required to complete specific tasks with less-skilled labour, it is likely that productivity will be negatively impacted. Lack of compensation and increased labourer age negatively affect labour productivity because labour speed, agility, and strength decline over time and reduce productivity (Heizer and Render, 1990).

2.10. Motivation:

Motivation is one of the important factors affecting construction labour productivity. Motivation can best be accomplished when labourers' personal ambitions are aligned with organization strategic goals. Factors such as payment delays, a lack of a financial motivation system, non-provision of proper transportation, and a lack of training sessions are grouped in this topic (DeCenzo and Holoviak, 1990).

2.11. Scope changes:

Construction projects often have design, drawings and specification changes as work proceeds. If drawings or specifications are unclear, productivity may decrease since labourers in the field are uncertain about what needs to be done. As a result, tasks may be delayed, or have to be completely stopped and postponed until there are clear instructions. There can be a 30% loss of productivity when work changes are being performed (Thomas *et al*., 1999). Work inspection by supervisors is an essential process before proceeding to subsequent stages. For example, contractors cannot cast concrete before an inspection of formwork and steel work, thus affecting labour productivity (Zakeri *et al*, 1996).

2.12. Availability of material/tools:

Productivity can be affected if required materials, tools, or construction equipment are not available at the correct location and time. If the improper tools or equipment are provided, productivity may be negatively affected (Alum and Lim, 1995; Guhathakurta and Yates, 1993). The size of construction sites and material storage locations have a significant impact on productivity especially in infrastructure projects where there are often large space areas for work, and labourers spend time moving materials from inappropriate storage locations, thus resulting in productivity loss (Sanders and Thomas, 1991).

2.13. Over planning and work methodology:

Improper scheduling of work, shortage of critical construction equipment or labour, may result in loss of productivity. Improper planning of project-initiation procedures may lead to lost labour productivity. Also, poor site layout can contribute to a loss of productivity. According to the Association for the Advancement of Cost Engineering (AACE, 2004) labourers may have to walk or drive long distances to lunch rooms, rest areas, washrooms, entrances, and exits, affecting overall productivity.

2.14. External factors:

Various natural factors affecting equipment productivity collected from previous studies are weather conditions and geographical conditions. Others factors such as fuel, water, and minerals also affect productivity to a certain extent. Productivity is found to be highly affected if the weather is too extreme (too cold, heavy rainfall, or too hot, as in the case of this study in GCC countries).

3. Methodology

This research investigates important factors affecting equipment productivity in construction in GCC countries. Understanding these factors is helpful for construction professionals who work on all project phases, especially on the initial phase of construction planning, in order to efficiently deliver project plans. The main goal of the research is to provide essential information about factors affecting construction productivity. Factors which affect construction productivity are a lack of required materials, disputes between the major parties, weather, changes during construction, accidents, and other items. The research study aims to provide knowledge of construction project-related factors that affect productivity. The data collection instruments used in the research are a questionnaire survey, followed by interviews with practitioners. The research passed through the following phases in figure 1:

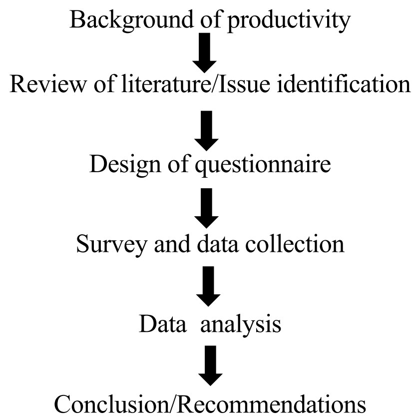

Figure 1: research phases

The data collection process used in this research had the option of two basic methods: questionnaires and personal interviews. A questionnaire was preferred as the best effective and suitable data-collection technique for the study. The questionnaire was a self-administered tool with web-design questions. A questionnaire in a web-survey format comparatively requires less duration and saves cost for the researcher while permitting participants to respond to the questionnaire at their convenience. However, for this approach the response rate is usually lower as compared to face-to-face interviews. Data was collected for the literature review from books, journals and articles. The population for the survey was employees from different professions involved in construction in GCC countries.

3.1. Questionnaire and results

Participants were asked to indicate to what extent factors affect equipment productivity on infrastructure sites in GCC. Responses were scored as 1 – not applicable; 2 – does not affect it; 3 – somewhat affects it; 4 – directly affects it.

3.2. Survey and questionnaire revision

Face-to-face discussions were conducted with ten construction practitioners. This procedure improved the formation of the web-survey. A total of 130 questionnaires, were sent by e-mail to contractors, architects, owners, project managers, and project engineers of various construction organizations. In addition conducted collection process with qualitative interviews with construction professionals.

3.3. Questionnaire distribution

The target groups in this study were professionals from the construction industry. A list of 550 building-construction organizations was obtained from the Construction Week online the GCC magazine. The sample size can be calculated with the following equation for a 94% confidence level (AlShahri, M *et al.*, 2001; Moore *et al.*, 2003):

$$n = \frac{n'}{\left(1+\frac{n'}{N}\right)} \quad (1)$$

Where, n = total number of population, N = sample size from a finite population, n' = sample size from an infinite population= S2/V, S2 = the variance of the population elements and, V = a standard error of the sampling population (usually, S= 0.5, and V = 0.06). n'= S2 / V2 = (0.5)2 + (0.06)2 = 69.44, for N=550, n = 69.44 / [1 + (69.44 / 547)] = 62, to obtain 94% of confidence level, it was calculated to send the questionnaire to minimum of 62 participants.

3.4. Data collected from the web survey

To successfully achieve the objective of the study, one of the most important phases is collection of accurate data. Data collection is a procedure of collecting crucial data records for a certain sample or population of observations (Bohrnstedt and Knoke, 1994). shows the participant's characteristics: The characteristics of participants involved in the survey were tabulated in Table 1. The average work experience of the participants involved in construction industry is 15 years with managerial level and majority belongs to control debarment. This indicates reasonably a high work experience profile within GCC construction industry.

Table 1: Characteristics of participants/ Company classification

Participants	*Questionnaire distributed*	*Responses returned*	*Percentage of responses*
Client	*5*	*3*	*18.80%*
Consultants	*5*	*2*	*12.50%*
Contractors	*100*	*11*	*68.70%*
Sub-contractors	*5*	*0*	*00.00%*
Suppliers	*5*	*0*	*00.00%*
Total	*130*	*16*	*13.33%*

3.5. Analysis method used

In order to facilitate the study, after the literature review and the focus interviews, a plan was formulated for collecting field information and creating an evaluation process and numerical values. It was necessary to provide straightforward communication to participants to ensure a clear understanding of all the applicable definitions, procedures, and guidelines that were used in collecting data.

3.5.1. Ranking

Ranking of the various factors according to their relative importance index (RII) for affect ranges: (1 – Not applicable; 2 – Does not affect it; 3 – Somewhat affects it; 4 – Directly affects it). RII for each factor as follows: *RII*=ΣW/A*N, where W is the weighting given to each factor by the participants (ranging from 1 to 4), A is the highest weight (i.e. 4 in this case), and N is the total number of participants. For the interpretation of the *RII* values, *RII* is ranked from the highest to the lowest.

3.5.2. Analysis

Table 2 illustrates RII a rankings of 29 common factors affecting productivity of equipment as per previous studies, and factors were categorized into five major groups and were ranked. The results show that clients, consultants, and contractors all agreed that the external group of factors affecting productivity was the most influential. Resources factors were considered the second most important factor affecting productivity in construction projects followed by Misc., Operators and communication.

Table 2: Top factors affecting equipment productivity in construction projects in GCC

Factors affecting construction equipment productivity at infrastructure sites	*RII*	*RANK*
1- *Operators*		
Lack of experience	*0.83*	*2*
Disloyalty	*0.73*	*6*
Age	*0.41*	*31*
Personal problems	*0.50*	*30*
Absenteeism	*0.70*	*10*
2- *External*		
Implementation of standards, government laws & regulation	*0.83*	*3*
Rework	*0.84*	*1*
Lack of Supervision	*0.81*	*4*
Permits delays from the authorities	*0.73*	*6*
Variations & design changes	*0.61*	*23*
Complex designs in drawings. Incomplete drawings	*0.72*	*9*
Payment delays	*0.63*	*18*
Lack of training	*0.63*	*18*
3- *Communication*		
Misunderstanding between owner, contractor and designer	*0.61*	*23*
Disputes with owner/designer	*0.64*	*16*
4- *Resources*		
Lack of required construction materials or/and price increase	*0.73*	*6*
Availability of required equipment	*0.78*	*5*
Poor site conditions or/and differing from plan	*0.69*	*11*
Differing from plan	*0.61*	*23*
Poor access within construction job site	*0.61*	*23*
Violations of safety laws	*0.61*	*23*
Insufficient lighting	*0.61*	*18*
Inadequate construction method	*0.63*	*11*
Inadequate transportation facilities for workers	*0.69*	*23*

Material storage location	*0.58*	*29*
5- *Miscellaneous*		
Shortage of water and/or power supply	*0.66*	*15*
Working overtime	*0.63*	*18*
Power supply	*0.63*	*18*
Weather conditions	*0.64*	*16*
Accidents during construction	*0.67*	*13*
Project objectives are not well defined	*0.67*	*13*

4. Conclusion and Summary

This research provides study and knowledge of construction productivity and focus on factors affecting equipment productivity in infrastructure construction projects in GCC countries. The study sought the views of clients, consultants, and contractors on the outcome of infrastructure projects especially public projects that influence economics. Prior knowledge of labour/equipment productivity during construction can save cost and time. Investments for these projects are very high and because of the complexity in construction, various factors can highly affect overall productivity, thus projects can end up adding even more time and cost. The research is intended to identify major common factors affecting equipment productivity in infrastructure projects. This study investigates all possible factors through a structured questionnaire administered in GCC countries. The survey results are subjected to analysis, and the ranking of factors is calculated using Relative Importance Indices (RII). The study showed that all the three groups-clients, consultants and contractors of participants generally agreed that out of a total of 29 factors the top 10 influencing factors affecting equipment productivity arranged in descending order of RII are:

- Rework
- Lack of experience
- Implementation of standards, government laws & regulation payment delays
- Lack of supervision
- Availability of required equipment
- Disloyalty
- Lack of required construction materials or/and price increase.
- Permits delays from authorities.
- Complex designs in drawings. Incomplete drawings

The results show that clients, consultants, and contractors all agreed that the external group of factors affecting productivity was the most influential. Resources group of factors were considered the second most important factor affecting productivity in construction projects followed by miscellaneous, operators and communication factors. In addition, the study showed 10 factors that affection productivity of excavator in infrastructure projects, that the top influencing factor affecting excavator productivity using RII is soil characteristics. From previous studies, it has been shown that the nature of the construction industry, usually involves the separation of design and construction functions. This has affected construction productivity through delays in drawings, design changes, and following rework. Clients have sometimes delayed projects because of their lack of suitable knowledge about construction procedures. Moreover, being an outdoor industry, construction performance is significantly affected by weather conditions. In addition to the factors discussed, health and safety regulations, and codes of practices are other external factors influencing task operations and productivity. Factors internal to construction companies include management inadequacy resulting in a waste of resources and consequent losses in productivity; adoption of modern technology and training for labourers would increase productivity. This research was carried out in infrastructure construction projects in GCC. It may be that the issues of the key factors, the model developed and the alternative solutions here can provide guidance to the other studies and researchers. Concepts such as waste and value are not well understood by construction personnel. They often do not realise that many activities they carry out, do not add value to work. Waste is not only associated with waste of materials in the construction , but also other activities that do not add value such as rework, waiting time and delays. These issues contribute to a reduction in the value of construction productivity.

5. Recommendations

Construction projects are high risk and often lead to a disputes and claims as work progresses, which then subsequently further affects progress. The environment within construction organisations should be suitable to successfully complete projects. In construction, it is necessary to identify potential problems in advance, in order to avoid and overcome possible impacts on cost or project time. Detailed below are recommendations which were found to improve equipment productivity on the infrastructure projects in GCC countries:

Material delivery schedules should be provided for projects and monitored closely by contractors. Using suitable materials and tools also has a positive effect on tasks and thus, better labour productivity can be achieved. Material should be stored at appropriate locations and should be easily accessible. Project managers should provide suitable logistic plans at the initial phase of projects. Good equipment management begins at the time the equipment is purchased/hired. Purchasing/hiring the proper equipment that matches the need of assigned tasks, while achieving lowest costs is necessary to attain suitable equipment management. Proper record keeping provides information for planning maintenance/ replacement, ensuring that they occur at the proper time. Organizations should make sure sites are safe and undertake continuous safety training. Various external and natural factor risks should be considered in budget estimations to minimize delays due to closures and material shortages. There should be suitable contingency budgets to cover increased costs of material. Motivation and training systems, should be implemented to create competition among the employees, thus achieving better productivity. Complex designs and incomplete drawings should be avoided and care should be taken to avoid confusion among the various construction agencies. Absenteeism at work site can be reduced with inclusion of appropriate paid time off and vacations to all employees.

6. Future Research

Further research should focus on the holistic barriers of implementing models for managing site resources (labour, equipment and materials) in addition to construction waste management, and development of a universal implementation framework that can fit into any construction environment and type. In the same vein, further work should be undertaken on applying the research in other developing economies. Similarly, additional research should be made in the adoption of lean construction tools and techniques within GCC countries such as Location Based Management Systems (LBMS) and Last Planner Systems (LPS) (Abdelaal, *et al.,* 2015).

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Walking the line: Navigating the space between calculus-based and relational trust in construction supply chains

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Abstract

Literature suggests that trust can take a number of forms, two notable ones being calculus-based and relational trust. Researchers have also argued that it is important to understand how these forms can be blended in different situations. However, there is limited empirical work that has explored how this blending can be managed in construction settings, where calculus-based forms of trust have often been overemphasized. In these situations, parties often depend excessively on contracts, incentives, and deterrents in ways that are counterproductive, perhaps even leading to distrust. Existing models of trust provide limited guidelines on how to achieve an optimal mix. We use qualitative case studies and actor-network approaches to explore these forms of trust, along with the movements between them, in two settings. Based on our findings, we argue that trust can initially emerge not just as calculus-based but also as dominantly relational and that trajectories of trust reflect complex, non-linear paths between the two pure forms. These findings allow us to enrich existing models that suggest that trust begins as entirely calculus-based and eventually changes to relational forms. We also point to potential areas for future work in terms of exploring the antecedents and outcomes of trust in various forms.

Keywords: trust, calculus-based, relational, capital, construction supply chains

1. Introduction

Trust has been defined as "a psychological state comprising the intention to accept vulnerability based upon positive expectations of the intentions or behaviour of another" (Rousseau et al 1998, p. 395). In collaborative contexts, trust has been described as "the glue and lubricant" that that holds relationships together (Bryson et al 2006, p. 47). Trust as a construct has received considerable attention in the field of construction, an arena where relationships have been described as conflict-laden, lacking in trust (Chan et al 2004), and adversarial (Phua and Rowlinson 2003). Studies suggest that trust in construction settings has multiple benefits: it helps supply chain partners fulfil their commitments in terms of service or product delivery, allocate appropriate resources to the required tasks, and facilitate team work among the project development team (Chow et al. 2012). High levels of trust among partners also result in a clear focus on the long-term benefits of their relationship (Davis 2008). An appropriate organisational culture that values trust is also a prerequisite to maintaining a sustainable supply chain partnership (Cheung and Rowlinson 2011). In the same vein, a lack of trust would result in unsuccessful collaboration (Akintoye and Main 2007). Trusting relationships therefore play a critical role in developing long-term relationships among partners. Interestingly, trust can have surprising complexities: studies have shown for example, that trust can lead to inefficiencies and waste as reported by Khan et al. (2011).

Researchers from within and outside the domain of construction have sought to understand trust theoretically and empirically by developing models that unpack trust in different forms. A number of these have analysed trust by proposing typologies ranging from calculative, economic, highly rational notions of trust, to affect-driven, relational forms that are seen to emerge from long-term interactions. In management literature, for example, Rousseau et al. (1998) proposed that trust as a micro, meso, or even macro-level construct, can come in three different forms. Calculus-based trust, they claim, emerges when one party concludes, based on the assessment of credible information (reputation, academic credentials), that a trustee (the actor being trusted) "intends to perform an action that is beneficial" (p. 399). The actor therefore becomes willing to engage with the trustee. The process is described as a highly rational approach, and is utility-driven in the sense that it focuses on benefits that can come from deciding to trust. However, this type of trust is limited in the sense that actors engage only in a small pool of select exchanges, and the actor seeks to maintain its own well-being maintaining some protection through the presence of deterrents. In contrast to calculus-based trust, relational trust emerges when one party engages with a trustee in repeated interactions over time, forming a relationship which in itself becomes the basis for trust. The relationship usually involves emotion and a higher level of faith as compared to calculus-based trust. The result of this type of trust is a broad range of exchanges typically transcending arms-length transactions (Rousseau et al. 1998). Apart from calculus-based and relational trust, Rousseau et al. (1998) also discuss a third type of trust, institution-based trust, which explores the role of entrenched norms, rules and practices in shaping conditions for trust. Other researchers have proposed similar typologies. Lyons and Mehta (1997) likewise argue that trust can be economic in nature, resulting in what they call "self-interested trust" (SIT); in contrast, trust can be social in nature, resulting in what they call "socially-oriented trust" (SOT). There are considerable overlaps between SIT and calculus-based trust, just as there are considerable overlaps between SOT and relational trust. SIT is based on an actor's calculating a future returns or benefit as the outcome of trusting in another party. SOT, on the other hand, assumes that social factors (for example an affective component) drive an actor to behave in trustworthy ways to others.

Similar categorizations of trust have emerged in the field of construction. Khan et al. (2011), for example, distinguish between cognitive- and affect-based trust. Cognitive-based trust is based on the professional competence of the service or product provider. In contrast, affect-based trust is the emotional attachment that gets developed among partners over a period of time. Zhagloul and Hartman (2003) likewise propose different types of trust, two of which are trust based on competence (based on the question "can you do the job?") and trust based on intuition ("does this relationship feel right?").

The persistence of typologies (economic/ rational/ calculative versus affective/ relational/ social) across these four models is worth noting. Also common across at least two models is the idea that different types of trust can be present in a single situation. Rousseau et al. (1998), for example, argue that different situations can be characterized by all three forms of trust, combining into a trust bandwidth. They propose a model that shows the changing composition of this bandwidth over time:

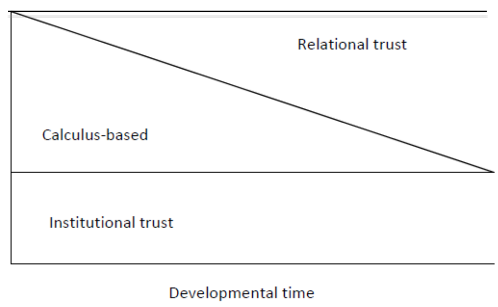

Figure 1: A model of trust (Rousseau et al. 1998, p. 401)

A key feature of this model is the proposal that the calculative component of trust begins as dominant relative to relational trust, but is gradually replaced by relational trust over time.

Lyons and Mehta (1997, p. 254) likewise argue that multiple forms of trust can be present in a situation, and that "[different forms of trust] may be used to reinforce each other, though they are likely to be present in different blends of relative importance". However, they argue that the specific blend of trust that is present in a given context is an empirical question often riddled with complexity:

> *We do not claim that one is universally true and the other is not, nor that there is room for only one type of trust in each relationship…It is possible that one type dominates in one group of firms and the other in another. It is also quite possible*

that the same individuals act with SOT with respect to one trading partner, but only SIT with respect to another. Certainly, we must expect both to evolve differently over time.

Our purpose for this paper, then, is to explore the two types of trust (economic/ rational/ calculative versus affective/ relational/ social calculus-based trust) in the context of two qualitative case studies. For the sake of brevity, we refer to these two types as calculus-based versus relational trust, although our findings for this specific paper would also support SIT/SOT and cognitive/ affective categorizations. The empirical examination of this blending process is particularly important, given that researchers have argued that "[i]n today's complex business relationships, like construction projects, the most effective approaches to developing 'business trust' are based in between these two extremes of egoism and altruism" (Rahman and Kumaraswamy 2002, p. 47). Still, negotiating this "space in between" has proven to be far from straightforward. Lyons and Mehta (1998, p. 254) warn against making simplistic conclusions, for example those that argue that "both [types of trust] are equally important". Equally dangerous is the tendency to ignore one type of trust completely. In the field of construction, for example, calculus-based forms of trust have often been overemphasized, with parties depending excessively on contracts, incentives, and deterrents in ways that are counterproductive, perhaps even leading to distrust (Kadefors 2004). There is therefore a need to explore, particularly in construction-related situations, how different forms of trust can best be combined in specific situations, and how the nature of these blended forms of trust can be allowed to emerge, rather than forcing them into a predetermined path. In our empirical study, we seek to discern and unpack how this blending takes place in nuanced ways. Our findings allow us to propose, among other things, a number of ways that the model of Rousseau et al. (1998) can be enriched.

2. Methods

This study is part of a three-year project exploring collaboration in housing supply chains using novel offsite manufacturing approaches in Australia. The study's emphasis on collaboration makes an examination of trust necessary, as there is a close link between the two (Bryson et al., 2006). For this paper, we focus on the issue of trust in the context of two qualitative case studies. Organization A is a large national developer that operates in a large Australian capital city. It focuses on the design and construction of medium-storey timber-framed apartments. Over the last decade, the organization has made it a priority to move away from purely site-based construction approaches and to explore alternative construction methods. In 2013, it began a five-storey apartment building project that involved the design and use of an innovative cassette floor that could be manufactured offsite and later craned into place. Upon completion of the project, it was assessed that the use of the cassette floor led to a cost savings of 25% per apartment. While use of the cassette was successful in retrospect, the development of the prototype of the cassette was a stage that was fraught with considerable uncertainty and resistance. There was therefore a period when Organization A found itself having to build relationships with suppliers and contractors in ways that fostered trust and encouraged these partners to launch into this new undertaking with them.

Organization B is a regional provider of housing solutions with two main locations, one being a small town in South Australia. The company specializes in both site-built houses as well as transportable homes that are manufactured on company premises then trucked to specific locations. Organization B has evolved over time, having its beginnings with a small firm founded by a single entrepreneur, and then expanding over time to include multiple businesses, four owners, and multiple managers. Apart from building homes, the firm also maintains properties and provides kitchen solutions. Organization B has, until recently, been operating with partners who have long-standing personal relationships with the owners, relationships that have persisted even in the absence of formal contracts. In 2014, Organization B took on a new general manager, and one of her goals is to professionalize and formalize structures and processes in the organization.

Our purpose is to examine trust in the context of the two construction-related organizations that are embedded in larger supply chain networks. Data was gathered primarily through interviews of managers and external partners of both organizations. Fourteen interviews have so far been conducted across both organizations. Interviews lasted one hour, were fully transcribed, and then analysed thematically using NVivo.

In analysing the data, we employed actor-network theory (ANT) as a methodological approach. ANT overarches a range of theoretical and methodological approaches based on the premise that much of social reality can be understood as the outcome of actors (human and non-human) interacting in heterogeneous networks (Law 1992). From an ANT perspective, complex phenomena such as organizations, technologies, IT systems, and communities are all networks made up of people, objects, documents and other entities exercising some form of agency, shaping their relationships with other actors, and in doing so creating network effects. Much of the "work" of creating network is often, though not completely, carried out by a key actor (referred to as a prime mover). The prime mover seeks to enrol other actors into a network, and to subsequently stabilize this network, in order for the network to address a certain problem (Callon 1999).

We used ANT to identify key players in both organizations, to examine how they established interactions with other actors, and to explore what forms of trust emerged between human actors. Many of the quotes can be understood to be coming from "prime movers" with considerable influence on the direction of an organization. These prime movers' views (whether on strategic issues or on things like trust) are important, but are not to be taken as the views of the overall organization. Acknowledging this also highlights that in these case studies, it is not the organizations as monolithic entities that "trust"; it is specific people who trust in certain ways. Trust in this case is therefore examined primarily on a micro level (as linked to an individual's notion of trust), although it should be noted that when referring to "trusting a partner", the term "partner" is loosely employed, at times referring to a partner organization, other times to a representative of that organization. It should also be noted that trust can be multifaceted to the extent that people "possess" it different forms and mobilize it in different ways. Analysing organizations as composed of different actors with different interests and views is consistent with the assumptions of actor-network theory.

3. Findings

We discuss our findings as follows. First, we describe what we discerned to be the roles of calculus- and relational trust at the relationship formation stage, that is, at the stage when managers from Organizations A and B were selecting and recruiting partners. Second, we examine the trajectories of these two types of trust over time, suggesting that the so-called switch between calculus and relational trust requires more complex conceptualizations than the suggestion that relational trust eventually replaces calculus-based. These two sets of findings become the basis for discussing future areas of research, specifically in terms of exploring antecedents and outcomes of various forms to trust. Due to space limitations, we do not discuss institutional-based trust here.

3.1 Forms of trust: the role of the relational component

The model of Rousseau et al. (1998) suggests that trust begins mainly as calculus-based. This may seem intuitive, given than trust based on economic thinking has tended to dominate business settings (Lyons and Mehta 1997). Our data from Organization A also supports this, as key managers describe partner selection for their innovative project as a systematic, well-researched process. For example, a manager who played a lead role in the 2013 project we described recalled,

> *I mean we still tendered out all the other basic trades but we knew who our core subcontractors and suppliers needed to be. And in doing so we had to* ***research*** *on that company and make sure they were capable of doing what we needed as well. So we went out to the* ***largest*** *frame and truss manufacturers who had the best detailers in their, I guess, pool of employees. We went to a flooring company* ***who had the ability*** *and cashed up to be able to do all the independent testings that we wanted to be done. And we had the* ***best engineers*** *on board. All those things all clicked, that's all. So* ***we knew who we needed to make it to work.*** *(emphasis ours)*

The reference to "research" suggests that there was a deliberate and systematic search for credible information about potential trustees, and this is consistent with the definition of calculus-based trust. Managers at Organization A thus moved to the decision to trust partners on the basis of trustworthy attributes: being "capable", being the "largest", being the "best".

We do note, however, that the case of Organization B was not as straightforward. Our data-gathering at Organization B was not at a point when new partnerships were being formed; however, it was at a point when a new general manager and sales director had just been appointed, and were reassessing existing relationships with suppliers, as well as how these relationships came about. Their assessments did yield some insights on the basis of these existing relationships, and a number of points were noted. First, there was no mention of screening or researching on potential suppliers at the start of the relationship. References to the history of partner relationships were mostly centred on the role of the owners "because [the owner] obviously built the relationship over the years". When this owner was interviewed, he made reference to what was important in partnerships:

> *I know a lot of builders will chase the dollar, and we don't seem to and it's a good place to be when you don't chase the dollar because you sort of burn those relationships... So yeah, I do like running the business where I can keep relationships alive with suppliers.*

This seemed to indicate that relationships were important in partner selection; in fact, the statement may even be interpreted to mean that monetary targets ("chasing the dollar") were less important. Either way, an argument can be made for saying that relational trust can be significant from the very start of the relationship.

Adding weight to this argument is the fact that many of these long-term partners were not providing the most in terms of economic benefits, but they were still being kept on as partners, often as the sole partner for a specific good or service. A new manager commented,

> *…one of my bug bears with [owner]… is he won't switch suppliers sometimes. When I know we can get it cheaper …and that's why we love him and people love us because [he says] no, he's a good guy, he's honest, he looks after me, the price, he's around the mark, he's not, you know, so we'll stick with him... So, we've got a core group of suppliers for each products, usually it's only one, other builders are a bit more intelligent…*

> *…you've got to love [owner] for it because he's just about relationships and but, you know, just got to find that happy balance, we're a bit too happy families at the moment, yep, but that's fine.*

A third point that seems to emphasize the dominance of relational trust over calculus-based trust is that there had never been any formal agreements in place that could have protected Organization B. The new general manager commented

> *… there's no agreements in place, there's no pricing grid there's no SLRs [service level reports], there's no any of those things. So I'm trying to bring to that, like get some agreements in place. Because I want to understand timeframes, for me, it's about, time costs quality, and get that, and less of the handshake.*

The emphasis on "not chasing the dollar", the need for "less of the handshake", along with the persistence of long-term relationships without formal agreements and despite suboptimal economic benefits, seem to suggest that these relationships did not start out as purely calculus-based. The argument we make here, then, is that, contrary to Rousseau et al.'s (1998) model (see Figure 1), relational trust can have a role at the beginning of a relationship. It is worth exploring in future studies, therefore, how relational forms of trust can exist even without a long history of repeated interactions.

3.2 Trajectories of trust over time

A second point about the model of Rousseau et al. (1998) is related to what we call the trajectory of firms in the journey related to trust development. Rousseau et al. (1998) suggest that over time, firms move away from calculus-based trust, and as they do so, relational trust comes to dominate. The model thus suggests a simple, linear trajectory with calculus-based trust decreasing as relational trust increases.

We can see this, albeit only up to a point, in the case of Organization A. Organization A is largely characterized by a professional work environment, and multiple interviewees discussed how work and processes have been explicated and formalized in programs, minutes of meetings, and contracts. Still, key actors in projects have on occasion chosen to depart from these formal program and contractual commitments, in order to accommodate partners in vulnerable situations:

> *Look, there are contractual boundaries here and we have got a serious job to do, and that element of contracting is still black and white. But for the sake of getting this moving I want to have another element which sits above it, and that is that we're all here to work together and to cooperate.*

The quote seems to suggest that Organization A can shift from calculus-based trust, to relational trust. The shift to relational trust, though, does not proceed indefinitely to the point of completely removing the need for calculus-based trust. Our data shows that, even as managers create space for relational trust with partners, they still curb this trajectory by moving "back" to calculus-based trust. A manager describes how a situation involving an underperforming partner once came up, one involving a "brilliant" man who for some reason had begun underperforming, with the project starting to "come off the tracks." The manager then described how this was dealt with:

> *I wanted to find out why… Now, if ultimately we can't get it back on track we have got a contract sitting behind it. I can't do anything about that. We're both commercially - we're both commercial entities and we've both got outcomes we have to achieve. So that will come into it at some stage.* ***But at this point in time they're not the place I want to be. Right now I want to work out how can we get you back on track, because if I can get you back on track I'm going to win, you're going to win and everyone is going to look good.*** *(emphasis ours)*

This would suggest that, prior to the occurrence of problems with this partner, there was a clear contract embodying clear accountabilities (calculus-based trust, with deterrents). A lapse in partner performance took place, and a decision was made to accommodate this (relational trust, despite the contract). However, in the end, in the end, the expectation was that the contract would still take force (back to calculus-based trust).

This non-linear movement between calculus-based and relational trust can also be seen in Organization B. In this setting, people have operated primarily in a space of relational trust, but they have begun to move this into something more calculus-based and formalized:

> *So yes, I am very conscious of, now, that I'm bringing in price agreements, service level agreements, and all of those things, and I'm very conscious of how I deliver the message to the supplier and to the business….the conversation is, I value the relationships and I appreciate those, but at the same time again my instruction is to make a profit.*

Again, this trajectory is not expected to continue indefinitely, this time with calculus-based trust completely replacing relational trust. Data shows that, despite the move to more calculus-based trust, the manager still brings in the ideal of "valuing the relationship", but it must now be weighed side by side with economic accountabilities. The persistence of the relational component of trust was mentioned again when this same manager clarified, "I don't want to burn the relationship, but I want to find the boundaries in a relationship, too, that we need."

Close scrutiny of the data suggests, then, that these firms are weaving complex, non-linear paths which, at different points in time, mix both calculus- and relational trust. In the case of Organization A, calculus-based trust seems more important at the beginning of the relationship, as well as at times of "final accounting", but relational trust is privileged during times when pre-screened partners go through periods of vulnerability. In the case of Organization B, relational trust seems to have been privileged in the beginning and for much of the organization's life, but the organization is now in a period of transition where key people are seeking to carve out a space for the long-term institutionalization of calculus-based trust. A possible representation of these pathways is shown in Figure 2.

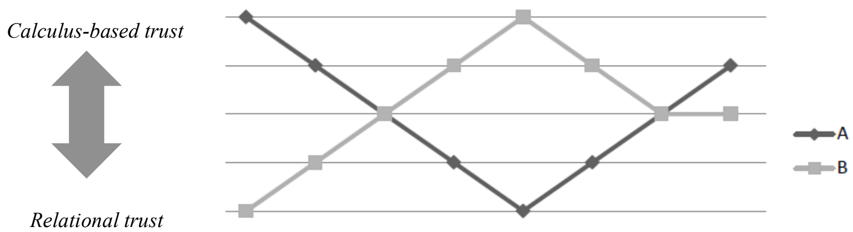

Figure 2. Trust pathways of Organizations A and B (note that the figure is meant to illustrate trajectories, and is not meant to show a precise mathematical function)

4. Discussion

The argument that trust often emerges in blended form foregrounds a number of questions that could lead to enriched understandings of it in organizational contexts. We note two that are important questions here: the question of antecedents of trust, and the question of outcomes of trust. We discuss these as two potential research directions.

The question of antecedents of trust could focus on the specific conditions and resources that give rise to trust, whether calculus-based or relational. In Organization A, trust emerged when managers obtained information about potential partners' competencies and accomplishments, and processed this in a rational way. In Organization B, trust emerged mainly from the nature of a long-running relationship. We believe that these forms of trust did not arise in a vacuum, but were closely linked to different conditions for trust that can be examined systematically. Pierre Bourdieu's (1986) concept of fields and symbolic capital provide an analytical apparatus for examining these conditions. Bourdieu argues that much of the social world can be explained by treating parts of society as fields, such as the fields of art, politics, and education (Swingewood 2000). Each field, for example housing construction, has its own rules, practices, and ideals as to what makes up the good life. Importantly, fields can be understood as networks of positions, some of which are dominant, others dominated. Positions are occupied by actors, and actors consistently seek to ascend to better positions. Fields are thus "a terrain of contestation among occupants of positions differently endowed with the resources necessary for gaining and safeguarding an ascendant position within that terrain" (Emirbayer and Williams 2005, p. 692).

To ascend to a better position in a field, actors seek to accumulate capital in various forms: economic (money), social (relationships), and cultural (which can be embodied, objectified, or institutionalized). Embodied cultural capital is acquired by investing in resources that "form long-lasting dispositions in the mind and body" (Bourdieu 1986, p. 84), a process which takes time and which must be done first-hand. Objectified cultural capital (paintings, monuments, books) takes material form and becomes transmissible. Institutionalized cultural capital generally takes the form of recognized academic qualifications. We are proposing that future work can explore the link between trust and capital two ways. First, researchers can explore the extent to which parties with more capital are considered more trustworthy. Second, researchers can explore the extent to which specific forms of capital are linked to specifically to calculus-based or relational trust.

Preliminary insights on these issues can already be discerned from our case study data. Organization A, for example, chose to trust in firms endowed with embodied cultural capital in the form of capabilities possessed by employees ("You need to judge fairly quickly what their capabilities - capacity and capability is and their expertise"). It also privileged firms with objectified cultural capital, in the sense that these were firms that had a track record of producing good quality artefacts. In contrast, this emphasis on cultural capital was not evident in the case of Organization B. Instead, trust seemed to be based on social capital, and social capital was portrayed to be more important than other forms like economic capital:

> *Like I could get on the phone to any one of my suppliers and if I'm in trouble or I've made a mistake they will get down in the trench with me and help me. Whereas if you burn relationship chasing the dollar you don't get that level of support, you're on your own, because obviously they haven't got that level with you.*

A second important question that can be explored in future research is the question of outcomes, or how different forms of trust actually shape specific behaviour. We are specifically interested in the types of *collaborative* behaviours that emerge from different types of trust. Trust and collaboration are not the same thing, since trust is a psychological state (Rousseau et al. 1998) while collaboration implies some form of interaction, hence it is enacted. This means trust can exist without being enacted in a collaborative relationship; and collaboration can be enforced by other means when trust is absent. Still, they are often linked in the sense that trust can facilitate and deepen coordinative activities (Kadefors, 2004). Our tentative findings suggest that relational trust appears to be accompanied by behaviours of accommodation, but these findings warrant deeper investigation. It is therefore worth exploring if different types of collaborative behaviours and arrangements can be linked to different types of trust.

5. Conclusion

In summary, theoretical work on trust has persistently showed that there are at least two forms of trust. However, attempts to understand the relative importance of one over the other in specific sections have been limited by simplistic conceptualizations. Furthermore, trust in the context of construction projects has not been explored extensively (Bresnen and Marshall 2000). This paper contributes to the small and growing body of work on trust in construction settings. It empirically explores calculus-based and relational trust in the context of two case studies. Our findings call into question the assumption that calculus-based trust tends to give way to relational trust over time. Instead, our analysis suggests that relational trust can have a significant role in the early stages of interaction between parties and that the movement between calculus-based and relational trust is a complex, non-linear path. Future work can explore the antecedents of various forms of trust using the Bourdivian concept of capital as a lens, as well as the behavioural outcomes that emerge.

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Part II: Constructing Commitment and acknowledging human experiences

3. Health and Safety
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6. Users, Clients and Stakeholder Engagement

TAMPERE UNIVERSITY OF TECHNOLOGY

Rethinking the link between public engagement and project success

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Abstract

The practice of engaging the public in decision-making during the planning or development stages of construction projects has become prevalent around the world in recent years. This is especially true of government projects, where the end users, and hence the people affected the most, are members of the public. A strong theoretical link exists between public engagement and successful planning, drawn from democratic theory. The same cannot be said for links between public engagement and project management. From a project management perspective, public engagement practices are often justified as a deterrent against public protests which may lead to bad press, political upheaval, and possible eventual frustration of the project. The success of public engagement then is linked to how it might enhance the possibility of success for a project, using whatever metrics by which project success is usually measured. While this view has been useful in its application in numerous studies, conceptualising public engagement in this manner also has its limitations. This paper critically evaluates the theoretical assumptions that have been used to establish the dominant view of public engagement as a risk management exercise strongly linked to project success. In doing so, we propose an alternative way of conceptualising public engagement, which views public engagement as a phenomenon decoupled from project success. An argument is made for accepting the uncertain nature of public engagement processes and placing emphasis instead on how events change and develop over time.

Keywords: Public engagement, project success, project governance, processual research, phenomenology

1. Introduction

In recent years, public engagement has become more commonplace, allowing for the public to be involved in decision-making activities that have formerly been regarded as strictly state-related. Examples of the mechanisms that facilitate public engagement include lay membership on science committees (e.g. Irwin *et al*. 2012), citizens' juries (e.g. Rowe *et al*. 2005), and consensus conferences (*ibid.*). Within the built environment, the mechanisms deployed include the distribution of community surveys and the organisation of focus groups (e.g. Legacy 2012). The moral rationale for engaging with the public is particularly salient for public sector projects, such as urban development projects, since a large proportion of the end users will be members of the public.

As the nature of urban development projects involve transforming conceptual designs into physical built forms, public engagement in this context tends to focus on collecting opinions that may be transformed into design solutions. The questions asked tend to be of a quantifiable nature, such as: How high? How dense? What sorts of land-uses? These types of feedback have to be incorporated into the project as it is being actualised, so the timeframe for public engagement process needs to work in parallel with the overall project. As such, public engagement issues are also project management issues.

The literature on public engagement tends to be more established in planning studies than in construction management studies, perhaps due to the strong philosophical link between planning and democratic theory. From a policy level, planning is seen as an activity of the state, so garnering public interest legitimises these activities. Hence, the public interest has been established as a criterion for evaluating planning and the various policies, projects and plans that are produced as a result of planning processes (Alexander 2002). These same planning and design activities may also be validly viewed as project management activities as part of the development life cycle. Yet the argument linking public engagement to projects in management studies is less congruent. From a project management perspective, public engagement practices are commonly viewed under the rubric of stakeholder theory. The activities are often justified as a deterrent against public protests, which may lead to bad press, political upheaval, and possible eventual frustration of the project. Thus, the success of public engagement is linked to how it enhances the possibility of success for a project, using whatever metrics by which project success is usually measured. However, as this paper will strive to demonstrate, the link between the public engagement and project success concepts are not robust enough to substantiate such a claim.

The aim of this paper is to critically evaluate the theoretical assumptions that have been used to establish the dominant view within construction project management, and assess their robustness. We begin by deconstructing the definition of 'public engagement', using the typology set up by Rowe and Frewer (2005) as our point of departure. An overview is then given of how public engagement is commonly depicted within project management literature, with particular focus on stakeholder theory. The assumptions connecting effective public engagement to project success are laid out and explored systematically, first by investigating what is meant by project success, then by assessing what, if any, causal relationships can be established between the two constructs. We then draw attention to the characteristics of temporal dynamism inherent in public engagement and how this influences the way it may be studied. We posit that focus needs to shift from how public engagement affects project outcomes to how it interconnects with project management processes. We conclude with suggestions of how public engagement should be studied in future.

2. What is public engagement?

The notion of involving the public in the decision-making of governments is in large part driven by the democratic ideal that deems it desirable to promote open discussion between private citizens and the state, within what Habermas would term the 'public sphere' (Habermas 1974). From this democratic ideal, the movement for 'citizen participation' was borne. Arnstein's (1969) seminal work on 'the ladder of citizen participation' remains a cornerstone for the movement, and for debates in the field on how efforts of involving the public should be judged to be sincere rather than tokenistic. In brief, her 'ladder of citizen participation' posits that engagement and participation with the public should aim to lead to a redistribution of power, and that different levels of participation progressively allow for this transfer of power to take place. The various strategies that have been used to put these ideas into practice have operated under a variety of terms, including 'community consultation', 'civic engagement', 'public engagement' and 'public participation', although there is a tendency to favour the term 'engagement' over 'participation' in recent times (Delgado *et al.* 2011). For the sake of consistency, we shall throughout this article use the term 'public engagement' (cf. Rowe and Frewer, 2005).

In their meta-literature review, Rowe and Frewer (2005) identified three main aspects of public engagement: public communication, public consultation, and public participation. These three forms of public engagement mechanisms hold distinctive properties that need to be considered separately when the question of effectiveness is raised for public engagement. In general terms, public communication entails the process of the project owner distributing information to the public, without any effort to collect opinion or feedback in return. Public consultation entails a process initiated by the project owner to collect and record information from the public, without any specific obligation to act upon or deal with this information. Public participation involves information exchange between members of the public and the project owner. A certain level of dialogue, usually in a group setting, is required for information exchange to occur. During this dialogue, each party is allowed time to respond to whatever information might be tabled, which may lead to one or both parties to change their opinions over time.

The comprehensiveness and representativeness of the typology described above may, of course, be debated further, but for present purposes it suffices in forming a working definition. Broadly speaking, 'public engagement' refers to any number of processes which allow the public to participate in decision-making processes; whereas 'public engagement mechanisms' are more specific, and involve mobilising mechanisms to facilitate an open dialogue between parties that enables the privilege of decision-making to be shared. Several distinctions do, however, need to be highlighted. Firstly, the three elements of ‘communication’, ‘consultation’, and ‘participation’ need to work together for the public engagement to have any merit. Secondly, there is an implicit chronology promoted in the definition, namely, that the public first needs to be informed with the relevant facts, then given the chance to discuss the matter at length, and then given time to digest the matter and give their feedback. The project owner, on their part, needs to prepare adequate and appropriate information for dissemination, spend time to communicate this information with the public, collect any views the public may have on the information presented, and be open to discussions that may serve to change their opinion of the project. Additionally, viewing public engagement as a chronology of events means that the time spent between the stages of communication, consultation and participation is a critical component in the engagement process. Participants are explicitly given time to reflect on the project and to give comments and feedback in due course; and the project sponsors must allow time to digest, analyse, and make changes to the program accordingly.

Finally, it should be noted that the underlying assumption for public engagement is that the feedback from the public has a chance to be taken on board by the project owner, although the extent to which feedback could (or should) be integrated is difficult to quantify. If project details are already settled before public engagement commences, with no intention of change, then the exercise will not meet the definition of public engagement. The public participation component will be missing, meaning that it will be public communication and consultation at best. This position aligns with Arnstein’s view of ‘citizen participation’, which aims to redistribute power from the government to the individual citizen. Hence, the ‘citizen’ must have an avenue to affect the outcome of a decision for the process to claim to be genuine (Lane 2005).

3. Public engagement from a management theory perspective

From a management perspective, stakeholder theory is often used to explain the relationship between the various parties involved in a project. The commonly accepted definition of a stakeholder is “any group or individual who can affect or is affected by the achievement of the organisation’s objectives” (Freeman 1984: 46). It follows that a project will have a variety of stakeholders, such as the shareholders, the staff, external governing bodies, and other parties that are not directly connected to the project, but who nevertheless have a stake in its outcomes. The project management literature commonly recognises the wider community as external stakeholders to the project (e.g. Moodley *et al.* 2008; Smyth 2008; Walker *et al*. 2008).

The literature on stakeholders can be classified as being normative, descriptive, and instrumental. It is normative because it acknowledges that stakeholders have legitimate claims on project goals and consequently, their interests have normative validity. It is descriptive because it provides a model of a corporation which describes the network of entities within it. It is instrumental as it allows for the examination of connections between the practice of stakeholder management and the achievement of various critical performance goals (Donaldson and Preston 1995). Extensive effort has been exerted to determine how stakeholders should be identified and how their influence to the organisation may be ranked or judged. For example, Mitchell *et al.*'s (1997) stakeholder saliency view, which is based on resource dependency theory, posits that resources within an organisation is limited and, thus, the resources used to manage stakeholders need to be prioritised. In this manner, any groupings of stakeholders may be sensibly ranked according to their salience, which is determined by assessing their power, legitimacy and urgency in relation to the organisation. Stakeholders who are demonstrated to be more salient should then be given priority in having their issues addressed (*ibid.).*

In the construction management literature the main focus when dealing with external stakeholders (including the public) seems to be how to manage them in order to minimise the adverse effects they may have on the organisation, or on the project. The key assumption for the application of stakeholder theory is that stakeholders have intrinsic value and the ability to affect the outcomes of the project. Hence, the appropriate management of stakeholders will impact on project success. A large number of studies have in this fashion advocated the use of stakeholder theory for engaging with the public (e.g. Hillman and Keim 2001; Olander 2007; Olander and Landin 2008; Yang *et al.* 2011). It is commonly argued that the effectiveness of stakeholder management can directly influence the success or failure of a construction project (e.g. Bryson 2004; Kolk and Pinkse 2006; Rowlinson and Cheung 2008). The dominant perspective is that the deployment of public engagement mechanisms is closely tied to the enactment of appropriate stakeholder management strategies.

4. Relationship between public engagement and project success

Despite its recent ubiquity in management studies in general, and construction management in particular, it would do well to note that by itself stakeholder theory does not have any predictive power of how stakeholders may behave. It also rarely addresses how the relationship between stakeholders and organisations develop over time (Friedman and Miles 2006). Problems further arise when attempting to apply the standards of project success, which are commonly used to study stakeholder management activities, to study public engagement mechanisms. Firstly, quantifying project success is not straightforward and is contingent on a number of issues, few of which have direct relevance to public engagement. Secondly, the link between project success and public engagement is tenuous at best. Thirdly, studying public engagement retrospectively confines it to be viewed as a product or an object. As public engagement is meant to encompass public communication, consultation and participation, it would be more appropriate to view it as an ongoing process. The following section expands upon the above argument and proposes an alternative method for studying public engagement.

4.1 Measuring project success

There are numerous models for examining and measuring project success; the most well-known of which is the 'iron triangle', coined by Martin Barnes in 1969. The 'iron triangle' places 'cost', 'quality' and 'time' at the triangle's apexes, indicating that a successful project should be on budget, on time, and of a good quality. Its relevance in the modern era has, however, been repeatedly contested. In particular, how it ignores aspects relating to 'people' and how different stakeholders are likely to view success in different ways (cf. Atkinson 1999; Vahidi and Greenwood 2009), and how success is best judged by the primary sponsor (Turner and Zolin 2012). Of particular importance to this line of argument is that stakeholders' attitudes toward project success are likely to change as the project progresses. Or in other words, how success is assessed is time-dependent (Shenhar and Dvir, 1997). For example, Shenhar and Dvir (2007) propose a model of project success that is based on five dimensions judged over different timescales: project efficiency; team satisfaction; impact on the customer; business success; and preparing for the future.

Furthermore, what it means to successfully manage a project, which only considers factors leading up to a project's completion, may be markedly different compared to how a project might be considered successful afterwards. To this end, some scholars have made efforts to distinguish between 'project management success' and 'project success' (Cooke-Davies 2002; Munns and Bjeirmi 1996). A similar argument could be applied to stakeholder management. The successful management of project stakeholders have different implications when comparing long-term benefits, such as business growth and continuity, to shorter-term goals such as client satisfaction and project performance (Rowlinson and Cheung 2008). However, the stakeholders usually referred to in this line of argument are internal stakeholders, i.e. those whose own interests largely align with the intended project outcomes. The same cannot be said for external stakeholders. Due to their proximity to the management and control of the project, as well as their dispersed nature, it is unlikely for all of the interests of external stakeholders to align with the intended project outcomes. At times, the two are in direct conflict with one another. In these cases, the successful management of stakeholders may not lead to long-term benefits for the organisation.

4.2 Relationship between public engagement practices and project outcomes

As alluded to above, there is often a direct clash between the goals of public engagement, and the goals of the project. This is unsurprising, given that the main goal of public engagement is citizen empowerment, whereas the goal of a successful project is the accomplishment of critical success factors for the owners of the project. Acknowledging this clash, some choose to view public engagement as part of a risk management strategy (e.g. Loosemore *et al*. 1993). The main argument put forward is that the failure to manage a project's external stakeholders can lead to the mobilisation of community based protests, which in turn can indefinitely delay or frustrate the project (e.g. Teo and Loosemore 2011). The proposed solution is a conflict management approach that essentially sees the public as a risk to the project, which needs to be managed, suppressed, and minimised. At times this might well be convincing, but the connection between the mechanisms for public engagement and conflict management is by no means clear. The tendency is to assert that public engagement will lead to minimised conflict for the project, without giving reasons as to how this might occur. The literature on public engagement is equally insufficient in support for a causal relationship between an increase in public participation and a corresponding decrease in participants' conflict with project goals. In the cases where it is brought up, conflict management usually refers to managing conflict within discussion groups to facilitate fruitful discussions in order to garner useful feedback. There is, as such, little focus on how to minimise the animosity participants may hold towards the project.

The question then becomes what the rationale for assuming that an increase in public engagement will lead to a decrease in animosity towards the project is. We can think of three lines of argument that goes towards supporting such a link. The first builds on the 'deficit-model' approach to decision-making, where public disagreement with official proposals are caused by sheer ignorance or misunderstanding of the technical details of projects (Rowe *et al.* 2005). The second relates to the 'consensus-building model' approach to decision-making, where project goals are defined and advanced collaboratively between stakeholders and project sponsors (Innes and Booher 1999). The third argument relates to 'trust-building' with the view that successful public engagement should lead to increased levels of trust between the public and project sponsors (e.g. Tsang *et al.* 2009).

Our response to each of the three arguments are as follows: The first argument relates to successful public communication rather than public engagement. The second implies a shifting of project goals, and hence a reassessment of critical success factors, rather than a risk management strategy established to meet certain project goals. Accordingly, both causes are inadequate for justifying public engagement as risk management strategies in project management. As for the third argument, we postulate that the complexities in optimising engagement efforts coupled with the imprecise underlying definitions of 'trust' dimensions means that a link between the two concepts cannot be readily established (cf. Petts 2008).

4.3 Dynamic and uncertain nature of public engagement

Studying and theorising around public engagement is by no means a trivial affair. Public engagement undergoes continuous change through time in response to shifts in the environment, which makes predicting its outcomes difficult. Deploying public engagement mechanisms involve preparing information for dissemination, active discussions with participants, collecting feedback from participants, and careful analysis of the feedback collected. The mechanisms have time sequences in-built explicitly for this purpose. Hence, it would be most appropriate to view it as an ongoing process. During this process, opinions are formed, developed, and morphed as information is presented; as time is allowed for reflection; and as discussion with other participants ensue. Yet, academic discussions have tended to focus on 'efficiency', 'success', and 'optimisation' (Rowe and Frewer 2004), which places emphasis on the results of conducting public engagement, rather than the practices of doing engagement. This predominately results-oriented approach necessitates studying public engagement in hindsight, or at most, under fairly simplistic temporal notions of 'before', 'during' and 'after'. The alternative is to view public engagement as a dynamic and complex phenomenon and acknowledge that a myriad of relationships are formed and disbanded in the process; and that these relationships, in turn, can affect future events. Of course, the tendency to focus on results is not confined to public engagement or stakeholder management. Recent years have, also, seen increased calls for a pluralistic approach to project management that similarly incorporates process research (Söderlund 2011). This means studying the project during different phases of its lifecycle and acknowledging projects as temporary organisations with evolving behaviours and goals.

5. Implications for future research

Having deconstructed the way public engagement is studied in the construction management literature, and the inherent problems of linking it to project success, the onus is now to offer an alternative conceptualisation. It would seem that part of the difficulty in merging public engagement with management theory has been the inability to rationalise public engagement in such a way that it bears clear associations with established constructs within management theory. Another problem seems to be the tendency to neglect the temporal dimensions of public engagement when exploring its impact both within its own system, and on other systems with which it comes into contact.

To address these problems, we posit that instead of trying to rationalise public engagement by finding specific connections to project outcomes, attention should be focused on understanding the public engagement process. This would shift attention to uncovering insights that lead to discovery of underlying connections between public engagement and project management processes. That is to say, it places more emphasis on the processes of managing the public as stakeholders to the project, rather than on how specific types of interaction will impact on project outcomes. The starting point would be to study public engagement as a phenomenon rather than as a means to an end, and to embrace its processes for all its dynamism, multiplicity, complexity and subjectivity. With this goal in mind, three major characteristics of public engagement are presented below.

5.1 Public engagement events attract a loose membership of participants

Public engagement for urban planning projects are exemplified by the inclusion of a large cohort of stakeholders, who break from their usual living routines to come together to discuss a particular project, within a specific and well-defined timeframe. Because many of the events are open to the public, participants may come and go as they please. For many of the open forums, there is no pre-requisite for attendance apart from pre-registration, and someone who participates at one event may not necessarily return to the next. Closed door discussions and focus groups may be more selective in its membership, but individuals may still opt to attend events out of sequence, or may become involved with the discussion at a later stage than the majority. Hence, membership within the public engagement process is changeable and eludes definition, and involvement is contingent on presence and participation. Each member who interacts with the project impacts it in different ways and to varying levels of depth, magnitude, and permanence.

5.2 The public engagement process is subjective and value-laden

All individuals enter the sphere of engagement with their own agendas. A participant may merely be curious about the project and wish to obtain more information. Alternatively, they may be personally affected and have a personal stake in the design, or may wish to lobby on behalf of a collective for certain facilities to be provided in the local vicinity (or conversely, to be removed from the vicinity). These ulterior motives are unique to each individual and will colour how they interact with the process. Similarly, project owners, as well as their technical consultants, also carry ulterior motives and it is worth noting that the value judgements held by owners and consultants, in themselves, have no greater inherent validity than those held by laypersons (Rowe *et al.* 2005). Accordingly, public engagement processes can never be value-free.

5.3 The timeline for public engagement differs to the timeline of the project

There is a temporal mismatch between the public engagement and the project design period, such that what may be achieved during public engagement exercises may be restricted by the information available about the project. For example, if the participants' estate has been earmarked to be demolished to make way for new development, their most likely concern would be the amount of compensation they can receive, and where they will be relocated to. However, the project owner will not be able to provide them with this level of information if they are still in the plan-making stage. Similarly, a hypothetical new development, which may bring vibrancy to the area and bring relief to the shortage of housing and/or employment opportunities, will target to benefit a population that does not yet exist and, hence, is unable to represent its interests at public engagement events. Conversely, those who are presently affected will dominate the proceedings. In these types of scenarios, which are by no means uncommon, consensual decision-making is unlikely to ever be reached, and support for the development are unlikely to be garnered.

6. Concluding remarks

The three observations above sketches out the framework within which public engagement operates, and gives an indication as to the difficulties of managing such a process. Some of these problems might benefit from the application of management theory. Indeed, early on in the paper we pointed out that, because public engagement is conducted concurrently to the project, public engagement issues are also project management issues. We suggest that public engagement and project management theories have much to offer each other, so as long as the underlying assumptions for each are made explicit. Our point of challenge is in the connection between public engagement and project success, a link which has been established by viewing the public as external stakeholders who have the ability to influence a project's outcome.

The dominate view within project management has been to conceptualise public engagement within a stakeholder theory framework. Using stakeholder theory necessitates placing external stakeholders, such as the public, on the periphery of a project. Conversely, the complex nature of public engagement as described supports the premise that these processes constitute complete ecosystems in their own right. Focussing on the complications and idiosyncrasies of these ecosystems, rather than on how public engagement influences project outcomes, frees us from needing to constantly reference it in respect to the project. This in turn allows us to make better sense of the interfaces between public engagement and the project through time and through the eyes of different stakeholders. Accepting the uncertain nature of public engagement processes, and placing emphasis instead on how events change and develop over time, allows us to understand public engagement as a phenomenon that is decoupled from project success.

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Consensus building in the pre-design phase of building projects

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Abstract

Building projects are unique manoeuvres in which numerous participants who possess different skills work together to complete various tasks. Working processes vary in complexity from simple to very complex. Although the building construction sector has traditional ways of structuring projects, project management professionals are continuously seek new process models and ways to cooperate between people and project participants. This paper focuses on processes in the pre-planning phase of a building project and is based on exploratory study where the conceptual and empirical literature about construction processes and decision-making were reviewed. Over thirty existent models were identified and thirteen of these models, which take a decision making into account, were more closely studied. In addition, decision-making models in other fields were surveyed. Using a hermeneutic cycle approach, the aim of this paper is to investigate a preferable model for the pre-planning phase of construction projects that can produce the main objectives, which is to best serve the end user and the project as a whole. As a final result a new model in the case of the pre-design phase of the building process is introduced and discussed. This paper asks what we have learnt from these foci.

Keywords: consensus building, target setting, decision-making, construction project management, pre-design phase

1. Introduction

For a typical building project, many stakeholders work together to set goals and to design and construct a complicated product that is somehow unique. What results is a combination of numerous actions and their interplays, both planned and accidental, that are produced among temporary participants in a constantly changing environment. Overall, building projects are becoming increasingly fragmented and more challenging to manage.

During the pre-design phase of construction projects, decisions are made that have fundamental and far-reaching effects on the product's appearance, performance, and costs. The pre-design phase begins with assessing the initial needs and continues to the schematic design phase, when a project's greatest assets can be added or left aside. In the pre-design phase, each participant in the building project has unique involvement and represents various desires for the project and final building. Those participant needs and requirements do not always coincide. In this type of environment, decisions are not easy to make. Too often, important decision-making is dispersed in a hierarchical manner, with local optimisation procedures hindering the achievement of high-value results (Kähkönen et al., 2013). Decision-making is the process by which organisations are structured and restructured. The variables to be considered are often uncertain, and decisions are constrained by incomplete or missing information. According to Hirokawa and Poole (1996), a group's decision-making process is much more than simply making decisions, as it includes information sharing, socialising, relating to both people and groups external to the group, educating new members, defining roles and status within the group, meeting rituals, and various physical activities.

The aim of this paper is to investigate a preferable model for the pre-planning phase of construction projects that can meet successfully the main objectives, which is to best serve the end user and the project as a whole. Conceptual and empirical literature about the process of construction and decision-making was reviewed. Over thirty existent models were identified and thirteen of these models, which take decision making into account, were more closely studied. In addition, decision-making models in other fields were surveyed. The study is using a hermeneutic cycle approach (Ramberg and Kristin, 2005), going through five deepening cycles to approach a deeper understanding. The acquired information was analysed and synthesised to find preferable decision-making processes for a building project's pre-design phase. In the context of the pre-design phase, a new decision-making model is introduced.

The rest of the paper is organized as follows: in section two the approach and the aim of the research have been presented including selection criterion for the final decision making model for pre-design phase of building construction projects. Section three introduces briefly twelve studied existent models for the pre-planning phase of construction. Section four presents a new decision-making model in the context of the pre-design phase as a result of used method. The discussion and the reasoning from the topic have been shown in paragraph five. Conclusions are drawn in section six.

2. Research approach and aim

The research is conducted by using a hermeneutic cycle approach and utilising literary research. The structural model for the cycles of iteration was a reducing spiral. Each iteration builds on knowledge from the previous cycle. In our study, it was possible to detach five deepening cycles in a hermeneutic approach to achieve a deeper understanding: to seek a model or approach that improves the target setting in the construction pre-planning phase, to define a theoretical approach, to recognize the existing models and those used in other fields, and to analyse and synthesise the results.

The aim of this research is to investigate a preferable model for the pre-planning phase of construction projects. The criteria for literature search were created as a result of the hermeneutic process. The following criteria were used: 1) the decision-making model can produce the innovative main objective, which is to best serve the end user and the project as a whole; 2) the know-how of all participants is obtained to support decision-making; 3) a systematic process for decision-making is used; and 4) an integrative method is used to control the fragmented building process.

Conceptual and empirical literature about the process of construction and decision-making were the main sources for understanding current practices and models behind those. Over thirty existent models in the pre-design phase of the building project were identified. Thirteen models which take a stand on the decision making were examined more closely. These models are shortly introduced in section three. In addition, potential decision-making models in other fields of industry were surveyed. In the context of a pre-design phase of a building project, decision-making model to determine the objectives was selected and it is presented in section four.

3. Concepts supporting decision making of a building project in the pre-design phase

Various concepts, models and systems can be used in the pre-design phase of a building project. Theoretical and practical concepts have been created to support decision making, albeit the decisions are usually made without using the existing concepts. Thirteen of existing concepts are shortly described.

Many concepts are based on comparison and evaluation of alternatives. Analytical Hierarchy Process (AHP) is a multi-criteria decision technique which is used as a base for many other concepts. It is a numerical approach which includes identifying the objectives, criteria and alternatives into a hierarchy, pairwise comparison, evaluation and the synthesis (Saaty and Peniwati, 2008; Mahdi and Alreshaid, 2005). Non-structural fuzzy decision support system (NSFDSS) is based on AHP and it helps decision making especially with complex construction problems (Tam et al., 2006). Decision support concept (DSC) is an application of multi-criteria method for decision making at the planning phase of construction (Janac et al., 2013). On-line system for construction (OLSC) is a multi-criteria method for analyzing various construction alternatives by taking into account economical, qualitative, technical and other issues (Kaklauskas et al., 2007).

Some concepts like quality function deployment (QFD) (Govers 1996; Kamara et al., 1999) and client requirements processing model (CRPM) (Kamara et al., 1999) help to improve the processing of clients' requirements in construction. Also the Generic Design and Construction Process Protocol (GDCPP) aims to figure out the client's needs at the pre-project stage. The Generic Design and Construction Process Protocol is a model which considers interests of all the parties involved in the construction project. The GDCPP is divided into subphases and the preconstruction phase concern especially the definition of clients' needs. (Kagioglou et al., 2000.)

Some concepts clarify stakeholders' roles and responsibilities in the early phase of project. Fuzzy Similarity Consensus Model (FSC) clarifies the roles and responsibilities of construction project owner and contractor project teams at the project initiation stage. The purpose of the model is to reach common agreement of stakeholders' roles and responsibilities. (Mohamed 2011.) The CPR System Models can be used to present the various parties' responsibilities in the project (Kartam and Ibbs 1996). Alliance is a project delivery strategy which aims to positive outcomes for all the alliance members by sharing the commitment to common project goals (Walker et al. 2002).

Schematic Design In A Day (SDIAD) is a process which is successfully used at project inception and schematic design phase. All members of the project together contribute, typically during a one day, the planning of the incoming construction project. (Miles 1998.)

Building information modeling (BIM) is a 3D-model which is a visualization tool and can contains information of quantity, costs, energy analysis, collision checking and more (Hessedal and Berglund 2012). The BIM can be used from early design phase to construction and also as a management tool. IDEF0 is a method for modelling the decisions, actions and activities and the functional requirements. The model is a graphical diagram where the series of presented hierarchical activities. (Bouchlaghem, Kimmance and Anumba 2004).

4. Consensus building

The consensus building approach has been developed as an alternative to parliamentary decision-making (Susskind and Chruikshank, 2006). Carpenter (1999) has argued that consensus decisions are suitable when a problem affects several parties, a clear solution is not available or when parties disagree with the solution. This method helps participants better understand an issue and the other parties involved and helps them find the solutions that are in the best interest of the whole. Consensus building is a process that enables various stakeholders to work together by helping participants to examine things in new way, which provides an opportunity for innovating and resolving issues (Innes, 1999). With this approach, parties aim for united and overwhelming agreement that is based on informed decision-making (Susskind and Chruikshank 2006). The use of consensus building requires certain things, such as all parties willingness to negotiate. The design of consensus building is commonly initiated by a neutral party, the group of participants, or other interested parties (Carpenter, 1999). The process itself is time-consuming, which is particularly relevant in matters of contention and uncertainty, in which all participants have incentives to find mutual reciprocity that is in accordance with their interests (Innes, 2004).

Consensus building has roots on practices and theories related to interested bargaining (Innes 2004). It is reported to have been utilised in many fields, such as urban planning (Balducci, 1999; Edelman, 2007), budgeting (Baiocchi, 2001), affordable housing (Susskind and Podziba, 1999), environmental management (Regan et al., 2005), health (Hughes et al., 1999; McKearnan and Field, 1999), regulatory negotiation (Ryan, 2001), water resource management (Connick, 2003), Growth management (Innes et al., 1994), international relations (Susskind et al., 2002), and several other fields. Although there have been attempts to make decisions based on the consensus in the construction pre-design phase, consensus building is not seen employed as a theoretical model in this context.

4.1 Benefits and criticism of consensus building

Consensus building can aid participants understand issues of importance, the values of other parties involved, and offeran opportunity to create a shared vision, values, and action. (Innes, 1999). The most important benefit is that using a consensus building process increases the quality of the solutions developed by the parties. This is the outgrowth of a comprehensive analysis of the problem (Gray, 1989). Because participants have different perspectives, more standpoints are considered. A variety of perspectives may lead to more innovative solutions (Gray, 1989; Innes, 1999). Consensus building guarantees that all parties' interests will be protected (Gray, 1999). In the process, participants make final decisions themselves, thus providing all participants with the opportunity to ensure that their interests are represented in the agreement. In the consensus building process, people who are most familiar with the problem are able to participate in solving it. The ability to participate in the problem-solving process also enhances the participants' acceptance of the solution and willingness to implement it. (Gray, 1989.) The participatory process also can foster greater group cohesion and interpersonal connection (Gray, 1989; Hartnett, 2011). As a result, participants have ownership of the outcome of consensus building processes.

Additionally, criticism has been presented concerning the use of consensus building. Consensus building is claimed to be a time-consuming process, but it is a common problem that some participants do not have the time, vitality, or authorisation to commit to this type of process (Yaffee and Wondolleck, 2003). In collaborative administration, one commonly noted problem is a power imbalance between participants (Short and Winter, 1999; Tett et al., 2003; Warner, 2006). Notably, it is problematic when crucial participants do not have their aspects of organisational infrastructure represented in collaborative processes. In some cases, the problem is that organised participant groups do not represent single participants collectively (Buanes et al., 2004) or that some participants do not have the expertise to take part in deliberations about technical problems (Gunton and Day, 2003; Lasker and Weiss, 2003; Murdock, Wiessner, and Sexton, 2005; Warner, 2006).

4.2 Models for Consensus building

The design of consensus building is commonly initiated by a neutral party, a group of participants, or other interested parties (Carpenter, 1999). There are multiple stepwise models for making decisions by consensus, each varying in the amount of detail provided for each step and the ways in which decisions are finalised. This paper introduces two consensus building models.

Strauss's (1999) consensus building model begins with the problems and issue and works toward a shared vision of the future using the following steps: star-up, process design, go/no go, consensus building, and implementation. These phases are introduced in figure 1.

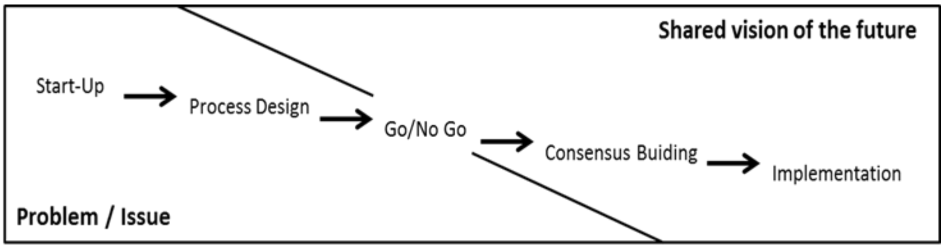

Figure 1. Stages of Consensus building (adapted from Strauss, 1999)

The "start-up phase" begins when some of the initial participants acknowledge that the problem is beyond the decision-making authority of a single participant and decide to explore the possibility of a collaborative decision-making process. Next is the "process design phase", where the assessment of the problem or issue plays a central role. This phase also involves determining who should be involved and how to proceed. After the first two phases, participants must decide whether to commit to a consensus building process, which is the "go / no go phase".

In the "consensus building phase", participants convene in a series of meetings. It is common that these meetings are mediated or facilitated by a third party. The consensus is built step-by-step, from creating a common understanding of a problem or issue to coming to an agreement about a solution. The "implementation phase" is the fulfilment of the agreement. Implementation is often performed by a single organisation; however, participants may want to monitor implementation to ensure that an agreement is precisely and effectively carried out.

Susskind's (1999) definition of the consensus building process differs from Strauss's (1999) analysis, though only slightly. In Strauss's model, the "process design phase" includes a conflict assessment, whereas in Susskind's model, assessment is included in the actual consensus building process, which may or may not continue after the first "convening phase". One interpretation of Strauss's model could be that the initial participant or participants go through a preliminary process design phase and decide whether it is necessary to begin a wider discussion at all (Edelman, 2007).

Similar to Strauss, Susskind (1999) sees the consensus building process as a five-step model: convening, clarifying responsibilities, deliberating, deciding, and implementing agreements. The essential steps of Susskind's consensus building model are shown in figure 2.

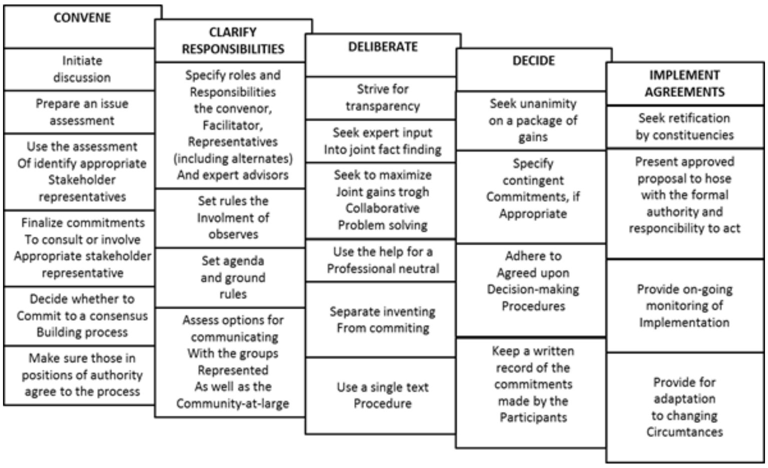

Figure 2. Susskind's essential steps of consensus building (Adapted from Consensus Building Institute, 2004)

The first step of Susskind's (1999) consensus building is convening, which means embarking on a discussion about whether to use a consensus building process. Typically, this is triggered by a key participant or interest group. The convenor or group of convenors must identify the first round of participants and the neutral mediator who will consider a consensus building process. After the initial mapping of interests, the first-round participants should be asked to name others who might be affected by the decisions and should be considered participants in the process. Accurate participant commitment and assessment of interests lead to singular summaries of participant conclusions concerning the issue. The activity associated with convening is the preparation of a written conflict assessment. The conflict or issue assessment is prepared by the neutral mediator, and it has two rationales: it maps the interests of all participants and helps identify other possible participants who may be affected by future decisions. The successful creation of an acceptable conflict assessment can lead to organising the consensus building process. Towards the end of convening, a decision is made to commit to the process.

After the conflict assessment and the decision to proceed are completed, the next step is specifying roles and clarifying the responsibilities of all participants. The round rules must be established and attached to final conflict assessment. Typically, the round rules define the general rights and responsibilities of participants, decision-making processes, meeting procedures, communication, ways to handle disagreements, and approaches to implementation of the agreement. All participants are required to sign the round rules.

The purpose of deliberation is to achieve collective gains through the collaborative construction of solutions and alternatives. Deliberation is the opposite of positional hard bargaining. The approach is based on unconditional reciprocal problem solving, even in the face of strong differences and personal antagonism. The consensus building should be transparent in all phases of the process, and the participants should be encouraged to actively listen to ensure that all communication is properly understood.

In a consensus building process, voting is not a primary decision-making method. The aim of the decision-making phase is to maximise mutual advantages without omitting any value-adding solutions. The significant parts of decision-making are to ensure the maximum joint gains of the whole and confirm that all who are affected by the decision can live with it. All available efforts are made to ensure the fulfilment of as many interests among the participants as possible. Consensus building is designed to achieve unanimity within the mutually agreed-upon schedule. In practice, decisions are considered complete when overwhelming support is achieved.

Once the decisions have been reached, the implementation of an agreement may be ratified by all participants and their constituents. The agreement should indicate how the implementation will be monitored and enforced and should provide a process for resolving conflicts that might arise.

5. Discussion

The complexity of construction and the fragmented nature of the construction industry have effectively resulted in linear, uncoordinated, and highly variable project processes, thus making cooperation challenging. Different interest groups of a building project have different points of view about the production of a solution. End users are interested in solutions that support their activities. For the constructor, the building is an investment that must be profitable. A contractor is interested in time schedules, achieving the necessary quality level, and so on. Additionally, teams and individuals who have different skills, knowledge, and expertise but who may not have previously worked together make integration difficult to achieve (Baiden et al., 2006). Nonetheless, the know-how of every participant is needed, and the process must promote the special know-how of all participants and get them to cooperate with each other. Traditionally many operators do not have motivation to work collaboratively, as they promote benefits that maximise their own gains without considering the benefits of other participants. However, in the context of the construction industry, successful project delivery and performance depend on how individuals' knowledge and experience can be integrated as a team (Moore and Dainty, 1999).

In construction projects, decisions that have fundamental and far-reaching effects on appearance, performance, and costs are made in the pre-design phase. However, it is often a disorganised and poorly structured phase that does not clearly add value to the whole project. Many decisions are made using an ad hoc process that subsumes the differences of opinions within participant groups. The targets often remain vague or are not well understood by the entire project group. A decision that has been made in one sector can affect the solutions of several other sectors. In the pre-design phase, a project's greatest values can be added or left aside. The selection of the most applicable management model is critical when pursuing the best outcomes for customers and all participants.

Consensus building is an interesting alternative to top-down decision-making, which is commonly practiced in hierarchical organisations. Consensus building is an organised, group decision-making model in which participants develop decisions in the best interest of the whole project without fear that their interests are not protected. In the process, participants make the final decisions themselves, giving all participants the possibility to ensure that their interests are represented in the agreement. The organised process can aid participants understand the issue of importance and the values of other parties, and it provides an opportunity for innovating and resolving issues by helping participants examine things in new ways. The consensus building model, that includes and respects all parties and generates as much agreement as possible, thus settings the stage for greater cooperation when implementing the resulting decisions.

Consensus building is claimed to be a time consuming process. That can be problematic for some participants who do not have the time to commit to this type of process. However, decisions with fundamental and far-reaching effects on appearance, performance, and costs are made in the pre-design phase. If the participants fail to make fundamental decisions in the early stage of the project, their repair can prove to be impossible or very expensive in the later stages of the project. A pre-design phase must combine the needs and requirements of all participants into one joint project. A decision making model that can utilise the know-how of all participants and find the solutions in the best interest of the whole is highly important for the success of the project.

Although consensus building has not yet been tested in the context of construction projects, it provides promising elements to produce surplus value. Consensus building is an alternative to parliamentary decision-making, and it can be an interesting approach to value adding. Therefore, in the context of construction projects, an integrative decision-making method is needed.

6. Conclusions

In the context of building projects, decisions that have fundamental and far-reaching effects on appearance, performance, and costs are made in the pre-design phase. These decisions involve diverse groups and are often the most difficult to make. The different objectives and opposing views of the parties can prevent them from finding the best viable solution. This is particularly the case when group members have competing agendas, opinions, and different knowledge bases. Decisions are often achieved using an ad hoc process, which lacks a clear decision-making process that subsumes the different opinions within participant groups. Our study reveals that there is a clear need for the participants' early involvement in the decision-making process, which is able to embrace the project in question and its different objectives as a whole.

Consensus building helps participants understand an issue and the other parties, and it offers an opportunity to create a shared vision, values, and action (Innes, 1999). Consensus building has been widely used in many fields. This new process for the pre-design phase of construction can be helpful for maximising the full benefits of diverse knowledge among participants. It includes systematic steps to combines different parties and it can aid them to make decisions, which benefits the project as a whole. Consensus building can be value adding component of early pre-design decision-making. The next logical step is to adapt the model to the context of building projects and test it in action.

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Mechanisms for industry transformation: analysis of organisational citizenship behaviours in a design-production innovation

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Abstract

A well performing housing sector is critical to national economic and social objectives. The Australian housing sector is failing. Significant inefficiencies in the construction process has resulted in a 40 per cent increase in average construction time over the last fifteen years which has resulted in increased costs. The sector is in need of transformation. Our study on design production technology innovation suggests such a transformation is catalyzed by extraordinary leadership that enables integrated systemic solutions in an aggressive, risk averse and litigious industry. The role of exercising such leadership often emerges among housing developers. A challenge to these leaders is that the housing sector is highly competitive and aggressive and actors are motivated primarily by profitability. Such behaviors tend to be institutionalized and thus inhibit change. It is proposed that leaders can institute a major change initiative without compromising on organisational profitability. Large scale innovations require extraordinary levels of collaboration among key actors and it is speculated that they are led by champions who display unusual citizenship traits. This paper reports on a nationally funded 3 year study on offsite manufacturing and seeks to explore the prevalence of such organisational citizenship behaviour (OCB) in the housing industry generally, and in housing developers specifically. OCB is a complex phenomenon which arises when individuals voluntarily assist in the workplace to implement courageous and risky initiatives without either implicit or explicit reward for seeking to achieve this noble greater 'good'. There is a body of research developed on OCB and although theoretically there is support for the conceptual effectiveness of OCB in an organisation there has actually been little empirical evidence linking OCB with effectiveness and outcomes. Some examples have been trivial and there is work to be done to identify linkages between OCB and significant outcomes as well as linking different types of citizen behaviours to different outcomes. OCB has not been explored to a great extent theoretically nor empirically in the housing sector. There is nothing more risky in the housing sector than introducing new policies, procedures or practices that may erode an organisation's profitability and therefore trust in leaders is critical. Identifying the prevalence of this construct both theoretically and empirically will contribute to the field of housing research and also to the practice of leadership in the housing sector.

Keywords: *industrialised building, industry leadership, citizenship, opportunity management*

1. Introduction

The housing sector has always been seen as an important part of the construction industry and is considered a key indicator of the health of the Australian economy. The housing sector generally makes up 50% of the construction industry and in 2012 the construction sector represented 7.7% of the GDP of an economy (ABS, 2012). In Australia in 2009 the residential sector accounted for approximately $70b and from 2000-2009 the average was 47% of the total spend in the construction industry (ABS, 2010). It is a critical time in the Australian housing sector. "Australia's housing system is under acute stress (Yates 2008; Grattan Institute 2013).We were once a nation characterised by good housing for all and the Great Australian Dream, but we now have one of the most unaffordable housing markets in the world (NATSEM 2011), chronic housing undersupply (National Housing Supply Council 2013), a rapidly shrinking public housing safety net (SCRCSSP 2001 and 2013), substantial pockets of concentrated poverty and disadvantage in the private housing market as well as in the social rental sector (Hulse et al. 2012) . Each night more than 100,000 Australians are homeless (ABS 2012)." (Baker et al, 2015). The housing industry is failing to meet demand (NHSC, 2012) and when demand is met the housing is costly because of construction inefficiencies. The industry is faced with a crisis in our capacity to plan, design and construct to meet our nations needs unless we act immediately to improve its capacity for a more efficient, effective and innovative supply system. These inefficiencies have resulted in a 40 per cent increase in average construction time over the last fifteen years (Gharie et al, 2010) resulting in increased costs. Over the last twenty years housing affordability has worsened; with the number of homeowner purchasers with housing costs in excess of 30 per cent of income more than tripled (Wood et al, 2014).

Housing research in the past has focused on policy and planning problems as the way to address supply challenges (Holmes et al, 2008). To date the housing supply debate has been largely focused on housing demand, affordability and land supply. Lack of innovation in housing supply is considered a barrier to the sector's capacity to meet market demand (NHSC, 2012) and yet very little attention has been paid to challenges experienced by those involved in the design and construction stages of supply. One of the suspected overarching key causal factors of poor housing supply is the fragmented nature of housing supply with numerous actors involved with their own objectives. A lack of coordination and integration between supply chain actors can exacerbate barriers to innovation. It is proposed that a more cohesive supply chain would prove beneficial to all housing sector stakeholders.

It has been proposed that one strategy for achieving greater cohesion in the supply chain is through offsite manufacturing. Offsite manufacturing (OSM) is a production technique in which prefabricated components of a building are manufactured in a factory and transported to the site for erection and assembly and is one of the most significant innovations that is now emerging in the Australian housing sector. Key outcomes of OSM is improved quality design, reduction in time, productivity improvements, improved safety and wellbeing, reduced rework and thus overall improved housing affordability. However, OSM requires re-engineering of the entire project development process, since traditional construction is achieved mostly through on-site activities. When housing developers attempt such re-engineering for new ideas it also requires support from key stakeholders for example, government agencies to set up projects to ensure the right conditions for such an innovation – as well as designers and fabricators with a deep commitment to solving design, construction and production problems. Thus a key overarching constraint to uptake is that OSM is perceived to require extraordinary levels of collaboration (London et al., 2014). Introducing innovations such as OSM in construction processes and design production technology can thus effect revolutionary change. Such innovations can only succeed with impact as whole-scale industry transformations through leadership that catalyses the entire development chain. To enable such integrated systemic solutions in what is considered to be an aggressive and litigious industry requires extraordinary leadership qualities. Past research has shown that housing developers are the *linchpin* in the urban development chain; they can significantly influence housing innovations (London et al; 2014). This research will therefore explore:

What is the nature of transformative leadership behaviours in the housing development chain in large scale offsite manufacturing collaborative efforts?

This study is important to housing construction researchers and practitioners because there has been very little sociotechnical research on adoption and diffusion of technical innovations, which are critical to housing sector performance and thus to national economic outcomes and individual/ community well-being. The housing sector is significant in most countries and investigation of innovations that ultimately improves housing affordability is vital. It is universally accepted that a well performing housing sector is critical to national economic outcomes. Housing also affects us at individual and community levels and influences our wellbeing. We all have the right to safe, secure and affordable housing. This paper is part of a three-year national Australian Research Council study: "Efficient Construction: analysis of integrated supply chains on novel offsite manufacturing housing" which is seeking to explore collaborative practice in housing supply chains in Australia. Through our analysis and results from the first two case studies it has emerged that an examination of individual leader behaviours is important, as there appears to be a close link between large scale collaborative efforts in OSM and leader behaviours. For this paper, we focused on the construct organisational citizenship behaviours in the context of two detailed qualitative case studies.

1.1 Conceptual Model of Influences on Collaborative Practice

The role of champions in driving large-scale industry change cannot be examined as a phenomenon separate from the relationships they forge in order to accomplish such change. Therefore it is critical to understand the collaborative relationships that leaders forge in order to carry out industry transformation. A model shall help us to understand the nature of large scale collaborative efforts in theoretical and practical ways as a blend of underlying economic and social structure and individual behaviour. We shall explore collaborative activity across four dimensions:

- Collaboration and the nature of work: Work in construction involves project based work. Work may be unpredictable and volume of production may vary. Work in construction can also have very different outputs ie large scale complex projects that run for many years to small scale short term projects. OSM products and operations may still have to be flexible and responsive to project environments.

- Collaboration and the nature of individuals: Construction collaboration is focussed on performance ie time, quality, cost. However, the link between collaboration and performance measures is not simple. Collaboration achieves other outcomes- new products and processes, learning, power, better coordination and communication which are difficult to capture and quantify but often lead to more tangible outcomes. People invest in the collaboration act to achieve social, cultural, intellectual and financial capital. Such investment may involve trade-offs and failures and may not result in immediate success.

- Collaboration and the nature of markets: Collaboration takes place between organizations or between organizational units. Supply chains are embedded in a larger context shaped by institutional factors: economics, laws, governance, regulations, industry and societal culture. These 'institutions' create and recreate the 'rules of the game' ie the way things are done. The formal and informal dimensions of institutions and organizations and how these shape and are shaped by collaborative activities influences collaborative environments.

- Collaboration and the nature of systems: Collaboration in construction is a mixture of technology and social processes. There is a complex ecology of human and non-human elements. Collaboration should emphasize the role of people. It is important to examine how collaboration arises between people. However, material elements like products, IT systems, artefacts and equipment can play a critical role in collaboration as well.

Underpinning all dimensions of the model is the question of whether collaboration and competition are mutually exclusive. We suggest that there are creative ways to manage the tension between the two. We also suggest that collaborative practice more than likely both influences and is influenced by these four dimensions (see Figure 1). This paper focusses on the *nature of individuals* dimension

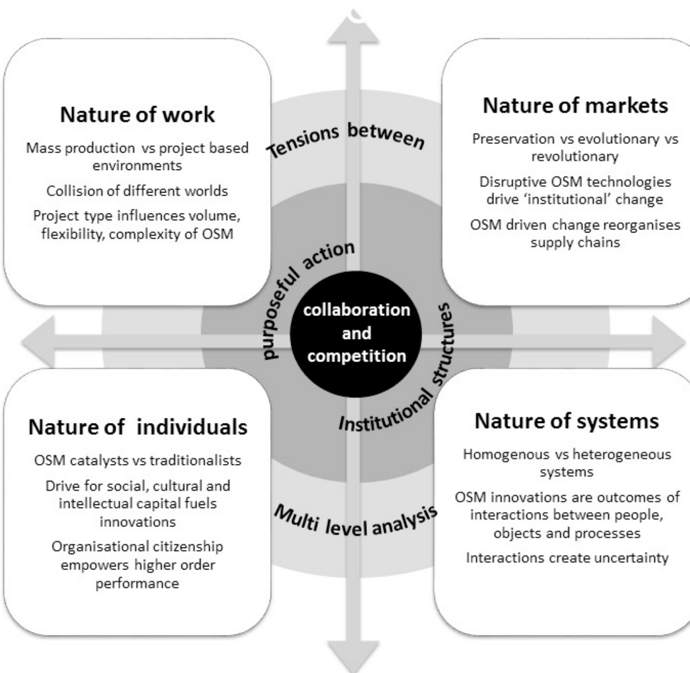

Figure 1 Influences on Collaborative Practice in OSM Housing Innovations

2. Transformative change

Introducing new initiatives is problematic because existing institutions inhibit change. An institution is a tradition, custom, convention, norm or ritual which has developed over time and has become standard practice. Such “rules of the game” can be identified through institutional analysis. In certain sectors such as urban residential development, institutions can hamper opportunities for innovations, in particular when these interlocking institutions are designed to support profitability at the expense of change. Yet leaders with vision may institute a major change initiative without compromising on organisational profitability. Two major change initiatives were explored using urban residential developments as the prime research site where innovations were achieved alongside profitability. The housing developer’s role as the key orchestrator and change agent in creating, inhibiting and changing the ‘rules of the games’ is critical to the housing development process. Importantly, such large scale innovations were found to require extraordinary levels of collaboration among key stakeholders.

2.1 Housing Innovations:

An innovation in the housing industry that has received increasing attention over the last five years is offsite manufacturing. Offsite manufacturing has been posited as a technology solution to many of the problems in the industry particularly increased construction time which is then linked to increased cost and thus decreased housing affordability. One of the suspected challenges that offsite manufacturing can assist with is the lack of coordination and integration between the actors in the development chain. It is proposed that a more cohesive development chain would prove beneficial to all housing sector stakeholders. Ad hoc examples and applications by housing developers attempting to integrate to solve specific problems, such as productivity, has had some success. However, these achievements and the detail of how integration is achieved has not been diffused readily throughout the sector and thus has had little real impact on overall sector performance. Whole-scale industry improvement requires a concerted effort to undertake a stepwise change. A key to the solution is to investigate successful examples of integrated chains which have resulted in wholescale change in the sector (London and Siva, 2011). The current housing construction model is characterized by traditional craft-based on site construction techniques (Loosemore et al., 2003) and there have been very few innovations in the housing sector that have created transformative change. However, one particular example of an innovation in Australia that had significant impact on the sector was a technical system that fundamentally changed the way in which footings are built. The Australian Housing Supply Chain Alliance commissioned a study to investigate this particular innovation so that lessons could be learned about the pathway for highly innovative firms seeking to explore and commercialise novel ideas. The study identified that the housing developer held a significant degree of influence over others in the chain, coalesced the actors and was the champion of the innovation (London and Siva, 2012). This study presented an innovation process pathway which identified the role of social, cultural and intellectual capital in changing barriers into enablers. Through narrative analysis, barriers to innovation and enablers were identified. Through the collection of stories, a key tool in narrative analysis barriers were identified to include; professional jealousy whereby engineers chose not to adopt the system as they were in competition with the inventor of the system; negative perceptions and attitudes to the innovation and to change; high costs incurred by the distributor of the footing system which in turn resulted in inflated prices of the system and lengthy and costly patent disputes and adversarial litigations.

Further to this various enablers to the innovation process were also raised including:

- mutual understanding and trust and strong support between participants to create a solution
- shared but different business and altruistic motivations
- participants shared philosophy towards risk taking which was influenced by the following considerations; economic rewards, trust in the credibility of other players and the authority and influence associated with specific participants whose support for the waffle footing system offered its members the confidence to adopt the system.
- the role of champions in the innovation process was raised as an important enabler. An innovation champion may be viewed as "a charismatic individual who throws his or her weight behind an innovation, thus overcoming indifference or resistance that the new idea may provoke an organisation" (Rogers, 2003, p. 414). In the case of the waffle footing innovation its wider diffusion was reliant upon not just an individual champion but also a group of champions working together across organisations.
- explicit and appropriate identification, alignment and integration of capacities between participants and development of alliances or relationships and collaborative efforts between participants to access required expertise and capacity for the innovation process
- acquisition and use of artefacts in developing reputation enabling credibility to be associated to the innovation. It was important to provide evidence [ie 'artefacts'] that were clearly understood and well accepted by the industry; these included accreditations, approvals and production of publications. They were critical for initial acceptance and also wider diffusion of the innovation.

The nature of leaders' behaviours in this particular detailed case study emerged as important to creating and enabling the innovation to be diffused in the sector. This concept is taken up further in this paper and explored in more detail.

2.2 Organisational citizenship behavior

A key characteristic of transformational leadership is organizational citizenship behavior and it is not well considered in the construction leadership literature. Construction leadership literature tends to focus on the individual's attribute, the 'hero' model, without explicit connection to their place of work or the organization; that is, not just the qualities of the person but underlying this is how the person identifies themselves and their place in the world – '*citizenship*'. Organisational citizenship behavior (OCB) is a complex multi dimensional phenomenon which can be an important aspect of human behaviour at work. Dennis Organ is generally considered the father of OCB. Organ expanded upon

Katz's (1964) original work. Organ (1988) defines OCB as “individual behavior that is discretionary, not directly or explicitly recognized by the formal reward system and that in the aggregate promotes the effective functioning of the organization.” Organ’s definition of OCB includes three critical aspects that are central to the construct. First, OCBs are thought of as discretionary behaviors, which are not part of the job description and are performed by the employee as a result of personal choice. Second, OCBs go above and beyond that which is an enforceable requirement of the job description. Finally, OCBs contribute positively to overall organizational effectiveness. OCBs arise when individuals voluntarily assist in the workplace to implement courageous and risky initiatives without either implicit or explicit reward for the behaviour for some noble greater ‘good’ (Organ, 1988). The ‘good citizen’ model includes the display of such behaviours as altruism, conscientiousness, loyalty, sense of fairness, individual initiative, acts of creativity and innovation, self-development, ‘sportsmanship’, courteousness and civic virtue (Podsakoff et al, 2000). Although there is extensive research on OCB and although theoretically there is support for the conceptual effectiveness of OCB on an organisation there has actually been little empirical evidence linking OCB with effectiveness and outcomes. Indeed according to Podsakoff et al (2000) some examples have been trivial in this area of research and there is much needed work to be done to identify linkages between OCB and significant outcomes as well as linking different types of citizen behaviours to different outcomes. There is a close relationship between OCB and transformational leadership. It is also speculated that individuals that display OCBs may tend to engender trust in followers and this is a most powerful motivator towards taking risky behaviours. This however has not been explored to a great extent theoretically nor empirically (Podsakoff, 2000).

There is nothing more risky in the housing sector than introducing new policies, procedures or practices that go to the heart of the organisation’s profitability and may erode that profitability. Identifying the prevalence of this construct both theoretically and empirically will not only contribute to the field of housing construction research but also to the practice of leadership and change in the housing sector. London and Siva (2012) have conducted a comprehensive analysis of innovation diffusion research and identified numerous studies in different disciplines. Each discipline typically sought to concentrate on investigating one main type of innovation. In this study we would seek to analyse the two innovations with the intent of identifying any industry wide patterns within the context of organisational citizenship behaviours. We build upon the earlier housing innovation small scale study that London and Chen (2011) conducted where some elements of like-mindedness and altruism were identified in the champions of the innovation. We suspect that there is significant merit in developing this construct as a way forward for the industry as we have already seen that the key champion displays some of the behaviours. The housing sector is rarely considered from the vantage point of the ‘developer’ or the development chain and yet this is how change is catalysed or undermined. Not only are there theoretical limits within the research on housing construction innovations but it is well acknowledged that there is a dearth of empirical work and available data supporting delivery of housing innovations. No study captures developers’ responses to grappling with and reconciling the dichotomy of a sense of citizenship towards ‘housing affordability’ and a commitment to organisational profitability.

3. Methodology

In analysing the data, we employed actor-network theory as a methodological approach (see Figure 2). Actor-network theory (ANT) overarches a range of theoretical and methodological approaches based on the premise that much of social reality can be understood as the outcome of actors (human and non-human) interacting in heterogeneous networks (Law 1992). From an ANT perspective, complex phenomena such as organizations, technologies, information technology systems and communities are all networks made up of people, objects, documents and other entities exercising some form of agency, shaping their relationships with other actors, and in doing so creating network effects. Much of the "work" of creating a network is often, though not completely, carried out by a key actor, referred to as a prime mover. The prime mover seeks to enrol other actors into a network, and to subsequently stabilize this network, in order for the network to address a certain problem (Callon 1999).

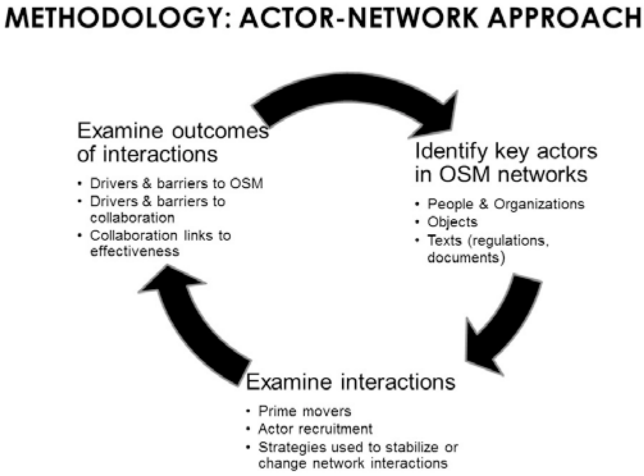

Figure 2 Actor Network Theory Methodology

Data was collected from two case studies. We used ANT to identify key drivers of change in both organizations and to examine how they established interactions with other actors in order to effect such change. Eight interviews were conducted in the first company and six were conducted in the second. The results of the analysis is presented and in particular summaries of the thematic coding of barriers and enablers to offsite manufacturing and then barriers and enablers to collaborative practice are summarised in Tables 1 – 4. The data was then interrogated specifically for evidence of organisation citizenship themes including the display of such behaviours as; altruism, conscientiousness, loyalty, sense of fairness, individual initiative, acts of creativity and innovation, self-development, 'sportsmanship', courteousness and civic virtue. Specific quotations that suggest these leadership qualities were extracted.

4. Results and Discussion

The empirical settings of our study are referred to here as Company A and Company B. Company A is a diversified property group that was recently acquired by an international real estate company. It focuses on the development of residential, commercial, industrial, and investment properties, as well as on income development/ investment and property management, and it has an established reputation for carrying out mega-projects. One of its key projects was its involvement as a partner in a joint consortium undertaking the multi-stage redevelopment of the Athlete's Village for the 2006 Commonwealth Games into a residential estate, a project valued at more than AUD $40 million. The plan for the residential estate involved the construction of over 1000 dwellings, with one fifth targeted for the provision of social housing. The project also included refurbishing a number of heritage buildings as well as the creation of wetlands and parklands. Such projects are in line with the organization's aim of achieving sustainable communities; as one executive mentioned, it was not the company's style to just "build houses and walking away". An important element of the development effort was the design and construction of low- and medium-storey apartment buildings, usually made up one one-, two-, or three-bedroom apartments, in five stages. In the first three stages of the development, managers from Company A noted that there were recurring problems related to the way floors were laid, notably risks of falls from heights and the potential inhalation of dust by workers as they sought to grind floor panels. In 2012, Company A brought together key suppliers, designers and consultants into a team that developed a prototype for a cassette floor, one that could be prefabricated offsite and was light enough to be craned into place. After six months of frequent, face-to-face meetings, a prototype was developed and was eventually used in Stage 4 construction, which involved a five-storey timber building. The use of the cassette floor reportedly led to the building being completed one month early and to building costs being reduced by 25%. The cassette floor is showing significant potential in terms of driving large-scale projects; shortly after the successful incorporation into the five-storey building, it was successfully used in the construction of 48 two-storey homes which were completed swiftly over a six-and-a-half month period. We chose Company A for this study because of its drive for innovations which have strong potential for driving future large-scale initiatives, coupled with its distinct orientation towards "higher order" performance goals such as community sustainability and worker well-being and safety. Company B is a regional company operating in two locations in South Australia. Organization B has evolved over time, having its beginnings with a small firm founded by a single entrepreneur, and then expanding over time to include multiple businesses, four owners, and multiple managers. The company maintains properties and provides kitchen solutions, but its core business is in the design and construction of site-built houses as well as transportable homes, with the latter being manufactured on company premises then trucked to specific locations. The company's capability for building transportable homes has allowed it to penetrate a number of markets that had previously been underserved, mainly because of the absence of trades in specific areas. In recent years, Company B has pushed its transportable line even harder through the development of a new innovation: a concrete floor that remains light enough to be transported, but allows houses to be buried or installed at ground level. The lightweight concrete floor is in contrast with other transportable examples, which are generally built half a meter above ground level and are generally linked to energy, noise, and ventilation issues. We chose Company B for this study because its innovations in transportable housing have positioned it for potential large-scale projects in diverse sectors. The company has successfully undertaken retirement village projects;

notably this potential for serving aging communities could be further heightened with its new concrete slab innovation because it allows for easier (ground-level) access to homes. Company B has won allocations under national rental affordability schemes, which indicate its potential for serving markets in need of affordable housing. The Company has provided temporary housing structures for the mining sector. It has partnered with the Department of Defense to address housing issues on Indigenous lands and has also explored taking their innovations into more commercial spaces; for example, one of their proposals involved the use of the concrete slab as a component for prefabricated bathrooms for a hospital in Adelaide. At the same time the company executives have stated that they strive to maintain a key position within the community. The company is well-known to its regional customers as a dependable and trustworthy provider of homes, and to its suppliers as a partner who builds fair, long-term relationships that transcend "chasing a buck".

4.1 Barriers and Enablers

The barriers and enablers to offsite manufacturing were identified across the two companies. The four most commonly considered barriers included technical challenges, resistance to the new innovation, need for significant investments and regulatory challenges and the five most common enablers included; champion, performance incentive (revenue), readiness for change, performance incentive (cost) and transferability of innovative solution from another situation. Importantly the role of the champion was considered the most significant enabler to catalysing the offsite manufacturing innovations. Our analysis also included coding text in relation to commentary on collaboration barriers and enablers. The four most predominant collaboration barriers were lack of skills, focus on own goals, lapses in information-sharing and championing the relationship over performance. The most predominant collaboration enablers included; working off shared plans, co-location, frequent meetings; recruiting people with the right qualifications, shared history and loyalty and the leader enablers diverse and multiple contributions. These appear to match the attributes of organizational citizenship behaviours. However we then developed another layer of analysis whereby we selectively attempted to identify commentary and explicitly identify quotes to map evidence of organizational citizenship behaviours.

Table 5 Organisational Citizenship Behaviours Mapped to Cases

OCB CHARACTERISTIC	CASE 1	CASE 2
Altruism *feelings and behavior that show a desire to help other people and a lack of selfishness*	And I guess that's relevant because I wanted to give you that sort of background and who we are as a company, we're very focussed on obviously making money. That's what we're in business for ***but we also have very strong sustainability focus and that's sustainability outside of just environmental sustainability*** even though that's a key part of it ***but it is also just about community sustainability and the development of what we call communities as opposed to just having a development where we buy a block of land and build 300 homes and walk away.*** We actually have a very strong vested interest in how that community operates, how it integrates with a wider community and all those sorts of things, which is a big sustainability focus.	…the company is not one to chop and change. ***It doesn't burn relationships. And sometimes we know we pay a little bit more,*** but we're not – we might get something a bit cheaper down the road. Yeah, I think so, ***but you've got to love Wayne for it because he's just about relationships*** and - but, you know, just got to find that happy balance, we're a bit too happy families at the moment, yep, but that's fine.

OCB CHARACTERISTIC	CASE 1	CASE 2
Conscientiousness *very careful about doing what you are supposed to do : concerned with doing something correctly*	…they're little things. I think some of those things that are just good building practice, like one of the first days that they were out there doing stuff, when I'm out there walking they were starting to do a job to put some bearers up and I said to them, "Show me the screw that you're using," and the screw they were using, to my mind, wasn't long enough, and it just didn't look right, so it was, "Guys, I want to see confirmation that that is even the right screw or you get the right screw," and they went away and they, "Oh, no, they're meant to be 50 ml longer." ***But there's those things that are just attention to detail and you just need somebody to walk around.*** ***So there were a lot of workshops and we went through everything*** from safety, what happens if the cassettes are lifted for the first time and it disintegrates in the air, what are we going to do because you're going to have Work Safe on board - on site, the site is going to be shut down. What do we do now? How do we then determine what the issue was? ***So we went through every scenario you could think about.*** So it wasn't just naively walked into. We certainly went through a lot of planning.	***So I want it to be as foolproof as it can be***. It's like in our new displays we've gone and put set downs and hobs in the showers, so just making sure that was all – so when you start getting flex in a truck with the transportable side of it, making sure they were going to hold up. So then we had to go back to the glue suppliers and the primers and all that and make sure everything was going to stick properly in there so that it doesn't pop the tiles, ***because I've never had a problem with tiles popping on a floor and I'm not about to start***. So when they wanted to start doing that I said, hang on, we've just got it all right. Because Port Lincoln had a problem with them early in the piece and they were using the wrong primers and wrong glues, so unless you get that right – so that way we're relying on the supplier's technical advice to get that all over the lines ***just to make sure we're putting the best product in we can.***

Table 5 Organisational Citizenship Behaviours Mapped to Cases

OCB CHARACTERISTIC	CASE 1	CASE 2
Loyalty *a loyal feeling : a feeling of strong support for someone or something* *C1: Quotes are more of loyalty in relation to teamwork, that is, being loyal to a collective* *C2: Quotes are more of loyalty in relation to growing a relationship over time*	***You're working as one collective who are delivering one outcome***. So you're not sitting there looking at Joe Bruno saying, "You work for Irwins. You must do this." ***Everyone understood that we were coming together, we were doing something fairly unique and so from that point of view they're helping each other*** and Joe can go over to Rob de Brincat's built site… Factory, and talk to him and sort of helping, "You've got this problem with the cassette." Now, cassettes have nothing to do with Joe in the end. Joe is involved and Irwins are involved in providing the overall structure to the building, not to do the flooring. I think when we finished it all I think we got a third of the way through the project and we had already done the first two levels, I sent out an email and just said, ***"Look, these are the people to thank in the industry for this. It wasn't me."*** I sent it out. I said, "Irwins have done this. Tillings have done the (33.36). Bowens and Timbertruss were involved." I actually named them. I thought, I'm going to name these people and just spray out an email to the whole of Australand and just let people know this wasn't about us. ***This is about them coming together and being able to commit and cooperate the way they did. I think you've got to do that***.	The best part is everybody works as a team, right from council approvals through – you walk past and everybody's firing a question at everybody. It's not, "That's my department done," and walk away from it. ***You can go to anyone at any stage and they're all willing to put their input in*** and say, no this is what's happened. So we had to create our own labour force and then our own - with the view of we knew that subcontractors is the best way to run a business. So we had to create this trade set that turned into contractors. So eventually we could turn it into contractors, which it's worked really well. We've nearly completed it. ***We've probably got I think half a dozen apprentices still on our books and the rest we've turned into contractors that work for us. So yeah, it's just been a fantastic result.*** ***Don't burn bridges.*** I mean - - - there will be a time where you've got to work with that person again I'm sure, and it's happened, it's happened, and I've had to work with people. I've called them up to come back in on other occasions. So if I had to get nasty I wouldn't be in this game.

OCB CHARACTERISTIC	CASE 1	CASE 2
Sense of fairness	*C1: Fairness here is related to making sure that in a relationship, neither party ends up being taken advantage of by the other* ***There's things you can do. So that gives him a bit of relief from a financial point of view and then you start paying him as soon as cassettes come on site***. You've actually already got the invoice and you're ready to pay him on that day. ***So the cassettes come on site, boom, the money is straight into his account.*** Now, what you have to explain to them is once we get this up and running that's not going to be the normal contractual arrangement. …***But for a first-off project if that's what gets the industry going*** and still gives me a cheaper building than the rest of the builders in WA, you know.	*C2: Fairness here is related to delivering what was promised to another party, and being up front about it* …***we've got some really good long term relationships, we'll always try and foster those***. We won't try and do the, you know, try and get you down and then play you off each other, we just don't do that at all. We try not to hide anything, that's the thing. You've got an upfront cost, people might say you're dearer, but then they might come back six months later and go, you weren't. There was nothing hidden in ours, ***and that transparency helps you sell stuff too***, especially out in the country.
Individual initiative	Now, luckily for me, I was probably silly enough, ***naive enough that I just thought, let's go***. ***I'm the sort of person who just wants to go for something.*** So if I can see a way that's going to come - the outcome is achievable, my view is let's go for it, and that's what we did from that meeting.	And like, yeah, anything with this one, the – particularly Keith, he is the one that's our true entrepreneur. I like that, I'm going to go do that. Bang. And the company has to keep up.

Table 5 Organisational Citizenship Behaviours Mapped to Cases

OCB CHARACTERISTIC	CASE 1	CASE 2
Acts of creativity and innovation	It's not about one building. ***It's about what innovation we have brought that can actually lead to newer and better things that we can do going forward***… It was a matter how we can actually improve on what we already had accomplished. So that's probably where the company decided to go with that five storey building at Parkville. And in doing so we had to obviously review everything that we've done previously and make sure that we've got all our ducks in line ***to be able to take the next step into building five storeys in lightweight because the whole— it was a completely different challenge to us.***	***We're always open to change***, that's how things move forward. Otherwise nobody would have a concrete slab home, concrete slab transportables. ***So we would be having a beer and he would come up with some silly ideas. We would be throwing just ideas around all the time.*** That's (the concrete slab) only one of many. So we would sit down and we would smash that stuff out over a beer for months until we thought, yeah, no, we've got it, that's the go.
Self-development	…so we did Parkville stage 1, again timber frame construction, a mixture of two and three storeys on top of car parking. It wasn't that efficient and it wasn't very well built. ***I think we were learning a lot within ourselves as to how to put a project like that together.***	***it's probably a bit of a ridiculous reason in some ways but we thought that we should be servicing the market with transportables*** but didn't have – and had had a client, a particular client, that wanted 50-odd cabins, and because I had experience in it we looked at better ways to do it than we've done in it in the past, or I've done it in the past because I knew a lot of the pitfalls and I'd been involved in the industry and then stupidly thought yeah, I reckon I can do it and do it better this time.

OCB CHARACTERISTIC	CASE 1	CASE 2
Courteousness and civic virtue *C2: Civic duty here is one's everyday behaviour being shaped by concern for the community*	*C1: The quote for altruism can apply*	For me ***the owners are your typical country sort of people, very open, very trusting, very focused on relationships and just good people to work with***. You don't – it's not – and I'm coming from a real corporate environment, so previously I worked for Rivergum Homes and I was there for 10 years – a cut-throat corporate, very difficult to work in that sort of environment for any length of time anyway. For 10 years I made it. That was the goal. And so for me it was ***a really refreshing change to come into a company that cared about its people, its suppliers, its contractors, and its product***. we don't want anyone going around saying we're trying to, you know, rip money off…Yeah, in the community, ***so the community is huge for us***.

5. Conclusions

Theoretical work on organizational citizenship behaviours has indicated that there are at various characteristics associated with leaders' who display OCBs. However, attempts to study the phenomenon and link it empirically to performance outcomes have been limited. In the two case studies we have mapped explicit OCB in the two case study organisations who have lead major transformational change. The introduction of a new way to design, construct and install timber flooring as an integrated cassette module which is built off site and placed onsite as a major unit required significant changes in processes. The second case study whereby all design and construction of a house is completed remotely from the site and then is transported to the final location also required significant process change. The interactions between the various actors required not only technical solutions but also new business models and new ways of working. The two case studies are considered exemplar technical solutions as well as highly successful business initiatives for the lead actor organisations. There was clear evidence in both case studies of altruism, conscientiousness, loyalty, sense of fairness, individual initiative, creativity and innovation, self-development and courteousness and civic virtue. The paper contributes to our understanding of leadership qualities of key actors who champion risky initiatives in the housing sector and in particular offsite manufacturing innovations. Leadership in construction management research has tended to focus on leadership types (charismatic etc) and less so on qualities that engender deep respect and trust – qualities which motivate others to follow. We have confirmed empirically a link between OCB with effectiveness and outcomes. We have not linked different types of citizen behaviours to different outcomes though and interestingly all behaviours were exhibited except for 'sportsmanship'. Future research shall explore the relationship of the different OCBs to an examination of interactions in the actor network; namely how the behaviours enable prima moven actors to recruit other actors into the network and the various strategies that are used to stabilize or change the network.

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Overview of dual process behavioural models and their implications on decision-making of private dwellers regarding deep energy renovation

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Abstract

Understanding both rational and heuristic thinking is important for explaining pro-environmental behaviour. Theoretical findings regarding dual process models can be useful to explain and influence decisions of private owners in the context of energy renovation.

The existing building stock has a big potential in contributing to the reduction of energy consumption. Even though surveys show that dwellers acknowledge the importance of energy efficient buildings and the technologies to achieve nearly zero energy buildings (nZEBs) are accessible, many dwellers prefer minor interventions or the status-quo rather than a deep energy renovation of their dwelling.

The present paper will explain the gap between intention and action with the use of dual process models (DPMs), consisting of a rational, central processing of the information (System 2) and a heuristic, peripheral one (System 1). We will focus on the peripheral System 1 that represents the heuristic, intuitive, fast and not so rational thinking that works as a shortcut for the rational processing of information. Dual process behavioural models will be classified according to the triggers of the heuristic shortcuts. An important aspect is the fragile balance between the two systems that is influenced by the need for cognition and need for affect. An overview of behavioural insights in heuristic thinking that might influence decisions regarding house renovation will be presented. The hypothesis verified with the use of a questionnaire is that positive arguments of the house owners in favour to renovate are mostly rational and the negative arguments are mostly heuristic.

Based on theoretical and empirical findings on dual process models, implications for policy making and informational campaigns concerning deep energy renovation will be proposed.

Keywords: Energy renovation, behavioural change, heuristic thinking, nudges, energy efficiency

1. Introduction

Europe is characterized by a 50% rate of owner-occupied dwellings and many countries including Belgium have even higher rates of over 70% (BPIE, 2011). Therefore in order to reduce residential energy consumption it is important to understand the mechanisms behind individual dwellers' behaviour. The present paper will focus on decision making aspects of private owners regarding deep energy renovation. These one-off decisions are different from daily energy use, where habits and curtailment prevail. When we refer to deep energy renovation we intend energy efficiency measures that aim to achieve a Nearly Zero Energy Building (nZEB). It implies investments in: insulation (wall, floor, roof insulation, energy efficient glazing); energy efficient HVAC technologies; systems on renewable energy (PV, solar panels, geothermal heat pumps).

The existing approaches for the uptake of energy renovation can be divided in two main categories: the one based on neo-classical economics' assumptions and the one based on environmental consciousness. The first approach considers the householder as *homo economicus*, who in his pursue of utility maximization, is able to choose rationally between the multitude of available energy efficiency measures. Nevertheless this approach has the limitation of considering individuals more or less as 'computers' with unlimited cognitive abilities and complete emotional self-control (Thaler & Sunstein, 2008). The Utility maximization model states that eventually the wrong estimations will be corrected with experience, yet the renovation decisions are usually one off and irreversible.

Whereas the first approach is based on financial arguments (extrinsic motivation), the second approach addresses the environmental consciousness of the individuals (intrinsic motivation). Energy related behaviour is explained with values, attitude formation, personal norms and self-efficacy (Perlaviciute & Steg, 2014), (Owens & Driffill, 2008). Various public and NGO informational campaigns have the purpose to relate energy consumption to environmental impact.

The vast majority of dwellers acknowledge the importance of energy efficiency. According to the Flemish Energy Agency VEA more than 90% of Flemish consider energy saving as rather to very important (VEA, 2013). Yet the figures of environmental consciousness resist to translate into action. Large-scale surveys (Bartiaux, et al., 2006), (Ceulemans & Verbeeck, 2015) document the gap between self-reported intentions and the actual energy efficiency measures undertaken.

Consequently, filling the intention-action gap with information regarding monetary or environmental benefits proved to have a lower impact than expected. Both approaches are based on the assumption that dwellers are exclusively rational in their reasoning. In reality decisions are systematically affected by the *"self-control problems, unrealistic optimism, and limited attention"* characteristic to humans (Sunstein, 2014). People tend to escape the slow and cognitive processing of the information with the use of a shortcut called heuristic or bias (Darnton, 2008). Figure 1 illustrates two ways of thinking: **the rational (System 2)** and the

heuristic (System 1). System 2 is the slow and deliberative, while System 1 is fast, automatic and intuitive. These two routes process the information concurrently, hence the models are called Dual Process Models (DPMs).

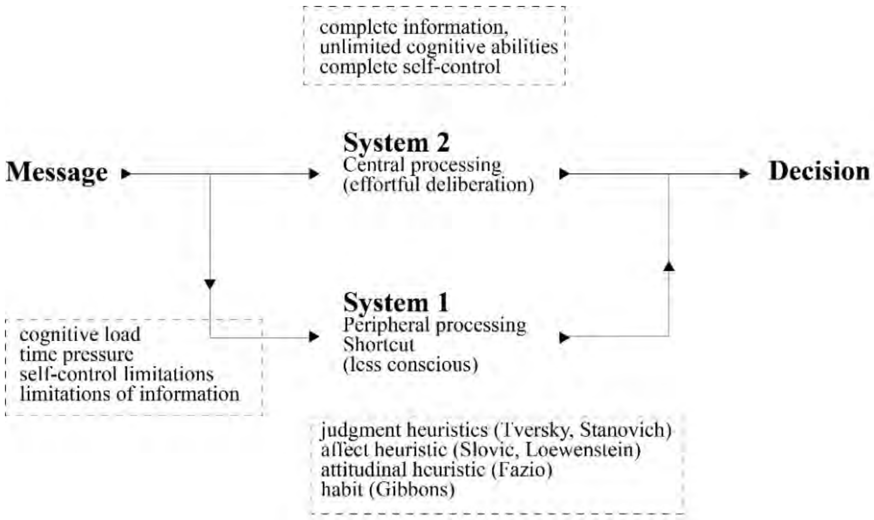

Figure 1 Scheme Dual Process Models

Certain DPMs constitute the theoretical background of the nudges – "*any aspect of the choice architecture that alters people's behaviour in a predictable way*" (Thaler & Sunstein, 2008). The raising interest towards nudges as a policy measure in various fields including energy efficiency provides a vast literature (Momsen & Stoerk, 2014), (Sunstein, 2014), (Behavioral Insights Team, 2011). These mostly contain applied behavioural insights without exploiting the mechanisms and models behind these biases. On the other hand, reports comprising all the behavioural models (Darnton, 2008), (Chatterton, 2011) do not consider the dual process models separately since their purpose is to give a general framework.

The present paper will give an overview of exclusively DPMs, from the perspective of their implications to energy renovation. The second chapter contains a classification of the DPMs and the balance between the rational and heuristic thinking. Part 3 details heuristics and biases of the System 1 that might be applicable in the context of energy renovation. In order to verify if dwellers' arguments regarding energy renovation are mostly rational or heuristic, a questionnaire was elaborated. The target of the questionnaire are the private owners in Flanders and it will be presented in chapter 4. In conclusion will be proposed implications for public policy based on the findings of the survey.

2. Overview of the existing dual process models

2.1 Classification of the DPMs

Starting from 1950s on, research in the field of psychology provides empirical evidence of the dual processing of information as a reaction against the ever increasing belief in rational decision making in economic models. An overview of the existing DPMs is given here below and summarized in Table 1. Insights into how these models apply to energy renovation, is offered in chapter 3.

Certain DPMs focus on decisions taken under uncertainty, time pressure and cognitive load, when people tend to avoid the difficult cognitive deliberation with the use of a fast, intuitive shortcut (Darnton, 2008). This principle is the theoretical basis of behavioural economics, with Simon Herbert's model **Bounded Rationality** (Simon, 2000); Tversky and Kahneman´s **Judgment Heuristic** (Kahneman, Slovic, & Tversky, 1982) and **System 1/ System 2** of Stanovich and West (Stanovich & West, 2000). When considering different alternative energy renovation measures, dwellers usually face difficult technical information. Besides the complexity of the information and the variety of possible solutions, the problem of uncertainty persists. There is little consensus on which option is more suitable or cost effective for a particular dwelling, since the sustainability of a technology in its complete life-cycle is strongly context dependent. For example the efficiency of solar technologies depends on the micro-climate conditions, proper installation; the sustainability of biomass technologies depends on the availability and origin of the biomass, etc. Under these circumstances the effortful analysis of the information is often shortcut by a cognitive bias.

Other two models that stipulate the central (cognitive) and the peripheral (less conscious) processing of the messages are the **Elaboration Likelihood Model** of Petty R. E. and Cacioppo J. and the **Mode Model** of Fazio. These models underline the importance of attitude and motivation when facing effort demanding information (Darnton, 2008). Other factors for heuristic thinking are emotions and perceived risks. According to Slovic's **Affect Heuristic Theory**, "perceived risks and perceived benefits may be inversely related in people's minds" (Finucane, Alhakami, Slovic, & Johnson, 2000). Similarly, **Risk as Feelings Model** of Loewenstein G. F. stipulates a direct path between emotion and behaviour (Darnton, 2008). The characteristics of the individuals that include 'need for affect' will be explained in part 2.2.

Table 1 Classification of the Dual Process Models

Main trigger of System 1	*Model, theory*	*Authors*	*Year*
Uncertainty, time pressure, heavy cognitive load	*Concept of bounded rationality*	*Herbert S.*	*1955*
	Judgment heuristic	*Tversky A. Kahneman D.*	*1974*
	System 1/ System 2 cognition	*Stanovich K.E, West R.F.*	*2000*
Motivation	*Elaboration likelihood model*	*Petty R.E., Cacioppo J.*	*1986*
	Mode model	*Fazio R.H.*	*1986*
Emotions	*Affect heuristic*	*Slovic P.*	*2000*
	Risk as feelings model	*Loewenstein G.F.*	*2001*
Habit	*Theory of interpersonal behaviour*	*Triandis H.*	*1977*
	Prototype/willingness model	*Gibbons F.X., Gerard M.*	*2003*

Finally, for certain DPMs habit is the main trigger of the shortcut from the rational thinking. Models such as **Interpersonal Behaviour** of Triandis (Chatterton, 2011) and Gibbons´ **Prototype⁄ Willingness Model** describe frequently repeated actions that become automatisms. These models might be useful to explain the daily energy use of the dwellers, but are not appropriate for one-off decisions on energy renovation.

2.2 Balance between the rational and heuristic systems

The main feature of DPMs is the concurrent possibility of processing certain information in a slow, rational way (System 2) or in a fast, intuitive, heuristic way (System 1). Understanding the factors influencing this delicate balance is rather significant for policy making. If the arguments of an informational campaign are exclusively rational, it is important to verify if the target processes the information in a cognitive way.

One of the factors influencing the balance between the two systems is the way the message is formulated. Complex information is one of the main triggers of heuristic thinking. In the same line of thought, the BIT (Behavioural Insights Team) states the importance of simple and salient information in their EAST (Hallsworth, et al., 2014) and MINDSCAPE Methods (Dolan, Hallsworth, Halpern, King, & Vlaev). Elaborated in collaboration with the British Government, these methods aim to apply behavioural insights in public policy measures.

According to Baldwin, the 'First Degree nudge' has the purpose to enhance reflective decision-making and avoid an existing heuristic (Baldwin, 2014). If the information is easy, attractive and salient, it is more likely to be processed rationally. Besides the accessibility, the message framing should avoid possible existing biases. The 'Second' and 'Third Degree' nudges use an existing or a newly induced bias towards a predictable outcome, addressing System 1 (Baldwin, 2014).

At the same time, the balance between the systems depends on the individual's characteristics. Apart from intellectual capabilities of processing complex information, there are other parameters measuring the availability to engage in this processing, such as need for closure, need for cognition and need for affect. Due to heterogeneity of the population, the impact of nudges is not uniform, occurring the risk to "*discriminate against vulnerable parties*" (Baldwin, 2014).

Need for closure

Need for closure is defined by Kruglanski as "desire for a firm answer to a question, any firm answer as compared to confusion or ambiguity" (Kruglanski, Mannetti, & Pierro, 2006). In their urge for clarity, people with high level of need for closure are more likely to use the bias as a shortcut. In these cases it is important to implement the 'First Degree Nudge'. By simplifying complex messages, it is more likely to avoid existing biases and redirect towards rational thinking. Table 2 illustrates the characteristics of individuals that are more likely to be receptive to the three types of nudges.

Need for cognition

Contrary to the need for closure refers the 'need for cognition' to an individual's tendency to "engage in and enjoy effortful cognitive endeavours" (Cacioppo, Petty, & Kao, 1984). The higher the need for cognition, the higher is the probability that the individual will process even difficult information rationally via System 2, avoiding the bias. On the contrary, individuals with low need for cognition are more prone to avoid difficult cognitive processing and are more likely to be influenced by 'Second Degree' and 'Third Degree' nudges, see table 2.

Need for affect

Difficult to process information is not the only trigger of heuristic thinking. The dwelling is a home, not merely a physical house. The existing state of the dwelling is associated with warmth, family, pleasant memories. These emotional bounds can be an important impediment in assessing in a rational way the economic benefits of the renovation. For this reason messages or images promoting energy renovation should associate nZEB with warmth, coziness and well-being, and not only with convenience and technology.

The balance between a cognitive and an emotional evaluation depends as well on the individual's motivation to "approach or avoid emotion-inducing situations", also called his 'need for affect' (Maio & Esses, 2001). People with high need for affect and low need for cognition are less likely to process the information in a cognitive way since the two parameters are related.

Table 2 Impact of the three types of nudges depending on individual's characteristics

	First Degree Nudge (avoid existing bias)	*Second Degree Nudge (use existing bias)*	*Third Degree Nudge (induce new bias)*
Need for closure	*high*	*high*	*high*
Need for cognition	*low*	*low*	*low*
Need for affect	*low*	*high*	*high*

3. Applying behavioural insights from the dual process models to energy renovation

While System 2 thinking implies slow and deliberative thinking, System 1 is characterized by shortcuts: heuristics and biases. These are intuitive estimations of probability of the outcome that allow taking fast decisions. While in everyday practice these intuitive shortcuts might be useful in increasing the efficiency of small decisions, they can be dangerous in taking important decisions such as the ones regarding energy renovation. Previous research in behavioural economics has shown that System 1 thinking generates the heuristic assessment of probability and as a result systematic errors that can be predicted (Ariely, 2008), (Tversky & Kahneman, 1974). The present chapter presents relevant heuristics and biases in the context of deep energy renovation decisions. Some of them served as assumptions for the elaboration of the questionnaire described in Chapter 4.

Availability heuristic: the probability of an event or the frequency of an object is assessed by the ease with which it can be, recalled (Kahneman, Slovic, & Tversky, 1982). If the event is present in the memory, the bias is due to '*retrievability*' (Tversky & Kahneman, 1974). Often the choice of a certain renovation measure is based exclusively on its familiarity (already known information or singular cases from friends) or on its salience (PV panels have high visual impact, certain technologies have more coverage in media, etc.). The bias of *'imaginability'* regards the objects and events that are not present in the memory. For example, the aesthetical advantages of the refurbishments the architect describes are easier imagined than the energy efficiency measures' benefits such as thermal comfort, humidity control, etc.

Representativeness heuristic explains how people assess the probability of events merely based on the "*degree to which A resembles B"* (Tversky & Kahneman, 1974) ignoring important factors such as sample size and base rate frequency of the outcome. An example of representativeness heuristic is the way dwellers assess what is responsible for a high energy consumption (and respectively a high energy bill). They might overestimate the impact of their occupancy patterns and underestimate the importance of the characteristics of the dwelling. Everyday actions such as heating, cooking and showering *resemble* other activities such as buying groceries or dining out. All these actions are regarded as expenses depending mostly on the dweller's lifestyle. This way, the bill on the heating is associated more with the temperature chosen and less with the insulation of the dwelling. The characteristics of the dwelling are perceived as external factors such as prices on the menu that you have to accept if you opt to dine out. This heuristic might be an explanation for the distrust in the energy performance certificate of the dwelling. It is calculated for standard occupancy, while people expect the certificate to reflect their actual energy consumption.

Adjustment and anchoring: in order to estimate a certain value, people start from an initial value called '*anchor*' and try to adjust it accordingly. It is a good strategy for assessing subjective utility if not for the heuristic aspect according to which *"*different starting points yield different estimates*"* (Kahneman, Slovic, & Tversky, 1982). This is one of the reasons why framing of the message is highly influential.

The overall probability of a series of events is different from the probability of the elementary events of which it consists. The latter works as an anchor and people *"*tend to overestimate the probability of conjunctive events and underestimate the probability of disjunctive events*"* (Tversky & Kahneman, 1974). The renovation process is a concatenation of '*conjunctive'* events. In order to achieve the final result, all the elementary events have to take place, such as obtaining the renovation permit, etc. The success rate of each phase is very high, but the overall probability of the sequence is much lower. Often dwellers overestimate the overall success rate and underestimate the difficulty of the renovation process. It may lead to excess of optimism in initial planning and disappointment during the process.

On the contrary perform the *disjunctive* series of events, such as the risk of malfunctioning of the building' systems. In this case it is enough that one of the indispensable elements of the chain breaks in order to block the entire system. The probability that each element will malfunction is very low, the overall probability is higher but once again, the initial low probability works as an *'anchor'*. Therefore people underestimate the risk of malfunctioning of the systems and neglect their duly inspection and maintenance.

Satisfice bias: people aim for a satisfactory result, rather than an optimal result**Invalid source specified.**. When confronted with too many options and too complex information, often people rush for the 'good enough' renovation measure and avoid seeking 'the best' option (Frederiks, Stenner, & Hobman, 2014). People with a high level of need for closure are more likely to incline for the first *'satisficing'* option that is encountered. Moreover, satisfice bias might be related to **status quo bias** if the existing state of the dwelling is perceived as 'good enough' and, as a consequence, renovation is discarded altogether.

Social norms: the decisions are heavily influenced by others' opinions or others' undertaken decisions (Frederiks, Stenner, & Hobman, 2014), (Ariely, 2008), (Behavioral Insights Team, 2011). Social norms might explain the choice for under optimal, lock-in technologies. These solutions give the confirmation, recognition that these are the best technical, ecological solutions ("there must be a reason why everybody chooses it"). Besides it spares the hassle to compare multitude of available solutions in order to find the solution that best fits your particular dwelling.

Discount the future: smaller benefits in the present overweight bigger benefits in the future (Behavioral Insights Team, 2011). Time affects as a dimmer thus future savings on the utility bills resulting from energy efficiency investments are less appealing.

Endowment effect: people value more the things they own, not due to their characteristics, but merely because they own them (Ariely, 2008). This bias might be the explanation why people resist to change old appliances and boilers with energy efficient ones.

4. Questionnaire on rational and heuristic thinking in energy renovation

In the context of rational and heuristic thinking, a survey was undertaken to assess the way people process information regarding deep energy renovation. We verified if arguments in favour are mostly rational $\Sigma(R+) > \Sigma(H+)$ and the ones against are mostly heuristic $\Sigma(H-) > \Sigma(R-)$.

These two hypotheses are based on the hemispheric asymmetry theory. According to Schwartz' study from 1979 "*when subjected to positive affects, people tend to move the eyes to the right and when subjected to negative affects – to the left*" (Cacioppo & Petty, 1983). More clues supporting these hypotheses resulted from a focus group on behavioural insights in energy renovation organized in April 2015 with municipal officials in the context of Werfgoed Living Lab. Among arguments in favour of renovation were listed "*to reduce the footprint*" (ecological

1.1		I would place wall insulation because…	Positive	Behavioural Model/ Insight
	A	I want to live in a warm, comfortable house	H+	Affect heuristic (Slovic)
	B	I want to save money on heating	R+	Expected utility
	C	It is good for the environment	R+	Values: Schematic Causal Model of Environmental Concern (Stern)
	D	Everybody does it	H+	Social norms: Structuration Theory (Giddens)

1.2		I would not place wall insulation because…	Negative	Behavioural Model/ Insight
	A	I like my house the way it is now	H-	Affect heuristic by Slovic; Sunk cost fallacy, mental accounting
	B	I prefer spending money on interior design instead	H-	Mental accounts
	C	It doesn't make a big difference, my energy	R-	Self-efficacy: Social Cognitive Theory (Bandura)
	D	It is too expensive	R-	Expected utility

Figure 2 Example of questionnaire item with the explanation of the behavioural models (not visible to respondents) 1.1 Arguments in favour of insulation 1.2 Arguments against insulation

values, beliefs), "*house increases in value*" (expected utility); while among arguments against the renovation were listed "*a lot of cluster, noise, dust*" (affect heuristic), "*I like how my house looks now*" (endowment effect, status quo bias).

Before conducting the survey among Flemish owners interested in renovation, a pilot test was undertaken among 1983 employees of Hasselt University. The response rate was of 15.28% — 303 responses, out of which 248 were complete. The sample is not representative to the population due to high level of education and preponderance of the age group between 20 and 40 years.

The survey was structured in five topics: wall insulation, energy efficient windows, efficient boiler, solar panels and solar water heater. On each measure two questions were presented to respondents: with arguments in favour and against the uptake, see Figure 2. These were based on the most frequently reasons cited by Flemish private owners in large scale surveys (VEA, 2013), (Ceulemans & Verbeeck, 2015). Each question included four options, with two rational arguments (based on values, beliefs, Expected Utility) and two heuristic arguments (based on biases such as endowment bias, affect heuristic, social norms). The description of the behavioural models were not visible to respondents who had to rank the four options of the question. For our analysis we have assigned to ranking a score from 4 to 1 and for each respondent we have summed up the two rational options and the two heuristic ones.

For each measure the responses of the dwellers who installed it were analysed separately with the ones who did not or who are renters. For both categories of dwellers the hypothesis was confirmed for positive arguments, where prevail the rational thinking $\Sigma(R+) > \Sigma(H+)$, see Table 3. For negative arguments the results vary according to the measure. For wall insulation, PV panels and solar water heater still rational arguments prevail $\Sigma(H-) < \Sigma(R-)$, even if with a smaller difference than the positive reasons; while for efficient windows and boilers the rational and heuristic thinking are balanced $\Sigma(H-) = \Sigma(R-)$. It is important to underline that the latter measures are the most popular with respectively 74,6% (N=189) of respondents declared to have placed efficient windows and 59,7% (N=189) efficient boiler. Since these are stated reasons against the measure, the more a dweller acknowledges his own biases, the more likely he will install the measure.

If we compare the responses of the owners who have placed a certain measure with the ones who did not, we find a similar pattern according to the group of measures. Regarding efficient windows and boiler, the former group of dwellers are more rational in their positive attitudes. This underlines once more the necessity of 'First Degree nudge' that aims to enhance the rational thinking and avoid existing biases.

Table 3 Results of the paired t-test

	Owners who installed the measure				*Owners who did not install the measure*			
	Positive		*Negative*		*Positive*		*Negative*	
	mean Δ		*mean Δ*		*mean Δ*		*mean Δ*	
Wall insulation	*1.29***	H_1	*1.17***	H_2	*1.30***	H_1	*1.68***	H_2
Efficient windows	*3.18***	H_1	*0.27*	H_0	*2.69***	H_1	*0.15*	H_0
Efficient boiler	*3.08***	H_1	*-0.11*	H_0	*2.56***	H_1	*0.04*	H_0
PV panels	*2.80***	H_1	*1.07***	H_2	*2.47***	H_1	*1.82***	H_2
Solar water heater	*2.77***	H_1	*2.38***	H_2	*2.04***	H_1	*1.80***	H_2

Δ = Rational-Heuristic (min -4, max 4); H_1 $\Sigma(R+) > \Sigma(H+)$; H_0 $\Sigma(R-) = \Sigma(H-)$; H_2 $\Sigma(R-) > \Sigma(H-)$

A different trend shows the uptake of PV panels. In their negative attitudes, owners who installed them are more heuristic than the ones who did not. It suggests again that the dwellers who acknowledge their heuristics are more likely to undertake the measure. On the other hand, it might be explained by the fact that in the past the PV panels were heavily subsidized, and the social norms played a more important role in decision than the cost.

5. Conclusions

The traditional measures have proven to have a low impact in the uptake of deep energy renovation. New policy instruments that take into account the human limitation, such as nudges, are being tested in various fields including energy efficiency.

The preliminary results of the survey show that positive rational arguments prevail over heuristics, while negative ones are more balanced, depending on the measure. Since biases are already present especially in negative attitudes, there are two main strategies: to avoid them ('First Degree nudge') or to use them in the right direction ('Second Degree nudge'). Framing complex information regarding renovation in simple terms might redirect towards cognitive thinking. If unavoidable, existing biases can be used in a predictable direction. For example a right anchor would be nZEB levels and not the building stock average; right social norm would be the positive statistics (how many dwellers have placed a certain measure).

Since the survey contains stated preferences, it has the limitation of revealing only how people acknowledge they think. It is not likely for a person to admit or even realise his own heuristic thinking. Nevertheless, the survey reveals different patterns among positive and negative attitudes; among measures with a higher or a lower uptake; and in a lower degree, among owners who have placed the measures compared to the ones who did not.

Finally, in the elaboration of nudges have to be taken into account the heterogeneity of the population. Until now, the application of behavioural economics in policy making was mainly a simplified application of biases, ignoring the underlying dual behavioural models. The characteristics of the individual, such as 'need for closure', 'need for cognition' and 'need for affect' influence the balance between the two systems of thinking and might determine an asymmetric impact of the nudges.

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People and Activities in Energy Efficient Buildings: Comparative Study of User, Owner and Facilities Management Perspectives in Schools

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Abstract

Tightening the link between the design and operation phase of buildings is widely regarded as a solid approach towards improving their energy performance. Energy management strategies delivered exclusively from an asset management perspective may often neglect the impact from the people who use, operate and manage the assets. This paper presents the findings from two case studies that aim to deepen our understanding regarding how energy management practice is carried out within "high energy efficient" school buildings in Norway. The methodology includes individual semi-structured interviews with at least one representative from each of the following user groups: building occupants, facilities managers (operational, tactical or strategic) and building owners. Energy data routines have been gathered through interviews and strategic documents. Findings suggest a strong disconnection between the expressed energy ambitions of the buildings (i.e. energy standard to which to which the buildings are designed) and the actual delivery of energy management as a practice. Building occupants relate to the use and management of energy in the context of activities relevant to the building´s core function. Energy data routines as implemented by building operators reflect disassociation from the activities that end-users deem as strategic. Results from this study have strong implications regarding the role that professional bodies, organizations and educators need to play in ensuring that high energy ambition buildings are met with energy aware users. The knowledge developed can support further development of facilities management qualifications. Through an activity-centred approach, we are able to develop key insight that supports in identifying key areas for collaboration between building occupants and facilities managers and building owners.

Keywords: Energy Management, End-user Perspective, Facilities Management, Interdisciplinary, Collaboration

1. Introduction

Contribution from the built-environment to achieve energy efficiency (EE) goals is well established. Efforts to improve the energy performance of non-residential buildings can take the form of initiatives that: a) support the decision-making process at the design phase of a building. This is, to align principles of sustainable architecture with the adequate procurement of energy-efficient plant and equipment, in support of the sustainable operation of the building (Junghans, 2012, Ure and Camyab, 2016); b) support the development of energy measures that can be adapted or retrofitted into existing buildings. Beyond technology-based approaches, this includes solutions that can positively impact the way buildings are used and operated. Increasing evidence shows that buildings often perform worse than their design intentions. This issue is commonly regarded as the Energy Performance Gap (EPG). As suggested by Bordass et al. (2004), the EPG can escalate to affect market perception over the effectiveness of industry proven EE technologies for low-energy buildings. Causes for the EPG are many and stem from different phases in the life of a building (De Wilde, 2014, Valle & Junghans, 2014). Lack of knowledge at the design phase regarding how buildings are (to be) used and operated is often highlighted as one of the main causes for the EPG. Tightening the link between the design and operation phase of the building is widely regarded as a solid approach towards bridging the performance gap (Bordass et al., 2004) Technology-based solutions are the dominant approach towards improving the energy performance of buildings. However, energy management strategies which are delivered exclusively from an asset management perspective may often neglect the impact from the people who use, operate and manage the assets. Occupant engagement is widely acknowledged by both industry and academia as a critical factor towards achieving good energy performance (Janda, 2011, Menassa, 2014, TRUST, 2011, ENERGY STAR, 2013). This paper presents the findings from a selection of two case studies that aim to deepen our understanding regarding how energy management is carried out within "high energy efficient" rated school buildings in Norway. Central to this approach is the development of an activity-centred framework which facilitates identifying potential areas for collaboration between the different user groups that use, operate and manage the building. Findings from this study are complementary to current academic and industry efforts seeking to maximize energy efficiency gains through building occupant engagement.

1.1. Impact of building occupants on the energy performance of facilities: the need for end-user (occupant) engagement.

A report issued by the International Energy Agency (IEA, 2013) identified six key factors influencing building energy consumption, 50% of which can be linked to human interaction, including: a) building operation and maintenance; b) occupant activities and behaviour and; c) indoor environmental quality. Main areas of interaction between users and buildings include lighting, appliance electrical loads, ventilation, space heating, space cooling and domestic hot water (IEA, 2013, Demanuele et al., 2010, Hong et al., 2013). Nicol (2001) concludes that the use of controls in the building is linked: to climate conditions, particularly outdoor temperature, and to physical conditions related to user comfort, such as the need to improve indoor air quality. Haldi et al. (2008) present an overview of studies which led to further development of Nicol´s behaviour prediction model. Knowledge on occupant behaviour can lead to better energy prediction models, avoidance or at least minimization of interactions between building occupants and energy consuming systems. Occupancy patterns have been shown to have an impact on the energy consumption of buildings. Many studies have indicated that often buildings use a significant amount of energy after regular working hours (Bordass et al., 2001, Hoes et al., 2009, Menezes et al., 2012, Korjenic et al., 2012). The effect is felt most in buildings with large plain open spaces, as many of the energy consuming systems (e.g. HVAC, lighting) have to be kept on running on full system capacity just to provide basic working conditions for few people. Different analytical approaches can be used to evaluate impact of building occupants on energy use, including building simulation, site survey and a mixture of both of these approaches. Menezes et al. (2011) make use of Post Occupancy Evaluations (POE) to gather detailed data on the performance of a multi-tenanted (four tenants) office building in the UK. The data gathered is fed to an energy prediction model. Findings highlight that the differences in energy use between the tenants are linked to their particular organizational management styles and context relevant activities. It is reasonable to argue that buildings equipped with the state of the art of EE technologies, provide conditions that can minimize and even annul the impact of the building occupants on energy consumption. However, as pointed out by Stevens (2001), such a system would need to prove effective in keeping up with fast changing user demands for comfort. In addition, many studies on occupant satisfaction have shown that end-users become increasingly dissatisfied as their ability to manipulate their working environment is restricted (Galasiu et al., 2006, Hoes et al., 2009), and will often find ways to intervene the systems (Aune et al., 2009, Menezes, 2009, Morant, 2012). Aune et al. (2009) states: *"… even if user-interfaces are automated with intelligent systems, unexpected user actions, such as creative adaptation or even outright sabotage of systems, are frequent."* In this paper we support that end-users are to play a role in supporting the delivery of energy management practice. End-user engagement approaches are to be part of energy management practice. The benefits from end-user engagement must be perceived beyond the boundaries of energy performance, to include: better educated users, fewer interventions from users on building system and improved collaboration dynamics between end-users and facilities managers.

1.2. FM´s contribution to the delivery of high energy performance in non-residential buildings.

The FM industry deals with a great set of strategic management competences, including: Real estate management, financial management, organizational management, innovation and change management and human resources management (Atkin & Brooks, 2015). The European Standard for Facilities Management (EN15221-1, 2006) defines FM as the *"integration of processes within an organization to maintain and develop the agreed services which support and improve the effectiveness of its primary activities"*. Expansion of the FM industry is primarily driven by the need of organisations to remain competitive in an increasingly regulated business environment. In the built environment, the practices of sustainable production and service delivery are becoming progressively more legislated. Comparative energy performance measurements for buildings over specified floor area have been mandated (Atkin & Brooks, 2015). The strategic position of FM in driving the sustainability agenda at the building level has been acknowledged (Elmualim et al., 2012). The delivery of energy management practice is a service that the FM profession can provide (Junghans, 2013). Novakovic et al. (2012) adopt the energy management definition provided in the report "Energiledelse- Veileder for etablering og drift" (Energy Management – Guide to establishment and operation): *"Energy management is that part of a company's leadership responsibility that ensures that the energy is used efficiently"*. This definition falls short in failing to address the aspect of on-site energy production. Novakovic et al. (2012) also describe the roles of building owner, property managers and building users from a building and property management perspective. The strategic, tactical and operative levels at which the facilities managers interact with the organization have been theorized (Atkin & Brooks, 2015, Junghans, 2015, Novakovic et al., 2012). It remains unclear whether FM service providers embrace these theoretical models in the delivery of energy management service. The case studies in this project have been collected as part of a larger inter-disciplinary project called MINDER (Methodologies for Improvement of Non-residential buildings Day-to-day Energy efficiency Reliability). MINDER brings together the disciplines of Social Science, Design and Facilities Management, in the delivery of methods that can contribute to narrowing the EPG. The case study framework builds on the findings from a survey delivered in August 2014 which targeted representatives from 49 member organizations from a well-established Norwegian network for Real Estate and Facilities Management (See Valle & Junghans, 2015). Among other issues, the survey highlighted split opinion amongst FM practitioners regarding the impact of building occupants on energy consumption. Most facilities managers at the strategic level perceived that end-users do not have an impact on energy consumption.

2. Methodology

The aim of the case studies is to provide in-depth knowledge on the actual process of energy use and management in non-residential buildings in Norway. Semi-structured interviews are at the core of the process of data collection. Interviewees include representatives from building occupants, facilities managers (operational, tactical or strategic), and building owners. The case study framework is based on the deconstruction of the methods considered to be best-practice in the management of energy in non-residential buildings. This approach was developed during the design of the survey that precedes this study. The process is guided by the understanding that a method can be described as the sum of the actors, processes, tools, competences and outcomes required to meet an objective (See figure 1):

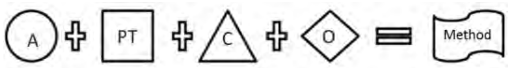

Figure 1. Model for the deconstruction of any given energy management method

- A= Actors. Refers to the key stakeholders involved during the lifecycle of a given method.
- PT= Processes & Tools. Series of actions and functions put in place to bring about a result.
- C= Competences. Range of skills, knowledge and abilities required to implement an action.
- O=Outcomes. Specific objectives of the method, either at a particular stage or as a whole.

From this perspective, it is possible to gain in-depth knowledge about particular actors, processes, tools and competences, to an extent where the risk of adoption or rejection of these individual elements within a particular context can be appraised. The strengths and weaknesses for each of the parts can be studied, and the threads which describe the relationship between the parts can be enquired. Based on the previous, a structure for the case study framework was produced and aims to gather: a) knowledge of the interviewee on the level of energy ambitions of the building; b) perception of the interviewee regarding the people who she/he perceives to have the most impact on the energy consumption and management in the building; c) Perception of the interviewee regarding the activities that she/he perceives to have the most impact on the energy consumption and management in the building; d) Perception of the interviewee regarding the people, processes, tools, competences and desired outcomes influencing delivery of energy relevant activities, and; e) knowledge of the interviewee on energy data routines, including how energy data is collected, stored, analyzed, communicated and used for improving the energy performance of the building. The latter aspect is only addressed with the person responsible for the day-to-day operation and monitoring of the building. For this study, only interview data relating to the activities that each of the interviewees considers relevant to the management and use of energy in the building was extracted. Identifying activity-based context is enabled by the data collection approach, which specifically asks from interviewees to discuss their understanding of energy management and energy use, within the context of the activities relevant to their day-to-day use of the building.

2.1. Case study selection

The criteria behind the selection of the case study buildings are: a) high energy performance buildings: The probability of learning about comprehensive energy management strategies and energy data routines is assumed to be highest among buildings with expressed high energy performance buildings. In addition, one is able to learn about end-user and FM perceptions in the context of highly automated buildings. Buildings complying with passive house standard (Passive House Standard NS3700/3701) were selected; b) significant energy saving potential: The sample is to be contained within the group of buildings considered to have the largest energy saving potential in Norway. The objective is to create solutions that have the potential to significantly reduce energy use from the perspective of the Norwegian building stock. The top three non-residential building types meeting this criterion in Norway are retail, office and school buildings, and; c) private and public buildings: The sample must facilitate comparability between energy management approaches from the public and private sector, as well as between similar building types. In this sense, eight buildings were selected, belonging to either office or school facilities (four from each group). This paper discusses the findings from two "passive-house" certified school buildings in Norway. The buildings are owned by different municipalities ("A" and "B"). The building owners sit at the level of the municipality, from where the energy management process is directed. Municipalities define their own energy management strategies according to their needs, knowledge and understanding of the energy management process. Municipality "A" assigns approximately one caretaker for every three of the 60 buildings in their portfolio (23 caretakers). On the other hand, municipality "B" looks over 41 buildings between kindergartens and other educational facilities. Within municipality "B", five building operators are trained on energy management aspects and oversee small clusters of buildings within the municipality´s portfolio. Rotation amongst operators is dependent on the knowledge and skills required to care for a particular building. Both passive-house projects were developed as annexes to existing building structures.

2.2. Analysis

This paper develops around the study of the activities that each of the interviewed user groups consider to be most relevant to the use and management of energy in the buildings they occupy, operate or manage. These images are used to identify missed opportunities for stakeholder integration in the context of the energy management process. This is an exploratory study, and findings are limited to the context of the buildings under study. Information on energy data routines is used to assess the extent to which energy data is used to support the high energy ambitions of the buildings.

3. Findings

First, the perspectives from all user-groups belonging to School Building “1” (SB1) and School Building “2” (SB2) are presented. Then, a brief description of the energy data routines as implemented by each of the municipalities is provided.

3.1. School Building “1” from Municipality “A”

The teacher and the director | representing the building occupants: Dancing and working with pupils are two of the main activities that the teacher perceives as relevant regarding the management and use of energy in the building. The first activity (i.e. dancing) was connected to energy consumption through the understanding that ventilation systems have to work harder in order to improve the quality of air: *“when we use this area outside here and we are dancing we can feel the air is with sweat and then the ventilation has to go faster to clean the air, so that's an impact”.* Working in rooms with small groups of pupils was directly connected to the need for additional heating. The teacher informs that when rooms are used below their normal occupancy level, it takes much longer for the temperature to stabilize at the desired set-point. From the teacher´s perspective, it is likely that this lag (i.e. the time in between the room is taken in use and the moment it feels warm enough) is consequence of a faulty or unbalanced heating system. Staff meetings were also indicated as activities with the potential to influence energy use in the building, as crowded meetings often result in poor air quality. As a result, participants turn to opening the windows as means to improve both the quality and temperature of air in the room. The director finds it difficult to connect her day-to-day work routines with energy relevant activities in the building. In turn, she narrates how teaching and “health & safety” meetings can have an impact on both how energy is used and managed in the building. With regards to teaching, the director argues that perceptions from both teachers and pupils regarding room temperature can be described as signals that lead to the adjustments of the building systems (e.g. heating and ventilation systems). Staff meetings were indicated by the director as the activity with most impact on how energy is managed in the building. Unlike the teacher, the *director* does not refer to the quality and temperature of air in the meeting rooms; rather, she comments on the opportunity to communicate about pressing matters regarding building use and staff concerns. Meetings are attended by staff representatives from different areas, including teachers, building operators, cleaners and union representative. The director comments on opportunities for integrating knowledge about the building´s unique energy features into day-to-day school curriculum; however, in practice, discussions about energy use and management are limited to complaints about indoor temperature, and rarely about initiatives aiming to improve the energy performance of the building.

The caretaker | representing the facilities manager at operational level: The caretaker comes from a background in general maintenance. Maintenance routines and building monitoring through the building management system (in norwegian: Sentral Driftskontroll or SD) are the two main activities indicated by the caretaker as relevant to the management and use of energy in the building. From his perspective, the first activity (i.e. maintenance routines) is considered to have the most impact on energy consumption in the facility. Reactive maintenance represents a significant component of the caretaker´s daily work. The caretaker indicates that the automated systems in the building were designed and commissioned to maintain an adequate balance of the building energy systems. In this sense, the caretaker fully relies on how the building systems were programmed by the contractors during the handover phase of the building. Accordingly, his role is primarily focused in providing timely response to the alarms generated by the building management system :*"I have some alarms on my SD that tell me if something is wrong… so I do this thing, that's mainly my job".*

The "Cost-focused" Energy Manager (CBO) | representing the building owner and strategic facilities manager: The role of the CBO is that of overseeing the technical aspects of the portfolio of buildings owned by the municipality "A". The CBO accredits most of the energy used in the building to activities which do not take place within the new passive-house portion of the school, but rather on adjacent community-shared spaces (e.g. use of pool and sports centre). The CBO speaks of the facilities and installed energy systems as finished products, meaning that they have been designed, implemented and currently work as intended. In this context, the CBO indicates that the energy efficiency of the building can only be raised by improving the work routines of the caretaker and increasing the energy literacy of all individuals who occupy the building. Energy use in the building is monitored through the monthly assessment of energy bills. In this sense, the municipality only initiates an action for a particular building when the electricity bill for a given period is perceived to be significantly higher than its historical value.

3.2. School Building "2" from Municipality "B"

The educator and the staff representative | representing the building occupants: The *educator* has been working in the passive-house building since it was handed over by the municipality "B" to the school staff. In addition to teaching, he is also part of a managing team that helps to steer school affairs. When asked about activities that impact on how energy is used and managed in the building, he refers to the use of computers by the pupils as well as to the automatic blinds. In the context of computers, the educator comments that equipment with long-battery life is preferred so as to reduce the amount of time used by students in charging their computers: *"...when you have a class you don't want them to be using the charger in the classroom, you want them to take the computer and use it without interrupting*." In this sense, he clarifies that the school's procurement strategy for computers does not aim to reduce energy consumption, but to minimize disruption of classroom activities. In terms of automatic blinds, the educator indicates that the system is meant to reduce energy use in the building; however, he perceives that the functioning of the system is not aligned with that of a school building, with the blinds often interrupting classroom activities. School staffs have demanded that control over the blinds is shifted from the municipality back to the building level. The *staff representative* fulfils a leading role mandated by national health & safety regulations, and acts as key mediator between school staff and the municipality. Ventilation is recognized as the activity with the highest impact on how energy is used in the building. She discusses ventilation in the context of community oriented activities that the school is mandated to accommodate for. The staff representative indicates that many of these services must be provided for free to community members. In this sense, ventilation is perceived as an increasingly requested and energy intensive service which impacts on the energy use and financial bottom-line of the school. The use of windows by building occupants is perceived to be the second most energy intensive activity in the building. The staff representative comments that she is not aware of the impact that opening the windows can have on the overall energy consumption in the building; however, she perceives that freedom to manipulate the windows is necessary as the building is not able to provide a consistent level of air quality.

The building operator | representing the facilities manager at tactical level: There are two aspects which dominate the conversation regarding how energy is managed and used in the building: First, the implementation of adequate automation and building management systems (BMS), and; second, the development of a solid energy metering strategy. The building operator perceives that organizations lacking well trained and knowledgeable staff regarding both of these aspects (i.e. BMS and energy data strategies) are at great disadvantage. Keeping up to date with the advances of technology is perceived as one of the most important aspects in supporting a highly energy efficient environment. In this sense, he argues that in line with current advances of technology, there is nothing else at the time that the municipality can do to improve energy use in the building.

The "System-focused" Energy Manager (SBO) | representing the building owner and strategic facilities manager: The SBO indicates that the most important activity regarding the management of energy in the building is the use of the BMS to monitor the operation of the building's energy systems. In turn, the focus is not to optimize the performance of specific energy systems, but to provide rapid response to the alarms generated by the BMS. Standardization of management systems across the building portfolio is perceived as essential: *"we are the only municipality in Norway with one system for all of our buildings… the absolutely most important (is) you have a system (all) people can use".* The frequency and extent to which the building is used by building occupants is considered to have a strong impact on energy consumption. The SBO indicates there is a gap between the occupancy levels defined in the national building standards for school buildings and the actual use of the school facilities. However, the SBO does not perceive this to be a problem since the building was designed to be used.

3.3. On energy data routines

Municipality "A" | Cost-Focused Energy Management: The building owner (CBO) from SB1 is unaware whether specific energy consumption goals are set for the building. Energy data are registered both by the caretaker by taking readings from the main utility meter, and automatically through a set of sub-meters which measure the energy used by the ventilation, heat pump and domestic hot water systems. Data generated from sub-meters are neither stored nor used. From the data that is collected (either manually or automatically), it is not possible to differentiate between the energy used by the existing building versus the new "passive house" facility. Further breakdown of energy use between different spaces (or uses) is not something the caretaker considers to be an advantage. On a yearly basis, the caretaker reports on the energy consumption of the building. Two actors demand this report: a) the municipality, with the purpose of validating the energy bills as issued by the utility company, and; b) a state owned agency that provided significant funding for the delivery of the passive-house portion of the building. Issues relevant to poor heat pump specification and the difficulty to separate energy use between existing and new facility are often included in reports to justify the building´s underperformance with regards to design intentions. On behalf of the caretaker, the difficulties experienced with the energy systems have led him to lose trust regarding how these systems are supposed to perform.

Municipality "B" | System -Focused Energy Management: The metering strategy implemented by the building owner (SBO) of SB2 follows the recommendations from the Norwegian Standard NS:3031 "Calculation of energy performance of buildings - Method and data". Energy data are collected from the main utility meter and a set of sub-meters, which register the energy consumed by specific systems, including: hot water, ventilation, lighting and technical equipment. The latter includes electricity sockets and computers used by the staff and pupils in the school. This approach facilitates identifying how much energy is used from extra-curricular activities, particularly during the summer when energy consumption from school-relevant equipment should be at minimum. Too much metering within a particular building is perceived to hinder the ability to take good decisions in support of the performance of the building portfolio. Seasonal energy profiles are used to benchmark energy performance data against previous years. Benchmarks are used to identify the building or group of buildings in the portfolio requiring primary attention. Alarms are raised when the performance of a particular building differs from its own performance on previous years. At that time, the SBO drops to the building level and evaluates what can be done to correct a particular issue. Comparing the energy performance between different school buildings in the system is possible; however, it is not a practice considered relevant within the municipality´s energy management approach.

4. Discussion

4.1. Perspectives from same user groups in different buildings

Perception from building occupants (as represented): both the teacher (from SB1) and educator (from SB2) relate to the management and use of energy in their buildings in the context of issues circumventing their daily work with pupils. Their focus is stronger on activities which impact on the consumption rather than the management side of energy in their buildings. Arguably, automated blinds are the only technical aspect discussed as a central activity; however, emphasis is placed on the disruptive impact that the lack of control over the blinds has over the educational activities that take place in the classrooms. As the level of responsibility increases, roles such as that of the staff representative and director embrace responsibilities relevant to stakeholder mediation and strategic thinking. Value is placed in seizing the opportunities created by the building´s unique energy efficiency qualities to further support the educational program. Awareness about impact from activities which fall outside of the building´s core function (i.e. community oriented services) is held at leadership or staff management levels. Broadly, building occupants perceive the use and management of energy in the building as a necessary expense for meeting a desired comfort level and achieving the school´s organizational objectives.

Perception from operational and tactical facilities managers (as represented): The differences in background and work experience between the caretaker (from SB1) and building operator (from SB2) seem to influence their understanding of and approach to energy management. With regards to the first, lack of sufficient knowledge regarding how the building energy systems are meant to operate may limit his ability, and arguably his willingness, to extend his role beyond providing reactive maintenance to the systems in place. In turn, the caretaker builds upon his current strengths (i.e. maintenance background) and focuses his attention on securing that the building systems operate as design intentions. Conversely, the building operator comes from a building automation background. He discusses the use and management of energy in the building from an integrative perspective; this is, through acknowledging the value of technologies (e.g. automation systems), supporting strategies (e.g. energy metering) and the training and knowledge required to seize energy saving opportunities. It can be said that both representatives (i.e. caretaker and building operator) understand the use and management of energy as a product of the technologies in place and the routines required to keep them functioning at optimal capacity.

Perception from building owners and strategic facilities managers (as represented): Both representatives (i.e. CBO and SBO) are responsible for the performance of a cluster of public buildings; in this sense, both relate to the use and management of energy in terms of scalable strategies that can be implemented across their building portfolio. The CBO and SBO hold contrasting views regarding the areas considered critical towards further improving energy use in their facilities. For example, the CBO focuses on activities aimed at developing the knowledge and skills of those who use and operate the building. Arguably, this view is enforced by CBO's perception that the building currently performs as intended; however, from the data gathered on energy metering routines, it can be said that the energy performance of the building has not been properly assessed. On the other hand, the SBO discuss the use and management of energy strictly from a technical perspective. The SBO acknowledges the impact of building occupant activities on the energy consumption in the building; however, the SBO rejects responsibility over the implementation of strategies aimed at managing the interactions between users and the buildings they occupy.

4.2. Perspectives from different user groups within the same building

Different user groups relate to the management and use of energy in the context of the roles, and consequently the activities, that each group embraces. One important aspect to discuss is the focus or objective that brings together the bundle of activities mentioned by each user group. In order to simply this task, this study asks: Is the focus of the activities related to the building´s core function or is it related to the building´s energy performance?

Figure 2 maps for each school building, the relationship between and focus of different user groups in the context of the activities that they consider relevant to the use and management of energy in the buildings they occupy or manage. The "Y" axis represents how much of the focus of the activities discussed is related to the building´s strategic function, and the "X" axis reflects how much of the focus is related to the actual energy performance of the building. As illustrated, building occupants relate strongly to activities aligned with the core function of the building i.e. support the effective delivery of educational and recreational activities. Their perspectives are disassociated from that of the people responsible for the operation and overall management of the building, whose primary aim is to support the continuous operation of the building. Within SB1, the activities carried out by both the caretaker and CBO can be perceived to have slightly more focus on energy performance than that of building occupants.

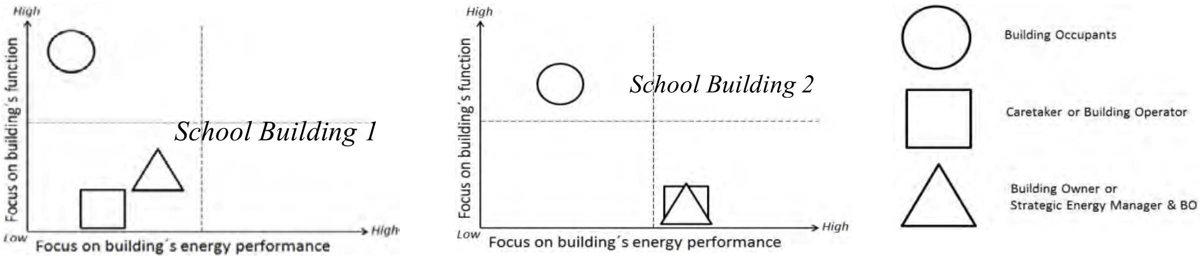

Figure 2. Images which mapping the relationship between and focus of user group perspectives on energy management practice from an activity-centred perspective.

However, energy data routines suggest that the lack of strategic guidance translates into operational routines that seek to minimize day-to-day disruption rather than support the building´s high energy ambitions. In SB2, energy management service is delivered with a solid technical foundation and larger focus on the building´s energy performance (when compared against SB1). With an energy strategy based on national standards, the SBO ensures that the knowledge and experiences gained through the management of one building are more readily applicable to the rest of buildings in the municipality´s portfolio. However, it can be argued that energy strategies that are designed uniquely from a portfolio perspective may fail to support individual buildings in achieving their particular high energy ambitions.

5. Conclusion

This paper described how representatives from different user groups (i.e. building occupants, facilities managers and building owners) relate to the use and management of energy within the passive-house school buildings that they occupy, operate or manage. Although contrasting views regarding energy management strategies were identified within the two buildings under study, strong similarities were identified with regards to how building occupants relate to energy issues on a day-to-day basis. Building occupants have a strong focus on supporting the building´s core function. This creates an opportunity for setting areas for collaboration between facilities managers and building occupants; in particular, collaboration is encouraged around the activities which building occupants consider as most relevant to the use and management of energy within the specific building they occupy. Further research will expand the set of case studies to include office buildings and investigate, among other issues, the attitudes from building occupants, operators and building owners to collaborate on EE aspects within highly automated buildings.

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Approaches to Safeguarding Sustainability Requirements in Public Construction Projects – the Client's Perspective

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Abstract

In recent years, the concept of sustainability has penetrated much of modern political, social and industrial discourse. Its recent popularization, stemming from the Brundtland report of 1987, has led to sustainability becoming a household term in nearly every industry, of which the construction sector is no exception. Considering the importance that sustainability has in the construction industry, and how it is particularly emphasized in construction financed by public funds, questions need to be raised in terms how capable the construction client is in meeting and achieving the sustainability requirements, often set by politics, that exist whilst safeguarding project delivery. The study is based on four interviews targeting public clients in Sweden and it investigates how sustainability requirements are managed in large public construction projects. What is of particular interest is the degree to which public client organizations either develop or procure systems/staff to ensure that the criteria for social, environmental and cultural sustainability are maintained and that the consequences of different approaches are managed. The results support the idea of having a multifaceted approach to sustainable construction, arguing that terms such as social and cultural sustainability may instead be dealt with separately from the more strictly defined sustainability terms of toxicity, waste and energy consumption. There is also a suggestion that once the client organization begins incorporating a sustainability mind-set in all of its affairs, members of that organization may begin working with sustainability on a perfunctory basis without necessarily understanding the underlying reasons for their actions. Finally, the challenge with sustainability is perhaps not so much that there is a lack of capability as much as there is a lack of resources for working with sustainability.

Keywords: sustainability, public client, requirements, capability

1. Introduction

It would be hard put to find an industry which does not find itself affected by the requirements that follows from the sustainability concept. As a strategic issue, sustainable development alongside social responsibility are now important considerations for companies in nearly every industry (Fiksel, 2006). In light of the movement toward sustainability, it has become commonplace for governmental institutions to conceive of grand visions and plans relating to sustainability, but as Wheeler (2000) points out, these are unlikely to come to fruition absent the necessary external pressure from social movements, nongovernmental organizations and the development of a coalition of interest that serves to strengthen the necessary political backing. More significantly, while there has been strong interest in sustainability as it relates to urban development, there has been a lack of clarification as to what constitutes as sustainable in the public construction context, most notably in relation to infrastructure projects. Questions regarding how sustainability can be quantified and the key contributors of sustainability in the urban context have all, to a large degree not been dealt with (KPMG, 2012).

Sustainability in construction is a comprehensive topic with many different facets; it includes a range of topics from air, water and noise pollution to ecological impacts (Shen, et al., 2007). Time delays have a direct impact on sustainability since as an increase in project delivery time is associated with traffic congestion, economic activities being disrupted, increased pollution, damage to ecosystems, and an impact on existing infrastructure systems (Gilchrist & Allouche, 2005). The sheer scale of the industry offers further testimony to the importance of considering the impacts of sustainability. In the European Union alone, it is estimated that the construction industry employs 11.8 million people directly, making it Europe's largest industrial employer accounting for approximately 28 % of industrial employment in the EU-15 (Ortiz, et al., 2009). In addition to this, the construction industry is responsible for nearly 40 % of the total energy consumption thereby cementing its role as a major contributor to the proliferation of greenhouse gas emissions (Abbas, et al., 2009). By the same token, the construction sector is responsible for other types of environmental problems, including both internal and external pollution as well as environmental damage and resource depletion (Ortiz, et al., 2009). With steadily rising populations, and significantly larger shares of people relocating to cities as urbanization rates continue to soar, one can only expect the environmental impact to become further exacerbated in the years to come. This sentiment is certainly shared by the UN as shown in a recent report stressing the sustainability challenges that continued urbanization will pose on society and its disproportionate effect on urban dwellers in the lower socio-economic strata (UN, 2014).

Contractors and consultants are primarily concerned with financial gains. It is therefore hardly noteworthy that these actors opt to adhere to sustainability regulations on the basis of it being a secondary concern. After all, current research shows no direct correlation between short-term business competiveness and sustainability performance although there are certainly grounds for contending that such an advantage could emerge from a long-term perspective (Tan, et al., 2011). It has been a standard belief among contractors that environmental performance accrues more costs than the proposed benefits it brings. Despite this, improvements in environmental performance in construction has been on the rise, specifically with respect to the handling of waste and its harmful effects on the environment (Shen & Tam, 2002).

This leaves the public client, the one actor whose prime objective is to represent the public interest of which the concept of sustainability plays an increasingly more important part (Raisbeck & Wardlaw, 2009). There has been a growing interest for investigating the role that the client has in relation to sustainability. Although there is no shortage of studies investigating the client's role in this regard, the research space has been dominated by studies focusing on sustainability policies that occur at a macro-level, in the realms of politics. This is made evident by likes of Chen and Chambert (1999), Deakin et al. (2002) and Melchert (2007). The importance to address sustainability at this level seems fairly intuitive due to the vast influence of governmental institutions, its importance is thus hardly a matter of contention. The study of sustainability related issues at a lower level than that of politics, as in examining the role of local public client organizations, does not occur in lieu of studying the political level but rather in addition to it. It is vital to ensure that sustainability issues are properly managed by the public recipients of said policies just as it is important for the policy makers themselves to formulate sensible requirements. Authors such as Ugwu and Haupt (2007) and Bröchner et al. (1999, p. 371) have examined the usefulness of the performance concept vis-à-vis sustainability and in the case of the former found that indicators for sustainability performance constitute an important first step in bridging the gap between global sustainability aspirations and local micro-level decision-making; and in the case of the latter that "there is an inescapable need for competence among those who formulate, monitor and follow performance requirements." This echoes the broader call that has been made for improving the capabilities of the client organization (Adam et al., 2014; Manley, 2012). In light of this inescapable need for competence, questions need to be raised in terms how capable the construction client is in meeting the sustainability requirements that are often dictated by politics without jeopardizing project delivery. This study attempts to address this inquiry. What is of particular interest is the degree to which public client organizations either develop or procure systems/staff to ensure that the criteria for social, environmental and cultural sustainability are maintained and how the consequences of different approaches are understood and managed.

2. Research method

The study is based on a set of interviews targeting public clients in Sweden and it investigates how sustainability requirements are managed in large public construction projects. What is of particular interest is the degree to which public client organizations either develop and organize or procure systems/staff to ensure that the criteria for social, environmental and cultural sustainability are maintained and that the consequences of different approaches are managed. In order to investigate this, a large public Swedish client organization was studied, henceforth referred to as PubClient. The study consisted of interviewing the manager responsible of energy and environmental related concerns. The results of the one-hour interview took place in one the facilities of PubClient and were then transcribed and analyzed. Additionally, three supplementary phone interviews were conducted for three different client organizations active in the Swedish construction industry. The objective of these phone interviews was to provide additional information and also assess to which degree the results obtained from PubClient were relevant in other public construction client organizations. Although a small sample of interviewees, the respondents were all representatives on a management level in a large city and thus covered the main organizations in this particular context. There is a risk of low validity of the data, however, as one key aspect of the data is descriptive the complementing telephone interviews can be seen as triangulation of the main interview data.

2.1 Overview of PubClient

PubClient procures and manages the construction of public facilities and the refurbishment of facilities on behalf of the municipality. With a combined floor space exceeding two million square meters and a total land area exceeding five million square meters, PubClient stands as one of the nation's largest public construction organization with a yearly expenditure hovering around one billion SEK. PubClient objectives include a variety of tasks, the main ones can be reduced to five:

i. Ensure good property management, which includes the management of land, buildings, installations and maintenance.
ii. Provide appropriate business premises and good service.
iii. Develop energy-saving measures.
iv. On behalf of the municipal government and customers, plan and build/rent new facilities or rebuild existing ones.
v. Administratively coordinate the Municipality's common building processes.

Aside from stating energy saving measures as one of its chief objectives, PubClient has consistently worked to initiate environmentally conscious procedures in all of its projects. This is due to a number of reasons, chiefly that they as a public organization should "do good" as they build and run their own maintenance with a long time perspective. Beginning from 2009-2010, all of PubClient's newly built facilitates were required to be of the low-energy consumption variety. This follows a larger trend in the country of building facilities that utilize less energy and that are more environmentally friendly. However, what sets PubClient apart in this area is not merely its scrupulousness in following government stipulated regulations but its insistence to follow internal regulations that are even more stringent than those demanded by the government. As such, the organization has received accolades for its role in actively working with sustainably issues in all of its affairs.

3. Sustainability as a concept

The modern concept of sustainability is based on the Brundtland commission report of 1987. It cemented the importance of sustainability in social and environmental affairs and gave birth to the commonly accepted definition of sustainable development as the development "that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Toman, 2006, p. 3).

Not long thereafter, the rising discourse on sustainability began to find its place in the area of construction. It also began to alter the established nomenclature, terms such as "green" building, became readily available and began to be associated with a number of positive outcomes, from lower overhead costs to higher employee productivity. This development can trace its origins to the idea of "sustainable construction", a term coined in conjunction with the first world conference for sustainable construction held in Tampa, Florida in 1994 (Miyatake, 1996). It was there where Kibert (1994), the convener of the conference, suggested that sustainable construction consisted of six principles: I). Reducing resource consumption. II). Improving resource reuse. III). Begin using renewable or recyclable resources. IV). Safeguard the natural environment. V). Maintain a healthy, nontoxic environment and VI). Strive towards achieving quality in construction.

Like much of the discourse surrounding sustainability, the term sustainable construction has been contested. Tough widely adopted by the construction community, as exemplified by the works of Ding (2008), Hill and Bowen (1997) and Kibert (2012) it has not been without detractors. Much of the critique rests on the apparent incompatibility of the phrase "sustainability" on the one hand which carries the connotation of something infinitely replenishable and the term 'construction' on the other hand which is by its very nature finite (Goodland, 1995). In order to avoid potential semantic disputes of what sustainability actually refers to and how it ought to be conceived in the context of construction, we opt for the definition put forward by Presley and Meade (2010) where sustainable construction is used to describe not only the construction phase of the actual projects but also all of the aspects surrounding it such as those imposed on social systems, transportation, waste management and so forth. The term 'green building' is used interchangeably, as is conventionally the case (Kibert, 2012; Presley & Meade, 2010; van Bueren & Broekhans, 2013).

3.1 Systems for complying to sustainability criteria

A range of different methods/systems have been developed to allow construction organizations to build in accordance with sustainable construction. These frameworks, such as the one developed by Presley and Meade (2010) is geared primarily toward contractors as a way to evaluate their sustainability performance by taking into account both strategic and activity-based criteria using well-established practices such as activity-based management, balanced scorecard, and multi-attribute decision models. Similarly, various organizations have begun issuing certifications ensuring that its holder have met certain criteria for the energy consumption of the building project as well as its water use, material use and indoor environmental quality. In Sweden, FEBY provides one such framework. Other certifications include, among others: Green Star (Australia); LEED Canada (Canada); DGNB Certification System (Germany); IGBC Rating System (India); Comprehensive Assessment System for Building Environmental Efficiency (Japan); Green Star NZ (New Zealand); Green Star SA (South Africa), BREEAM (UK), and LEED (US) (Azhar, et al., 2011). In a similar vein, Environmental Management Systems (EMS) have become a significant tool for achieving sustainable development in construction. As important as it may be, one should be weary of treating it as a panacea. Although EMS have been linked with a positive influence on environmental outcomes, it is also apparent that abiding by an EMS alone is not sufficient in guaranteeing optimal environmental performance (Lam, et al., 2011). Aside from its apparent use as a way to improve environmental performance, these systems are also employed in order to maintain compliance with environmental regulations, curb environmental costs, reduce risk and train employees. Typically, an EMS contains guidelines on policies, goals, systems for handling information, task lists, emergency plans, audits, regulatory requirements, and annual reports (Christini, et al., 2004). Although numerous EMS have been proposed, none have had an impact as great as the ISO 14000 series. This series of standards emerged as a by-product of the General Agreement on Tariffs and Trade (GATT) negotiations and the 1992 Rio de Janeiro summit on the environment (Kein, et al., 1999). The ISO 14001 constitutes the standard for developing an EMS, the rest of the standards in the series offer guidance and supporting documentation. In total since the end of 2013, over 300,000 certificates for ISO 14001 had been granted in 171 countries of which China, Italy and Japan stood out as the most prolific receivers of certificates (ISO, 2013).

4. The clients' responses

The importance of upholding sustainable ideals, especially with respect to the environment has become of paramount importance for construction clients. In the case of PubClient, the interviewee insisted that public client organization need to be at the forefront of the sustainability issue leading the way for the other actors in the industry. The client, and the public client in particular has the opportunity to play a significant role in advocating for the benefits of green construction, both through regulatory mechanisms as well as through raising awareness of 'best practices' with green construction. The challenges in upholding sustainable construction lies partly in the vastly different skillset, resources and capabilities that are required when adhering to green construction principles (Mokhlesian & Holmén, 2012). However, for PubClient, this viewpoint was somewhat contested:

> A project manager is supposed to know lots of other things, why shouldn't they be able to know these questions [i.e. sustainability]? It's not that much... It's not like you need to be a chemist or anything. It's fairly basic capabilities that one needs. But one has a bit of... I like to say that sometimes the "environment ghost" is looming in the corner and as soon as it is about the environment, everyone is all: I can't do this! But then you start to talk about it: but it's about these things! O, but I think I've got this, is this all that is to it? I think that in my field, it [i.e. sustainability] must become a natural part of everyone's roles, to know these areas. (*Development Manager of Energy and Environment for PubClient*)

The main contention here being that although environmental issues may demand a different skillset, nonetheless, project managers are inherently expected to have a varied skillset. Why then should sustainability not fall under this already wide umbrella?

The challenge of capability improvement becomes an even greater concern when taking into consideration the emergence of the performance approach. This approach essentially shifts governmental regulations from specifying technical requirements for products and materials to instead specifying the desired outcome of those products. The performance approach has been described as conducive to increasing the propensity for innovation in that it allows contractors a higher degree of freedom in how they wish to meet the stated requirements (Pries & Janszen, 1995). The reason why the development of capabilities becomes a great concern in regards to the performance approach is due to heightened need for competence in expressing, interpreting and monitoring the requirements that have been stated in terms of performance. This argument is echoed by Bröchner et al. (1999) who further add that the performance approach demands both acquiring and managing technical, environmental and administrative knowledge. Additionally, test methods and acceptance criteria need to be defined, a process that requires competence. The construction client can thus tackle the issue of sustainability from different angles, depending on the level that is of interest. Essentially, these measure can be grouped into either external actions that relate to parties outside of the inherent organization or internal actions that seeks to address the organization's own internal procedures.

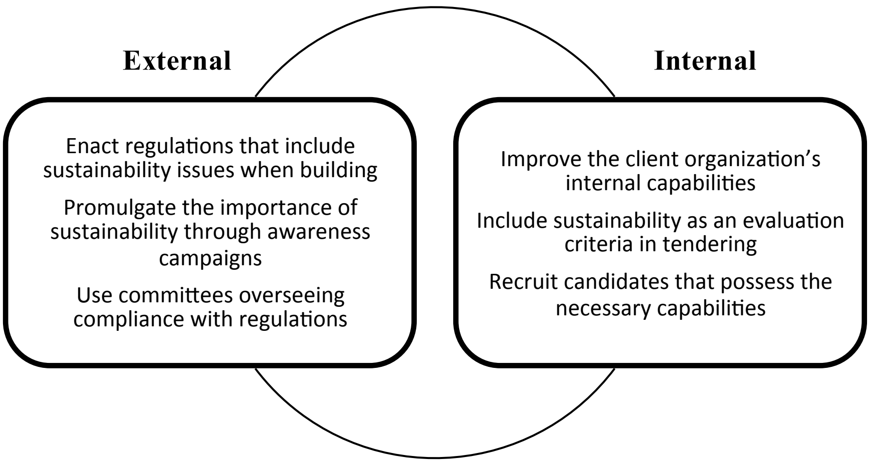

Figure 1: Approaches to safeguarding sustainability requirements, external and internal.

Bröchner (1999) as well as Mokhlesian and Holmen (2012) among others make the point that competence is at the heart of a successfully implemented environmental system. Building on this notion, one might take it further and state that the given EMS that the client organization uses is merely a reflection of its competencies. The more competent the organization and the individuals who partake in it, the more pertinent the environmental systems ought to be for its intended purposes. Therefore, it would seem that the optimal solution would be one that incorporates the different systems that are available to the client. It is not a singular holistic approach, but rather a diversified strategy that employs different systems where they are appropriate. This line of thinking goes against what seems to be the prevalent paradigm for clients in the Swedish construction sector where sustainability is often regarded as a monolithic issue, as made evident by the common structure of having widely different areas such as energy efficiency, toxicity, safety, social sustainability and cultural sustainability in the same division.

The latter two are particularly difficult to grasp as they seem to involve a subjective dimension which is more difficult to comprehend.

> It is as you say, a lot more difficult [to manage social/cultural sustainability]. It seems to be about primarily perceived values that are much more difficult to grasp than if one has used this type chemical or not, that's more black and white. (*Development Manager of Energy and Environment for PubClient*)

> You have no metrics [on social/cultural sustainability] what so ever. It is a bit of trumpery, really! The energy issues are a lot easier […] it is easier to place a metric on it. (*Environment and Energy coordinator for the Municipality*)

A proposed response to this is to specify separate personnel that deal exclusively with those issues or the more preferred option of creating an environment in which these sustainability considerations become an accepted part of the project manager's role.

> I feel that everyone still needs a lot of support in regards to environmental and energy related issues and [they] regard it as a separate issue whereas I would argue that it is a natural part of any type of role. In the long term, I would say that we need far less support for capabilities in those areas. As project managers, most environmental issues should be obvious. (*Development Manager of Energy and Environment for PubClient*)

This shift in mentality would essentially reduce or do away with specialized organizational units that deal with these issues. Instead opting for a solution where the project managers are expected to possess the capabilities needed to safeguard sustainability requirements themselves. This can also be viewed in light of the past changes that has occurred in the construction industry in regards to environmental concerns. Initially, such questions were often met with resistance by actors in the industry who questioned the soundness of more sustainable ways of building.

> The trend is essentially the same in the construction industry or the real estate industry. Although the public sector had even prior to this had it easier in discussing these types of questions, I think that there is a huge difference today. For example, energy-efficient construction, when we started there were many who did not believe in it at all, [claiming] you would construct bad buildings. That debate is surely not as prevalent. […] Now, I'd say that there's a great upswing regarding all these environmental issues for everyone. No one thinks it's weird to talk about biodiversity anymore which if you were to mention it in 2008, it was almost a bit nonsensical. But certainly in public organizations, I do not think that there is a single public [organization] that we have contact with, a property owner, who is not working with these questions and considers them important. (*Development Manager of Energy and Environment for PubClient*)

There are two notes that relate to this quote, firstly that although public organizations may be working with these issues, it would seem that the private sector has a more organized way of working as evident by one interviewee saying:

> Large [contracting] companies have worked with sustainability questions in a more structured way. (*Sustainability strategist for a municipal company*)

Secondly, that the state of the sustainability issue went from being something that is questioned to something that is obvious and part of every task in the organization. What occurred beyond this, however, shows a rather peculiar shift. Once environmental concerns had become a natural part of the organization, it was no longer viewed as a differentiating attribute of that organization. Initially, PubClient's project managers were fully cognizant of the importance of keeping sustainability in mind in all matters as this was a core issue that permeated much of the organization.

> There are a lot of new project managers [of ours] who can barely understand that we build the most energy efficient buildings in Sweden! We have very clear instructions and requirements [internally] and so on which they adhere to, but they do not get an understanding for what it is and what it really means. (*Development Manager of Energy and Environment for PubClient*)

From this, there seems to be an indication that as the organization becomes more capable in working with sustainability related issues, the more fluent it is in formulating stipulations and requirements to adhere to sustainability requirements. However, once the organization has worked with these issues for a sustained amount of time, they become part of the everyday mode of operation as opposed to something novel. This shift may then result in the members of the organization working with these issues in a perfunctory fashion without much forethought in why the work is carried out in the way that is.

Another reoccurring theme in the interviews was the tendency to regard the sustainability issue as one that could be easily managed if there was more awareness of the issue. The interviewees mostly rejected the notion that there was a lack of capability in the organization for how to work with the sustainability. There seemed to be an insistence on downplaying the technical skills required to work with sustainability related issues. Instead, they would point to a lack of awareness as the primary issue that needed to be addressed.

> Yes, I think so (i.e. that the organization is capable to handle sustainability issues). However, I do think that if one wants to get more results then there is a need for more people to work with these matters […] I mean it's not a difficult science […] I believe that the capability exists, that's my experience at least. If you look at [client organizations] in the city, I think there is tremendous capability […] we have knowledge, I think everyone knows what it is about. I don't think we can get more knowledge, it is about finding more in the organization and really go through with it and receive enough resources and

money to be able to go through with it. (*Environment and Energy coordinator for the Municipality)*

Instead of viewing the challenge of sustainability as a capability issue, perhaps it should be viewed as a questions of resource allocation. In order to work with this issue in an efficient matter, more resources, basically, need to be allocated to it. Or, by embedding sustainability in everyday work it becomes a discreet capability, it becomes something that is simply a part of the everyday work's starting point.

5. Concluding thoughts

Sustainable construction is essentially an umbrella term that contains a wide range of different activities that aim to improve the production and the outcome of construction projects in a way that ensures that long term effects are considered. Not only with respect to the environment but also to society. Although issues such as waste management, noise reduction and preserving the biodiversity of a local ecosystem could all fall under sustainable construction, these issues have few things in common both in their technical details as well as their strict relevance to construction. This invites one to ask: does it make sense to feature social sustainability, cultural sustainably and environmental sustainability under the same department? Much of environmental sustainability can be measured in hard figures, particularly with respect to pollution, and could essentially fall under quality assurance, whereas social and cultural sustainability cannot be measured easily and are handled using more qualitative assessments.

This study would also suggest that although the capability required to manage sustainability issues does not necessarily need to be extensive, there is however a need for increasing the resources required for managing sustainability in a more efficient manner.

The construction industry's fragmented structure dictates that any change that occurs needs to do so in the entire supply chain of actors for it to have any fruitful effect on the industry as a whole. It would similarly seem that a multifaceted approach for managing sustainable construction would too require that the different actors be involved. Environmental issues are treated as constraints, a necessary evil that must be addressed instead of a factor of equal importance to that of financial concerns and project delivery. At the same time, it is important not to downplay the shift towards a more sustainability-driven thinking that has slowly but unrelentingly found its way into the practices of the construction industry. From energy efficient houses to methods of production that involve burning fewer amounts of fossil fuels. This is all commendable and few would argue the contrary. The point of interest lies in finding ways to continue the trend of incorporating and embedding sustainably to the operations of the organization. However, what this study shows is that when the client organization does so and working with sustainability issues becomes part of the established modus operandi, there is a risk that the members of the organization work with these issues in a perfunctory way without understanding what they are doing and why they are doing it. If this is a development that should be regarded as troubling or merely the expected culmination of incorporating sustainability in all affairs remains to be seen. What can be said however is that the increased incorporation of sustainability will significantly alter the way in which that organization operates and the way that it is structured.

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Engaging End-users for Sustainable Repurposing and Improved Occupancy

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Abstract

Vacant commercial facilities are an increasing concern in many developed countries. Despite the low occupancy rates in existing facilities, new commercial facilities that better accommodate the needs of modern end-users are constantly developed. In addition to financial concerns, under-utilized spaces are a great environmental burden, as buildings account for approximately one third of the global energy demand. One of the most effective ways to reduce the greenhouse gas emissions associated with buildings is to increase space-efficiency, namely, reduce the use of space. Repurposing existing facilities for a new use or a different end-user, does not suffer from the embodied energy and material use associated with new construction and major refurbishments. However, it can be argued that even a repurposing project may lead to significant waste of financial, natural and human resources if the project is unsuccessful, i.e., the facility remains under-utilized after the attempted adaptation. This study examines two Finnish repurposing projects with special focus on stakeholder management and engaging end-users. Both projects are investigated starting from the early design phase. The data comprises stakeholder interviews, and observation in a planning workshop. As the researchers actively participated in the workshop, the research is also partially action-based. This paper presents a model for identifying and engaging end-users to a repurposing project. The key finding is that, active participation in the design phase leads to a sense of ownership of the space, which in turn is thought to promote the efficient use of space and improve occupancy. End-user engagement and higher occupancy together would support all three dimensions of sustainability: social, environmental, and economic.

Keywords: repurposing, end-user engagement, project management, stakeholder management, sustainability

1. Introduction

Vacant commercial facilities are an increasing concern in many developed countries. For instance in the Helsinki Metropolitan Area the occupancy rates reached a record low level of 82% in 2014 (KTI 2015). Despite the low occupancy rates in existing facilities, new commercial facilities that better accommodate the needs of modern end-users are constantly developed. Moreover, new construction carries with it significant embodied greenhouse gas (GHG) emissions. Therefore, in addition to financial concerns, under-utilized spaces are a great environmental burden, as buildings account for approximately one third of the global energy demand. One of the most effective ways to reduce the GHG emissions associated with buildings is to increase space-efficiency. Numerous companies have adopted this measure in their sustainability program, in the form of reorganizing facility portfolios. The popularity of the measure is largely due to the relationship between cost-efficiency and space-efficiency, but the reduction in GHG emissions is also evident.

Repurposing existing facilities for a new use or a different end-user, is gaining support globally and is considered a more sustainable option than new construction (Bullen 2007; Bullen and Love 2009, 2010; Langston et al 2007). Repurposing does not suffer from the embodied energy and material use associated with new construction and major refurbishments. However, it can be argued that even a repurposing project may lead to significant waste of financial, natural and human resources if the project is unsuccessful, i.e., the facility remains under-utilized after the attempted adaptation. In line with the Toyota Production System (TPS) definition (Liker 2004), a failed project is considered 'waste' (Silvius and Schipper 2014). Therefore, and for the purpose of this study, a repurposing project is considered sustainable if it succeeds in engaging the intended end-users and, consequently, improving occupancy levels. Based on previous literature, a sustainable project requires proactive stakeholder management and engagement early on in the project (Aaltonen 2010, Bai et al. 2013). Consequently, this study looks at repurposing projects from the point of view of stakeholder engagement in the design process.

This study examines two Finnish repurposing projects, which both place special emphasis on end-user engagement in the project design phase. The primary data sources comprise stakeholder interviews, and observation. As the researchers actively participated in the workshop, the research is also partially action-based. A model for identifying and engaging end-users to a repurposing project is presented. The study finds that, active participation in formulating a joint vision and participating in the design phase leads to a sense of ownership of the space, which in turn promotes the efficient use of existing commercial buildings. However, based on the findings, end-user engagement in the early phases of the project is not enough, but engagement should continue throughout the project and during operations also.

The remainder of the paper is structured, as follows. The next section introduces the theoretical background for the research. The following Section 3 describes the study design, including a description of the cases, data collection and analysis. The findings of the empirical analysis are presented in the fourth section. The fifth section discusses the findings further, and the sixth and final section provides conclusions and suggestions for future research avenues.

2. Theoretical background

This paper utilizes two separate streams of research as a theoretical background for the study. First, literature on sustainable adaptive reuse of buildings is introduced. Second, the paper draws on previous work that has integrated sustainability into project management.

2.1 Sustainable adaptive reuse of buildings

Repurposing of facilities, where existing facilities are renovated for a new use or a different end-user, is gaining support globally and is considered a more sustainable option than new construction (Bullen 2007; Bullen and Love 2009, 2010; Langston et al 2007). Bullen (2007) identified several sustainable outcomes of an adaptive reuse process, including: reducing resource consumption, reducing energy use and emissions, extending the useful life of a building, cost-efficiency compared to demolition and rebuilding, reclaiming embodied energy, and revitalizing existing neighbourhoods, to name but a few (Bullen 2007).

Langton at al. (2007) discuss the obsolescence of a building and bring up six different types: physical, economic, functional technological, social, and legal obsolescence. The cases studied in this paper best suit the description of the functional obsolescence, where the buildings are no longer needed for their original purpose, and social obsolescence. Social obsolescence was particularly visible in the case of the new learning environment, where behavioural change had lead to changes in space requirements. When buildings become obsolete, Langston et al (2007) argue, they require either demolition or refurbishment. Bullen and Love (2009) develop a viability process model to aid the decision making process of building owners on whether to demolish or refurbish the buildings. The overall conclusion is that the decision should always be based on the individual characteristic of the building, and that no consensus exists whether adaptive reuse is always the most sustainable option (Bullen and Love 2009).

This paper utilizes the theoretical framework recognising the sustainability of reuse of existing facilities. Nonetheless, neither of the case projects represent the type of major renovations that are described in the previous sustainable adaptive reuse literature. The presumption is that, minor repurposing projects are always innately sustainable, as they require even less energy, materials and other resources than major refurbishments. It should be further noted that better occupancy rates and space-efficiency along with avoiding new construction make the repurposing of buildings sustainable regardless of whether sustainability per se is a stated goal of the project. In other words, the motivation behind a repurposing project need not be achieving sustainability, but underlying motivations are in fact, most often economic.

2.2 Sustainability in projects

Recently, issues related to sustainability have received only minor attention in project management literature. Much of the discourse is emphasizing the role of stakeholder management, linking proactive stakeholder management to sustainability. Unlike sustainability, stakeholder management has received increased attention in project management literature in recent years. Special attention has been placed on the significance of proactive stakeholder management early on in the project, and stakeholder identification (see e.g. Aaltonen 2010). This approach is also found to promote project sustainability (Bai et al. 2013).

Both stakeholder management and sustainability management are crucial in large built environment projects, which inherently carry great environmental, social and economic impacts. Eskerod and Huemann (2013) argue that currently project managers falsely engage in “managing-of-stakeholders” rather than “managing-for-stakeholders”. The former simply attempts to make the stakeholder adjust to the project, while the latter is considered more sustainable as it proactively considers the diverse needs of the different stakeholders.

Silvius and Schipper (2014) define nine dimensions of sustainability in projects: Balancing the triple bottom line, balancing short-term and long-term orientation, balancing local and global orientation, considering values and ethics, considering transparency and accountability, stakeholder participation, risk reduction, eliminating waste, and consuming income rather than capital. They also list identification of the key stakeholders, stakeholder involvement, communication, project handover, and selection and organization of the project team as one of the relevant impact areas of projects. Successful handover and organizational learning are also seen as key components in sustainable project (Silvius and Schipper 2014).

Using the terminology and philosophy developed by Liker (2004) for the Toyota Production System (TPS), Silvius and Schipper (2014) consider a failed project to be ‘waste’. Waste of materials and resources is of course inherently unsustainable. Therefore, and for the purpose of this study, a repurposing project is considered sustainable if it succeeds in engaging the targeted end-users. Bai et al (2013) have developed a six-stage process for achieving sustainability in project through stakeholder management. The six suggested stages are: 1) identification 2) relating stakeholders to sustainability targets, 3) prioritization 4) managing 5) measuring performance 6) putting targets into action. The six stages approach requires that the project set measurable sustainability targets. It is therefore not applicable as such, as this study argues that a repurposing project is innately sustainable.

3. Study Design

The research approach is qualitative and explorative, with two cases studies. Case study research with a small number of cases allows studying phenomena rigorously and in-depth in their real-life context. For this research, both studied cases provide rich information on the phenomenon under study. The main source of data comprises interviews with key informants from both cases, participating in a planning workshop and development meetings, and archival data of the two projects. The in-depth, semi-structured interviews ranging between 60 to 90 minutes in length included questions about project stakeholders and the development process. Despite the extensiveness of the interview data, also archival data such as email correspondence were used as additional data sources. Moreover, observations by the researchers complement the data and provide also investigator and method triangulation. Finally, utilizing two separate cases for the study provide an opportunity to compare the cases and provides a richer empirical data base. Limiting the number of cases to two allows for in-depth analysis of both cases

This study examines two Finnish repurposing projects with special focus on stakeholder management and end-user engagement. The first case study is a private health care and wellness campus in Helsinki. The project was initiated because a major occupant is re-locating offsite. The vision of the property owner is to revitalise the campus by leasing the excess vacant space to several smaller, commercial tenants. The facility is a heritage building with conservational value, and even though restrictions do not apply to the interior or space design, only minor refurbishment is planned. Potential future occupants were invited to participate in a workshop and submit ideas for the new campus. The other case is a learning environment on Aalto University campus in Espoo, Finland. Several campus facilities suffer from low occupancy rates and are potentially subject to major renovations or demolitions. Simultaneously, new ways of working and learning continue to make traditional classroom settings obsolete. The second case project combines the need for new type of learning environments to the need to improve space efficiency on campus. The repurposing project transforms an old machine hall into an innovative networking and learning space for students. This exceptional project utilizes co-design techniques with students to create an innovative space.

Table 1: Description of the two cases

Case / *Theme*	*Case Energy Garage*	*Case Wellbeing Campus*
Facility type	*Alternative learning environment on campus*	*Full-service health and wellbeing campus*
Project type	*Developing a new learning space, refurbishing unused space*	*Improving space efficiency, energizing campus with new tenants*
Data sources	*Primary data source* • *19 stakeholder interviews (recorded and transcribed)* *Other data sources* • *80 archived documents including email correspondence* • *Observation during meetings and other site visits*	*Primary data source* • *Workshop* *Other data sources* • *14 stakeholder interviews (recorded and transcribed)* • *Observation during meetings and other site visits*

Based on previous literature, special focus of analysis was placed in the early project phases and how the first contact with stakeholders was managed. The distinct processes of the two selected cases are mapped, analysed and compared particularly from the perspective of stakeholder management.

4. Findings

The findings are first presented separately for each case, through introducing a project outline with detailed descriptions and quotes about events. Then, the findings are synthesized to form a suggested model for end-user engagement in a repurposing project.

4.1 Case Energy Garage

The development path of the learning environment Energy Garage has been described in detail in previous research (Kyrö and Artto 2015). Different phases, each with a different focus and different key stakeholders, arose from the analysis. The project has its origin in a research initiative, which in 2013 was decided to re-focus on students and learning. The project shifted from a faculty-driven research initiative to a student-led social learning environment.

Even though the project was initiated at the top management of the university, the project had a goal of bottom-up management. The university wanted to provide financing and support, but not micromanage the project. Instead, students were invited to be active members of the design team and a student was selected as a project manager. As one member of faculty put it: "*adults were left out of the design process.*" An experienced designer of learning spaces led the design efforts, however. Four interactive design meetings were organized. The lead designer stated, that her role was to be *"facilitating, instead of planning for the students"*. After the start of operations, students had the main responsibility of day-to-day management of the space. Additionally, a board consisting of student and faculty representatives meets every quarter to discuss user needs.

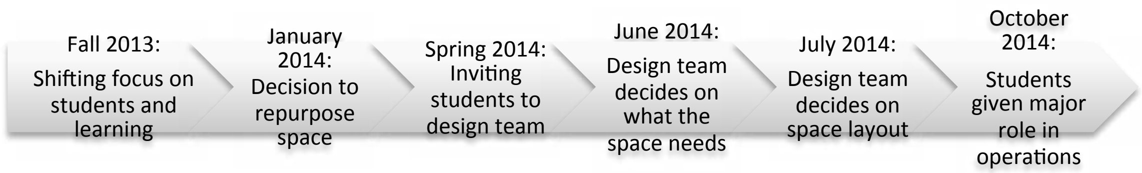

Figure 1: Timeline of Case Energy Garage repurposing project

The benefit of this kind of a co-design process was identified to be an enhanced sense of ownership experienced by the design-team. However, students are a problematic end-user group as they tend to graduate and move on, quickly. New students may have completely different ideals of an innovative learning environment.

4.2 Case Wellbeing Campus

The second case takes a different approach to the campus development, and utilizes a new form of an ideating workshop to catch the attention of potential new end-users and gain fresh insight. Ideating was sought with a distinct and novel workshop method. Potential end-users were first invited for a workshop on campus. Invitations were sent to private, public and third sector actors both from the health and wellbeing sector. Altogether 13 participants were present at the ideating workshop, aided by five facilitators and three persons assisting in documenting the workshop for future research use.

During the workshop, participants were first asked to recall a recent pleasant memory related to health and wellbeing. This was thought to focus the participants to the workshop theme in a positive way. For the remainder of the workshop the participants were divided into three separate groups. Each group member first considered which actors and activities they would prefer to locate on the campus, and present their suggestions to the group. At this point the participants were not allowed to select the organization they were presenting as a future campus end-user. During the second phase the group was to combine the best suggestions from each member to come up with a new unique set of actors and activities on campus. Once the activities were agreed upon, the next phase required the group to design the campus layout on a general level by placing the different activities on campus. Finally, the groups were asked to come up with a name and slogan for the campus. During the entire workshop the participants were reminded that they were not restricted by any existing physical of economic constraints of the campus. The freedom to innovate produced a range a truly special ideas for the future use of the campus.

The innovative workshop method produced a number of ideas for the campus development, and a few were selected for further implementation. The strength of the workshop method, the 'no restrictions' principle, also entails a challenge, as the unique, innovative ideas cannot be executed as such. However, the method was extremely successful in capturing novel ideas. As the instructions distributed to all workshop participants read: *"You will be able plan the campus with your peers in a good atmosphere and without any restrictions… Together we will create a business model concept of dreams. The results can later be compared to more traditional or implemented plans"*

Consequently, the ideas have been taken into account when planning the campus with existing tenants present. Moreover, the participants of the first ideating workshop remain stakeholders of the campus development project, albeit in a minor role.

4.3 Cross-case analysis

Next, some key features of the two projects are identified and listed in Table 2. Also the handover of the projects, which is known to be of significance to overall project sustainability, is discussed.

Table 2: Findings from the two case projects

Case / *Theme*	*Case Energy Garage*	*Case Wellbeing Campus*
Target	*Create a new learning environment for the students* *Improve occupancy*	*Energize the campus with new activities and end-users* *Improve occupancy*
Approach	*Proactive end-user (student) engagement starting from the early design phase* *Bottom-up management approach*	*Proactive inclusion of potential future occupants (public, private, third sector) in the early design phase*
Process	*Co-design team meetings*	*Single ideating workshop*
Strengths	*End-users experience ownership of the project and space*	*Innovative, 'out-of-the-box' ideas emerge*
Challenges	*Students as an end-users group change; the design team no longer represent the end-users at the operations phase*	*Financial constraints limit possibility to realize ideas* *Workshop participants do not represent end-users as such*
Handover	*Continued engagement of student groups during operational phase, e.g. membership in the board*	*Internal workshops with final end-users to refine the ideas to more realistic ones*

As seen in the table, the projects differ somewhat in their respective process, and therefore strengths and challenges. The strength of a long-standing, co-design process involving a group of selected end-user representatives meeting several times, is the enhanced sense of engagement and ownership of the space that the group was identified to feel. On the other hand, the innovative ideating workshop method, where participants were specifically told to leave all physical and economic constraints, produced a number of great, out-of-the-box ideas. However, as many ideas will not be realized, the process might lead to lowered sense of empowerment of the participants. It is noteworthy that both project faced the challenge of a change in the actual end-users compared to the originally planned. Due to this, the importance of stakeholder engagement also later on in the project is highlighted.

5. Discussion

This study sought out to increase understanding on how the repurposing of building could bring about environmental, social and economic sustainability. The results indicate that the most significant challenges are connected to the identification of the right stakeholders. Interestingly, both cases witnessed a change in the end-users compared to what was planned. Previous literature suggests that stakeholder engagement its crucial at the project frond end. However, based on these findings, engaging end-users early on in the planning phase is not enough if the end-users change and the management does not respond to the change. Instead, sustainable repurposing projects require stakeholder engagement throughout the project lifecycle. The importance of continuous, lifecycle management has previously been discussed earlier in the context of shopping centre facilities (Artto et al. 2015).

Based on the findings, a model adapted from the six-stage process for achieving sustainability in project through stakeholder management, inspired by Bai et al. (2013), is developed. The suggested model for repurposing projects comprises five separate phases, as follows.

1) **Identification of desired end-users.** This stage was handled differently in each case project, but nonetheless received significant emphasis on both. The identification was based on careful analysis of the desired future use of the space *(e.g. modern learning environment or energizing campus ecosystem)*
2) **Engaging potential end-users to the project.** This stage is particularly crucial for the further success of the projects primary goal, namely, improving occupancy at the end of the repurposing project. Despite different approaches in each case study, both cases place special emphasis on engaging the end-users through inviting them to participate in the joint planning activities.
3) **Formulating a shared vision with potential end-users.** Both cases were promoting a certain vision of the future space already before the joint planning activities, however, both openly allowed jointly ideating a new vision. This stage aids the sense of empowerment and ownership of the space.
4) **Co-design of activities and space.** End-users were also engaged in the actual design of the physical phase and activities that should be included. In both cases, this stage requires compromising between the different actors.
5) **Engaging final end-users to operations.** This stage is a requirement for the continued sense of ownership and end-user satisfaction. For both case studies, problems were identified as the final end-users differ from the potential end-users who participating in the previous phases.

The five stages are presented as a continuous project lifecycle in Figure 3.

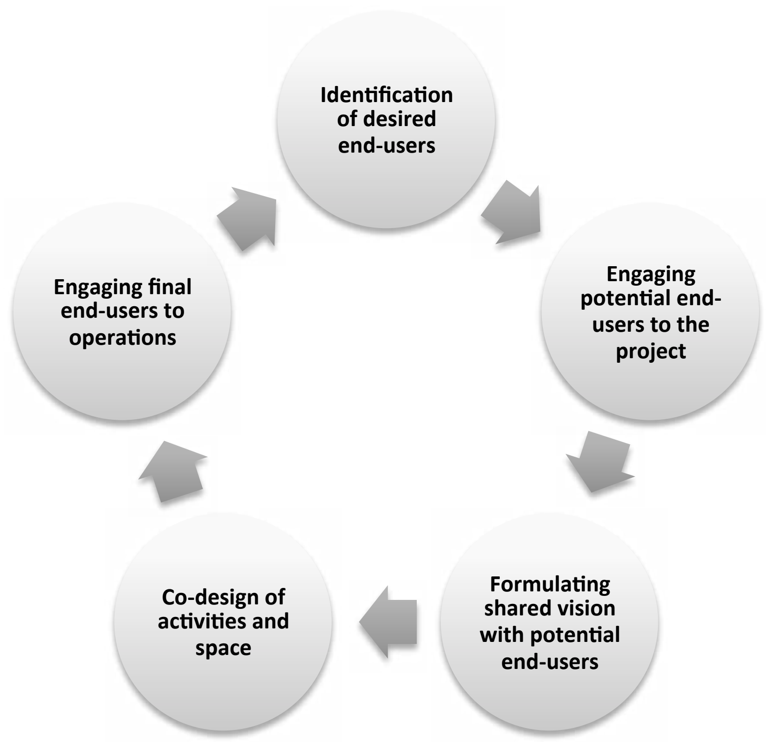

Figure 3: End-user engagement model for repurposing projects

The practical contributions may be used by real estate professionals in planning for repurposing projects, and utilized in the design process introducing these co-design principles. As new learning environments and campus retrofitting projects are becoming more and more common (Eriksson et al. 2015), the practical contributions are particularly current and relevant.

6. Conclusions

This paper has introduced the common goals of, and enhanced understanding of the concepts of stakeholder engagement, repurposing, and sustainability. Engaging stakeholders and managing sustainability have previously been linked, as have repurposing and sustainability, but all three combined provide a more thorough view of sustainable repurposing project.. It should be noted that improved occupancy rates and space-efficiency make the repurposing of buildings sustainable regardless of whether sustainability per se is sought after in the projects. In others words, the motivation behind a reuse project need not be achieving sustainability. This paper draws on empirical data of two exploratory case studies, and makes no attempt at statistical generalisation. In the future, analysing a number of case studies with available quantitative occupancy data after repurposing projects would provide interesting findings. The proposed, integrated stakeholder engagement model could be validated through these types of mixed method studies. Another potential future research avenue would be to study the relationship between sustainable repurposing and city planning policies.

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Veteran Workforce Development: How Veterans can make a Positive Impact on Workforce Development in the Construction Industry

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Abstract

Many different sources have reported on the looming shortage of labor for the construction industry. Simultaneously, veterans who are returning from deployments and transferring into a civilian career are facing significantly higher unemployment rates than the general population. This paper proposes that these issues can be partially solved by forming a working relationship between the two populations. To find relevant information and opinions on this topic, interviews were conducted with three different groups. These three groups were contractors, veterans who are currently working in construction, and groups or organizations who are working to promote the partnership of the construction industry and the veteran population. Since the data gathered was mostly opinions and experiences, qualitative data analysis techniques were used to find trends in the data. Comparing and contrasting these different groups gave an informative insight to the issue. This paper concludes that while there are many challenges to overcome, the veteran population is a sustainable source for future employees for the construction industry, which can, in part, help to lessen the forecasted shortages for both skilled labor and construction professionals. However, there are multiple steps that need to be taken before veterans will have the opportunity to easily transfer their skills into the construction workforce. Some of these are cultivating lasting relationships between contractors and local military bases, provide opportunities for veterans to learn about and connect with contractors, and offer targeted veteran training programs that allow veterans to gain trade specific skills before they leave the military.

Keywords: veterans, workforce development, construction industry, United States,

1. Introduction

In 2011, in the United States, it was estimated that there will be approximately 300,000 veterans exiting the military in the next year, and this number will continue to grow in the years to come (VetPop 2011). These men and woman who have served the country are returning home to another battle, the adjustment to civilian life. Veterans who have fought in post September 11, 2001 wars (known as Gulf War II – era veterans) face an unemployment rate that is roughly three percentage points higher than the average (Army Times 2013).

The construction industry in the United States, on a whole, is experiencing a shortage of labor (AGC, 2013). This shortage applies to both construction professionals and trade workers. As the US economy is recovering from the downturn that began in 2007, construction projects are once again in high demand. Almost three quarters (74%) of construction companies report having trouble hiring qualified workers to meet the demand for their increasing work (AGC, 2013). This is an issue that is not just a current one, but one that will persist long into the future if new avenues of finding laborers and employees are not established and continually sustained.

This paper proposes that these two issues can be solved simultaneously. Veterans need sustainable careers and construction firms need trainable, responsible workers. Yet, there still seems to be a disconnection between the companies and these potential employees. This study investigated if and why veterans were a good fit to work in construction and what is currently being done to pair these two populations together and what can be done in the future to increase awareness on both sides of the issue. This research aimed to explore the opportunities in, benefits of, and barriers to construction as a civilian career for recent veterans and to investigate how this population could help to solve workforce issues in the construction industry. The objectives of the research were to (1) assess the need for renewed and continual workforce development in the construction industry, (2) discover what skills, experiences, and training veterans of the U.S. Military have that have been and would be applicable in the construction industry and (3) to discover what efforts are currently being made to pair contractors with veterans and to suggest future actions to this end.

The study used qualitative research methods and techniques. Interviews were selected as the main method of data collection because of the personal nature of the issue at hand. The collected data was analyzed by summarizing, coding, narrative and comparative analysis methods.

2. Literature Review

2.1. Construction Workforce Issues

In 2013, the Associated General Contractors of America (AGC) released the results of a nationwide survey that revealed issues companies were having with finding suitable workers. Over eighty percent of the firms surveyed answered that they had expanded their professional or craft workforce in the past year and that they had trouble or are still having trouble filling those positions (AGC, 2013). This survey determined that 65% of the firms considered the quality of the available construction crafts workers was below average or poor whereas 77% of the firms considered the quality of general construction professionals as either average or less. Contractors are pushing more for higher productivity rates from their craft workers. This higher demand for quality and productivity is being opposed by the lack of proper training pipelines for future construction workers (Pace, 2003).

According to a leading management consulting and investment banking company for the engineering and construction industry (FMI), in a detailed 2010 report on construction trade demand, the estimated number of jobs that needed to be added by 2014 to fulfil the estimated amount of work was 1.5 million. Another source, the Construction Labor Research Council (CLRC) predicted that a minimum of 185,000 new construction jobs will have to be added annually in the next decade to keep pace with the demand for construction services. It was also predicted in 2010 that by 2014 almost twenty percent of the current construction workforce would retire or be on the verge of retiring. All of this comes at a time when the market for construction is finally climbing out of a six year recession (NCCER, 2013).

All of these facts point to, what is commonly referred to as, the “skills gap.” This skills gap highlights the growing break between the construction workforce and the skills and training that are needed for one to join the workforce and the general population. High school aged kids and other young people are not receiving or are not interested in receiving the proper training to enter a construction trade as a career. Over fifty percent of high school graduates are now attending college. Very few are attending trade schools. This shift in the US culture is leading to less funding for the secondary career and technical schools, which in turn leads to fewer workers and less ways for a hopeful employee to receive proper training (AGC, 2014).

The AGC released a workforce development plan in 2014 which outlines a number of ideas on how to combat the aforementioned problems about labor shortages and a lack of proper training programs (AGC, 2014). One section of this plan discusses how giving training opportunities to veterans can be a great source of future workers. There are already many programs in place that could help veterans gain the needed skills to enter the construction workforce, if they receive more funding and are grown into a national effort. The AGC also mentions that extending the Work Opportunity Tax Credit, which helps cover certain costs of hiring veterans for companies, would encourage more companies to actively seek out the veteran population as a potential market for future employees.

2.2. Veteran Unemployment Status

Bureau of Labor Statistics publishes the data for unemployment rates for veterans. The statistics for the unemployment rate for vets by period of service show that while many periods have lower rates than nonveterans, the Gulf War era II, which is defined as veterans who have served post 9/11/2001, is the youngest generation of vets and has the highest unemployment rate. The Gulf War era II generation is also comprised of a much larger population of women than previous veteran generations.

2.3. Veterans in Construction

The idea of pairing veterans with construction companies is not new, but it is one that still has plenty of potential to help both sides. There are multiple organizations and programs that have this goal in mind: V2C, Helmets to Hardhats, VIP, Veterans Build America, and V.I.C.E. or Veterans in Construction Electrical are just a few such programs (Jones, 2013). However the effectiveness of many of these programs is hard to quantify. If they truly are making a difference in the labor force as a whole has yet to be determined.

"Helmets to Hardhats" has been helping veterans find jobs in the construction industry since 2003 but recently lost its funding from the federal government thus greatly impacting its effectiveness (Cronin, 2013). V2C is a much smaller and much newer program. It has been developed and run thus far with no funding. The founding members of the program have essentially volunteered their extra time to run V2C, but they feel that to begin making a larger impact, funding must be procured soon (Jones, 2013).

VIP is the most different program from the previously mentioned ones. This is because VIP does not simply try to pair veterans with jobs, it actually provides the necessary training to become an apprentice in the plumbing and pipefitting industry for free. This program is twenty weeks long and guarantees job placement upon completion of the program. The program includes eighteen weeks of intensive training that takes place while the veteran is still stationed on base and then two weeks of transition assistance to assure the veteran a smooth shift back to a civilian life and career. All of these services are provided free to the veterans and paid for by the local UA (United Association of Plumbers, Pipe Fitters, Welders and HVACR Technicians). This program started on Joint Base Lewis-McChord in Lacey, WA and has spread to multiple other bases including Camp Pendleton, California and Camp Douglas in Wisconson (Terven, 2011).

The percentage of veterans working in construction is significantly less than other industries such as: automotive/mechanic, aviation, government, health-related services, security, and transportation (Abt, 2008). There is limited data on the make-up of the construction labor force and what percentage of workers and professionals are veterans.

A survey by the *Military Times* entitled "Best for Vets 2013: Employers" ranked the top 53 employers for veterans. Of the 53 companies listed none were from the construction industry. There are two contractors listed on the 2014 list of "Best for Vets: Employers." The decision was based on data such as percentage of employees who were veterans, percentage of veteran executives, and percentage of recruiting budgets dedicated to veterans. This survey suggests that the construction industry as a whole could improve its outreach towards veteran.

3. Research Methodology

The study was conducted using qualitative research methods and techniques. Interviews were administered to collect the data from three different groups consisting of twelve people in total.

The collected data was analyzed using qualitative methods such as summarizing, coding, narrative and comparative analysis. The answers from each group were examined individually, as a group, and comparatively across all groups.

Group One- General and Specialty Contractors. This group consisted of a representative or group of representatives from selected construction firms in the Southeast of the United States. These firms and individuals were chosen using convenience sampling methods.

Group Two- Veterans. This group was comprised of people who were currently working for a company that was involved in the construction industry and also had previously served in any of the branches of the United States military. This group was selected using both convenience and snowball sampling methods.

Group Three- Programs that are currently working to pair the veteran population with the construction industry. This group contained people in leadership positions in a group or organization whose goal is to pair the veteran population with the construction industry through a variety of different methods. These organizations and individuals were chosen using convenience sampling methods.

3.1. Interview questions

Group One was asked eight questions, Group Two were asked ten questions and the third group responded to six questions in total. Following questions were asked in the interview:

a) Interview Questions for Group One (Construction Company representative)

1. Does your company have or participated in any special hiring/training program for veterans? If so, please explain. If not, would you consider creating and or joining one?

2. Does your company actively participate in any kind of workforce development program? If so, please explain.

3. What are some positions that veterans currently hold or have historically held in your company?

4. In your experience, have veterans had more, less, or a comparable amount of applicable training than non-veterans who you have hired for similar positions?

5. Has your company experienced any difficulties in finding and or hiring veterans onto your workforce? If you have, please explain.

6. Has your company experienced any direct or indirect benefits of hiring veterans i.e. government relocation assistance or other paid expenses? If so, please explain.

7. Is there any specific factor that is keeping your company from actively recruiting and hiring veterans?

8. For your company, what would make the process of recruiting and hiring veterans a simpler and more regular occurrence?

b) Interview Questions for Group Two (Industry Veterans)

1. Were you involved in construction in any way during your time in the military?

2. Did you receive any construction related training while in the military?

3. Why did you get into construction?

4. Did you have any connections in the industry? If not how did you get in touch with construction companies?

5. Did you participate in any program or organization that helped veterans find jobs in construction or other fields?

6. Do you believe that the training you received from the military prepared you for a civilian career after you had finished your service?

7. Do you know of anyone that you served with who is now working in the construction industry?

8. What was your knowledge of and perception about construction before you started to work in the industry?

9. Did you consider any other careers outside of the construction industry?

10. Would you recommend a career in construction to a fellow recent veteran?

c) Interview Questions for Group Three (Veteran Program Representatives)

1) How/why did your program get started?

    a) Why do you think vets and construction are a good match?

2) What is the goal/mission of your program?

    a) Has it evolved at all?

    b) If so. Why?

3) What kind of progress has your program made and how has it changed?

4) What has been the biggest impediment to the mission of your program?

5) What is the biggest factor(s) that will help promote the partnership between vets and construction?

6) Where will your program go from here?

4. Results and Analysis

4.1. Data Trends

In this section of data analysis, the collected interviews were transcribed into written form. The interview transcripts were then comprehensively read multiple times. Trends in answers to the questions were identified and recorded as codes. The tables are reported below from each group with the codes as found in the text. This paper defines a trend as a topic that was mentioned by two or more (40%) of the interviewees in a certain group. The interviewees wording did not have to exactly match another's to be considered a code or trend, rather it was the topic of idea spoken which determined the trend. There are three fields in each of the tables below:

- Description—a brief description of the idea or topic that was repeated by multiple interviewees

- Mentions—This is the number of times the identified topic or idea was mentioned by the interviewees, this includes multiple mentions by a single interviewee, but at least two separate interviewees had to mention the idea before it was considered a trend

- Marker—this is the highlighted color of the trend (Table ,1 2, and 3)

Table 1: Contractors' responses

Marker	Respondents	Mentions	Description
(pink)	5	17	Veterans are hard to contact as a group
(yellow)	4	10	Veterans have the type of work ethic or attidue we are looking for in an employee
(dark blue)	5	8	We would like to hire more veterans
(red)	3	5	Veterans have the leadership skills we need in our workforce
(green)	2	3	Veterans thrive in teamwork enviornments

As demonstrated in Tables 1, 2, and 3, there were many trends found throughout the collected data. One of major takeaways from this form of analysis is that one of the main hindrances in advancing the relationship between the construction industry and the veteran population is the difficulty in finding, or lack thereof, established lines of communication between these two groups. A separate trend discovered in all three groups was that of how military training prepares veterans for their civilian careers. While most interviewees agree that the trade specific training is absent, the soft skills that military service men and women develop such as, work ethic, attitude, trainability, leadership, and teamwork combine to make veterans a great candidate for any job in construction.

Table 2: Veterans' responses

Marker	Respondents	Mentions	Description
	5	14	I gained skills in the military which helped me later when I got a civillian job
	4	13	I had a Family or Friend Connection in the Construction industry
	3	11	Construction is hard work
	4	8	I did not particpate in construction while in the military
	5	6	Construction is a hard field to get into if you do not have any connections with a company

Table 3: Responses from veteran construction programs

Marker	Respondents	Mentions	Description
	2	6	Online job sites are not the answer, there needs to be a more tangible solution
	2	6	The Military and Government are hard to work with
	2	5	These types of programs are good for the veteran community
	2	5	Veterans are hard to contact as a group
	2	3	Construction is a fragmented industry
	2	2	Veterans have the type of work ethic, attidue, and leadership skills we need in our workforce
	2	2	Veterans are trainable

4.2. Comparative Analysis

The diagram below (Figure 1) illustrates how the data trends from all three groups align with each other. This diagram shows that there were many interrelated issues mentioned by two or even all three groups. By representing the data in this way it is easy to spot the main issues and ideas for the entire collection of interviewees.

As illustrated above, one trend that stood out from all interview groups was the topic of communication. This theme was brought up by the interviewee in almost every interview. Every time communication was mentioned the tone was negative. The difficulties of trying to reach out from one population to the other or the lack of communication between populations were pointed out as the biggest obstacles in the way of the goal. All contractors had experienced indirect benefits of hiring veterans through their attitudes about work, and their abilities to thrive in team oriented environments. This idea was to back up all of the veterans' belief that the leadership and teamwork skills they developed during their time in the military were the cornerstone to their successful careers in the construction industry. The notion of veterans having the skills needed to be successful in the construction business was further reinforced by the fact that all three programs in this study were started by veterans who believed the same thing so strongly that they decided to do something about it, in a big way.

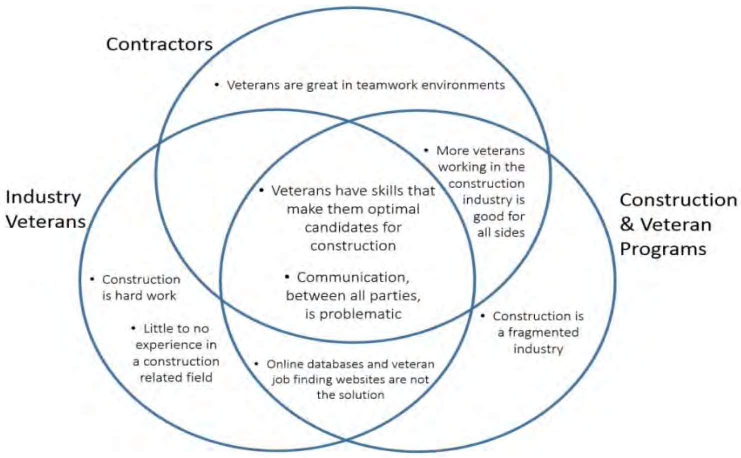

Figure 1: Conceptual alignment of data trends

The most prevalent difference between the group of contractors interviewed and the group of veterans interviewed was their outlook on veteran employability in the construction industry. Although all parties agreed that there are many similar skills needed and many parallels in the lines of work, the veterans were split evenly between recommending a career in construction to a fellow veteran, while contractors were unanimous in their desire to employ more veterans. While this result cannot be extrapolated to the populations as a whole, it certainly points out a gap that must be filled if the construction industry truly wants to recruit more veterans in the future.

5. Conclusions and Recommendations

There is no doubt that workforce development in the construction industry is a topic that needs to be addressed. Amid forecasts of labor shortages and the public's rapidly deteriorating attitudes about working in the construction trades, no contractor is denying this need. However, what the strategy will be to truly develop the workforce remains largely to be determined. Several different national contractors and industry groups have proposed plans of how to accomplish this task. As revealed through the interviews performed for this study, this issue cannot be solved with a singular solution or by a one contractor. Conversely, it must be handled through multiple avenues of attack and via an industry wide effort. The conclusions and recommendations of this paper alone are not enough to solve the construction labor shortage, nor are they intended to do so. To be successful, the following tactics must be accompanied with a heightened sense of awareness from all contractors and industry participants and a comprehensive, realistic plan of action from collaborative industry groups, unions, construction nonprofit groups, and individual contractors.

Ultimately, hiring a veteran is a business decision and as with any business decision, it is about return on investment. Veterans have been proven to have the intangibles needed to succeed in the construction industry in positions from trade apprentices all the way to senior management and owners. With the addition of increased awareness of the construction fields, opportunities to make personal connections with contractors, and readily available training programs, the veteran population could prove to be a renewable source of future employees for the construction industry for years to come. More importantly, these training programs and other opportunities will provide reliable avenues for service men and women to develop the skills and connections needed to smoothly transfer from active duty service into a prosperous civilian career. As a result of the research in this paper, the authors make following recommendations for the construction industry:

1) Begin the process of building a relationship with the veterans before they become veterans.

The construction industry is a fragmented industry with thousands of individual contractors spread across the country. Very few of the contractors have the time and or resources to individually establish a working relationship with the military. Likewise the veteran population, once separated from the military, is disjointed and near impossible to reach as a whole. Because of the conditions of these two populations it is important for a significant number of contractors, acting through local industry groups, such as the state chapters of the Associated Builders and Contractors, begin the process of building a relationship with the veterans before they are discharged from their final military stationing.

2) Recruit people with connections on both sides to become a liaison

This can be done firstly by recruiting someone with a strong network of connections in the military bases in the local community to be a part of this initiative. These connections are critical because, similar to construction, knowing who to talk to is half of the battle.

3) Establish a presence on local military bases

With the aforementioned connections in place it will be easier to establish a presence on the base. The idea is to get veterans to begin thinking of construction as a viable career. The most obvious groups of veterans to begin this campaign towards are those with construction related experience from the military i.e. the Navy Construction Battalion, or the Army Corps of Engineers. This group may prove to provide the best immediate return on investment, however, as revealed through this study veterans who were not assigned to these units can and will still make great employees for any contractor.

4) Offer construction specific career fairs and information sessions

To begin reaching out to these groups and establishing a credibility with the base command, groups should begin with relatively low cost, high yield strategies such as construction specific career expos. V2C has already begun this process and hopefully the rewards to all parties will be evident. Once these types of events have been successful it will become easier for individual contractors to reach out to these bases when they want to recruit more veterans. This strategy will diminish the largest complaint of both the contractors and veterans interviewed, which is the high level of difficulty experienced in trying to reach out and make personal contact with the other population.

5) Start a military specific training program

VIP has established a very effective training program specifically for veterans to gain the skills necessary to enter the welding and pipefitting trade. They have set up these programs to be run on base for active military personnel who are about to be finished with their military service. This is the optimal time to train the service men and women because of multiple reasons. Firstly, these men and women are highly trainable at this stage in their military careers and can absorb the trade knowledge and gain the necessary skills efficiently. This allows for training programs to be condensed, saving everyone involved time and money. Secondly, as they are still employed by the federal government, their living expenses and housing arrangements are fully taken care of by the military. This means that the veterans do not have to try and support their families by working a night job or by taking unemployment benefits form the government. This gives the veteran the ability to fully concentrate on the training program, which again saves everyone involved time and money.

The program that VIP has created is an accelerated eighteen week training regimen that is completely free to the veteran. The UA pays for the training which amounts to $15,000 per person. At the end of the program every veteran is guaranteed a job in the industry and also must join the UA. That amount of money may seem daunting at first, but not when one considers the thousands of dollars in union dues the graduates will pay back to the UA and the tens and possibly hundreds of thousands of dollars of work the graduates will produce in quality craftsmanship over the lifetime of their careers. It is important that the framework for this strategy continue to be developed and expanded into as many construction trades as possible. As of now, the UA is the only group with such a training program and the program is only available on a limited number of USMC bases. Unions and other trade groups, as well as general construction industry groups must find ways to finance, implement, and expand these types of training programs.

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Evaluating Urban Living Labs for Modernisation and Social Upgrading of Suburban Areas in Finland and Sweden

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Abstract

Across Europe, some 200 million people live in suburbs in great need of modernization and social uplifting. The JPI Urban Europe SubUrbanLab project has examined how these suburbs can be modernized and socially uplifted together with the residents and other stakeholders using the Urban Living Lab approach.

This paper proposes a plan for the evaluation of six Urban Living Labs. The Urban Living Labs were real life development actions implemented in two suburban areas using different Urban Living Lab methods: Alby in Sweden and Peltosaari in Finland. The evaluation plan is divided into two sections 1) evaluation of the Urban Living Lab methods and 2) evaluation of the implemented modernization and social upgrading actions.

The evaluation of methods provides insights into the appropriateness of using an Urban Living Lab approach for involving users and stakeholders in less valued suburbs. This evaluation is designed to include the whole process of developing, planning, implementing and following-up an Urban Living Lab. The evaluation of actions is carried out using both quantitative (e.g. CEA, physical indicators) and qualitative (e.g. online questionnaires and interviews with residents, municipal representatives, practitioners and other experts) methods. The evaluation focuses on how the implemented actions have contributed to these suburbs' attraction, sustainability and economic viability.

Keywords: modernisation, urban living labs, neighbourhood, people involvement

1. Introduction

Across Europe, some 200 million people live in suburbs in great need of modernization and social uplifting. The JPI Urban Europe SubUrbanLab project (2013-2016) has examined how these suburbs can be modernized and socially uplifted together with the residents and other stakeholders. The project developed and set up six Urban Living Labs (ULLs): three in Alby, Sweden and three in Peltosaari, Finland. These ULLs were arenas for co-creation of innovative urban solutions: a means to develop new forms of experiences on involving the residents and stakeholders into development in an urban context. The long-term goal is to turn these suburbs into more attractive, sustainable and economically viable urban areas.

2. Urban Living Labs methods

Urban Living Labs are development environments that integrate residents and other stakeholders to develop and test new solutions in their daily life. The users of the new services or solutions are active partners in the whole development process, which happens in the real urban context. Urban Living Labs utilize various co-design methods for understanding the needs, generating solution ideas, presenting ideas and evaluating the solutions in practice. In addition, citizen participation methods are used for participation in decision making and taking action. Voytenko et al. (2015) defined the characteristics of urban living labs based on a study of the ongoing research projects in Europe as follows:

- ULLs are placed in geographical area
- ULLs represent a specific form of experimentation, including processes of innovation and learning
- Participation and user involvement
- Leadership and ownership

In this project we have defined an Urban Living Lab as a forum for innovation and dialogue that integrates the residents and other stakeholders to develop and test new ideas, systems and solutions in complex and real contexts in order to solve challenges in the urban area (see e.g. Friedrich P. et al. 2013). The research and development are intertwined in a “living laboratory” – in the middle of people’s everyday living environment. An ULL includes the following features (Friedrich P. et al. 2013, Ståhlbröst & Holst 2013):

- it integrates researchers, public organizations, residents and companies to co-develop new solutions;
- the users of the developed services or solutions are active partners in the development work during the whole process;
- the solutions will be developed and evaluated in the real use context;
- besides producing the concrete solutions, the aim is to learn and exchange knowledge among the partners;
- the activities are encouraging and rewarding for all participants;

Before starting Urban Living Lab activities, several things have to be checked and planned. First of all, understanding the context is important. This understanding can be obtained by interviewing people from different backgrounds, observing the environment and familiarising oneself with earlier reports written about the area and its challenges. The next tasks is to define the goals for the development project based on the needs of different target groups, identify the residents and other stakeholders who should participate in the project and involve them in defining the aims, clarify the roles in the Urban Living Lab and define a transparent decision making process. Finally, the methods for the specific actions and the communication process should be planned.

Friedrich P, et al. (2013) have defined general boundary conditions and methods for successful Urban Living Lab implementation based on existing literature on citizen participation and consumer behaviour change. Additionally, municipality employees, active residents and participants in previous citizen participation projects were interviewed in the target areas of the project: Botkyrka municipality in Sweden and the city of Riihimäki in Finland. A summary of the defined methods with short descriptions (when necessary) and their suitability for face-to-face or online use is presented in

Table 1. More detailed descriptions for each method are presented in Friedrich P. et al. (2013).

Table 1: Participatory methods grouped based on their purpose and art of implementation

Purpose	*Method (description)*	*Face-to-face*	*Online*
Understanding people and issues	*Interviews (both open-ended and individual follow-up questions)*	*x*	*x*
	Observation	*x*	
	Questionnaires	*x*	*x*
	Focus groups (structured discussion groups led by a facilitator)	*x*	*x*
	Diaries (e.g. blogs telling stories and sharing observations around a certain topic)	*x*	*x*
	Cultural probes (a specific diary method consisting of inspirational material packages and tasks)	*x*	*x*
Generating ideas	*Workshops (including variations such as "rotating table", "dialogue café", "Open Space")*	*x*	*x*
	Walkshop (a workshop implemented by walking)	*x*	
	Brainstorming	*x*	*x*
	Idea competition		*x*
Presenting and evaluating solutions	*Scenarios (textual stories of possible futures)*	*x*	*x*
	Storyboards (a visual story of a planned service or solution, e.g. in a form of a comic)	*x*	*x*
	Films (further developed form of storyboards)	*x*	*x*
	Mock-ups (light weight prototypes illustrating aspects of the solution as a tangible object)	*x*	
	Field tests (testing new services/solutions in the real world context)	*x*	

Participating in decision making	*Dialogue meetings / forum (moderated meetings around a certain topic)*	*x*	*x*
	Citizen panels (regular meetings for selected participants to give input and feedback on a certain service/solution)	*x*	*x*
	Chat (real time on online discussion after or instead of a face-to-face meeting)		*x*
	Voting	*x*	*x*
Taking action	*Citizen parliament (a forum where the citizens take action themselves)*	*x*	
	Mini pilots (citizen driven projects sponsored by the municipality)	*x*	
	Change agents (voluntary citizens informing and activating their peers to change their behaviour)	*x*	

Online focus groups, workshops, panels etc. should be arranged in existing online forums that the target groups already use instead of introducing new tools that need to be advertised to the participants according to Brandtzæg et al. (2012). Also face-to-face methods should utilize already existing networks.

3. Implemented Urban Living Labs

Six Urban Living Labs as real life development actions were defined and implemented in Alby and Peltosaari districts during 2014-2015 as a part of the normal living and operation of neighbourhoods. Within the Urban Living Labs, residents and other stakeholders were involved using different Urban Living Lab methods in developing and implementing innovative solutions to increase the social, economic and environmental sustainability in these areas in great need of modernisation and social uplifting.

The first Urban Living Lab in Alby, "Shape your world", provided children and young adults (age 12-18) with the opportunity to increase their knowledge and understanding of sustainable development and urban gardening while participating in renewing their urban environment.

The second Urban Living Lab in Alby, "New light on Alby Hill", focused on how using new LED technology and light installations can transform a walkway on Alby Hill, an area that the residents earlier have perceived as insecure, into a more attractive and safe area.

The third Urban Living Lab in Alby, "Vacant Space Alby", involved a broad range of stakeholders, including residents, in the design and planning of temporary activities (time span 10 -15 years) to be implemented on a vacant 18 000 m2 space in central Alby. The stakeholders were involved in design of activities, based on local needs, using workshops and web-based co-creation tools.

The first Urban Living Lab in Peltosaari, "Energetic co-operation", focused on finding ways in collaboration with residents and the housing company for decreasing the energy use of rental apartment buildings. Discussion events with residents and other stakeholders were arranged to find out energy saving ideas and best ways to share information about energy efficient living.

The second Urban Living Lab in Peltosaari, “Sustainable decisions”, brought together decision makers and municipality representatives to find out ways for taking into account better and more actively the city’s energy and climate targets in the everyday decision making. Workshops were arranged for activating dialogue and co-development, and ideas for improving practices were gathered.

The third Urban Living Lab in Peltosaari, “Together more”, involved residents in the planning and development of their environment and provided local activities and meeting places for the residents. The goal was to improve the appreciation of the area and to increase the communal feeling among the residents. Several types of activities were piloted and residents were invited to discussion events to influence the plans concerning the area.

4. Evaluation of the implemented Urban Living Labs

4.1 Goals and evaluation process

The goals for each Urban Living Lab were formulated in a dialogue between different stakeholders and project partners, depending on the planned scope of the work. It has been important that both the involved project partners and the stakeholders have common expectations and goals for the Urban Living Lab from the beginning. Nevertheless, the individual goals of different stakeholders and partners need to be recognized. The goals defined for each Urban Living Lab concern both the modernization actions and the participation of residents and stakeholders.

The evaluation of the implemented Urban Living Labs is twofold: First, each ULL is evaluated regarding its contribution to environmental, social and economic sustainability in the area where the Urban Living Lab has been implemented. Secondly each Urban Living Lab is evaluated with respect to how it has lived up to the definition of an Urban Living Lab (the Urban Living Lab principles). The evaluations of each Urban Living Lab are hence focused around the following two parts:

1. Evaluation of the Urban Living Lab’s contribution to environmental, social and economic sustainability
2. Evaluation of fulfilment of general Urban Living Lab principles (Urban Living Lab definition)

The evaluation plan for each Urban Living Lab is specific to that particular Urban Living Lab, as the Urban Living Labs are focused on different actions, using different methods and set in different contexts with different users.

4.2 Evaluation of the Urban Living Lab's contribution to environmental, social and economic sustainability

The evaluation of contribution to sustainability depends on the goals of the particular Urban Living Lab but also on the local goals or views on social, environmental and economic sustainable development in the particular suburb. The evaluation of sustainability mainly takes its point of departure from goals set up for each Urban Living Lab and sustainability as seen from the context of the particular suburb, but will also discuss contribution to sustainability from a broader point of view. Some aspects of sustainability were not covered by local views/goals on sustainability or by the specific Urban Living Lab goals, but they will also be evaluated. As an example, the evaluation of contribution of sustainability will, as far as this has been possible, evaluate the economic viability (economic sustainability) for the Urban Living Labs.

In the evaluation of contribution to sustainability, both quantitative (e.g. CEA, physical indicators) and qualitative (e.g. online questionnaires and interviews with residents, municipal representatives, practitioners and other experts) evaluation methods will be used, depending on the specific Urban Living Lab. The evaluation focuses on how the implemented actions have contributed to the attraction, sustainability and economic viability of the target areas Alby and Peltosaari.

The evaluation can be based on a focus group or reference group that, after the project has been finished, discusses how the Urban Living Lab has contributed to local sustainability goals. For social sustainability, a before-and-after-survey can reveal changes over time concerning e.g. interest to contribute to the local society and commitment to sustainability. All Urban Living Labs will also, as far as this is possible, be evaluated with respect to the Urban Living Labs contribution to increased social cohesion and increased commitment among residents and other stakeholders to sustainability.

Relevant evaluation questions concerning the social issues and attraction are e.g. what kind of role do the implemented actions play in order to attract people and businesses to the suburbs? Have the actions increased the willingness of people to live in these suburbs? Do more businesses want to invest or get established in these suburbs due to the actions undertaken? Have the actions increased the willingness to cooperate with local stakeholders? Do the Urban Living Labs bring lasting and deepened commitment among residents regarding environmental matters and sustainability? How do the Urban Living Labs increase social cohesion? Are the developed Urban Living Labs mature to continue actions after the SubUrbanLab project ends? Are the responsibilities between different stakeholders clear for further collaboration?

Relevant evaluation questions concerning the environmental sustainability and economic viability are e.g.: How have the implemented actions contributed to environmental, social and economic objectives e.g. leading to improved environmental performance and creating new local jobs? Have the actions been implemented in a cost-efficient way? What is the added value, (even monetary) of Urban Living Labs in getting the benefits?

Economic viability refers to how cost-efficient the Urban Living Lab has been, e.g. compared to more traditional ways of implementing the same actions. Where possible, the project will use cost-effectiveness analysis (CEA) in order to evaluate the cost-effectiveness of the different implemented Urban Living Lab actions and to compare the different alternatives. Here the VTT-CEA tool (Tuominen et al. 2015) will be used for evaluating energy efficiency investments done in the case areas. The evaluation of cost-effectiveness is done to measure the performance and effectiveness of a project. From a public policy point of view, the main argument for evaluating the costs and benefits of projects is for ascertaining whether public support for the project is a sound investment.

4.3 Evaluation of the Urban Living Lab methods (participation of residents and other stakeholders)

The evaluation of methods provides insights into the appropriateness of the selected Urban Living Lab methods for involving users and stakeholders in less valued suburbs. This evaluation is designed to include the whole process of developing, planning, implementing and following-up an Urban Living Lab.

In practice, Urban Living Labs can make use of different co-design methods both face-to-face and online to involve all relevant stakeholders in the process of planning, designing, developing and evaluating new solutions. The evaluation of the Urban Living Lab approach will therefore especially focus on how residents and other stakeholders have been integrated to solve challenges in the urban areas or, in other words, how the knowledge, experience and input from the involved residents and stakeholders have been used in the whole process of the Urban Living Lab - when setting up and developing the Urban Living Lab, when planning the Urban Living Lab and when implementing the Urban Living Lab. Other aspects of the Urban Living Lab approach, such as the learning between partners and how invited participants have experienced their participation, will also be discussed.

To be able to evaluate this, documentation, such as meeting minutes, is vital during whole process of all Urban Living Labs. Interviews with and questionnaires among participating residents and stakeholders have also been important methods to be able to evaluate their involvement.

Inhabitants and other stakeholders were engaged to the implemented development actions through different participatory methods such as online Owela tool developed by VTT (Friedrich 2013), face-to-face meetings, workshops, interviews, questionnaires, field tests and mini pilots. The implemented Urban Living Labs used mainly traditional face-to-face-methods, such as workshops, discussions, surveys and questionnaires as these turned out to be suitable ways of co-creation with the target groups. Face-to-face meetings and discussions with the residents were focal in raising interest and creating commitment whereas use of digital tools for participation was not regarded natural by many of the residents.

Relevant questions concerning the evaluation of methods are for example: Were the relevant people able and willing to participate through the method? Was the group involved in the activity sufficiently representative of the targeted stakeholders? Did the contributions gained using the method have an impact on the activity? Did the method support interaction and mutual learning among the participants? Did the method provide equal opportunities to participate for different kinds of people? Could the method be adjusted based on the needs of the activity? Was the method laborious and/or complicated for the organizers or participants?

4.4 Preliminary evaluation results of two Urban Living Labs

The evaluation work is ongoing during the time of writing this paper. Here some preliminary evaluation results of the second Urban Living Lab in Alby, "New light on Alby Hill" and the second Urban Living Lab in Peltosaari, "Sustainable decisions" are presented (Karlsson et al. 2016b).

Alby Urban Living Lab "New light on Alby Hill" focused on how using new LED technology and light installations can transform a walkway on Alby Hill, an area that the residents earlier have perceived as insecure, into a more attractive and safe area. The sustainability objectives of this Urban Living Lab were: 1) Renewing the urban Environment, 2) Modernising Alby's identity and 3) Trying out new working methods at the municipality.

Several methods were used to evaluate the contribution to sustainability. Questionnaire surveys targeting the users of the pathway were carried out before and after the implementation of the new lightning. The energy use before and after the implementation was calculated including also the reduction of GHG-emissions. A focus group interview was carried out with the representatives of the municipality, private housing company Mitt Alby, Collage of Arts and the research partner IVL to discuss the contribution to sustainability objectives on different levels. A Cost Effectiveness Analysis (CEA) was conducted to examine the economic sustainability. All phases of the Urban Living Lab were continuously documented and reported in project reports "Selection of Urban Living Labs in Alby and Peltosaari" (Karlsson et al. 2015) and "Establishment and implementation of Urban Living Labs in Alby and Peltosaari" (Karlsson et al. 2016a) to be utilized in the evaluation process.

The contribution of the Urban Living Lab to social sustainability is here presented as an example. The contribution to social sustainability was evaluated by estimating the increase in the sense of security and participation and engagement.

The increase in the sense of security was evaluated using the results of the questionnaires. According to the results the new lighting on the pathway increased the sense of safety to some extent, especially amongst the women. The amount of women feeling unsafe or sometimes unsafe using the pathway during dark hours was reduced from 79% to 55%. The pathway was experienced to be better and lighter with the new lighting system but a high proportion of the respondents still felt sometimes insecure despite of the new lighting.

The residents’ involvement and participation was evaluated to be high in the project. The number of people participating in the project either through the Residents Council, by submitting images for the competition, by voting on their favourite picture or by participating in the opening ceremony was counted to be 160 people, but there has been some overlapping (for example both contributing pictures and voting). The specific Urban Living Lab website was visited by nearly 400 people. The residents on Alby Hill were also informed about the project via info leaflets and there has been also other information sharing utilizing e.g. posters and the municipality´s website. According to the results of the questionnaires, the amount of respondents feeling that they can influence changes in their outdoor environment raised from 31% to 52%.

Peltosaari Urban Living Lab “Sustainable decisions” brought together decision makers and municipality representatives to find out ways for taking into account better and more actively the city’s energy and climate targets in the everyday decision making. Workshops were arranged for activating dialogue and co-development, and ideas for improving practices were gathered. The sustainability objectives relevant for this Urban Living Lab were: 1) Support decision making on energy efficient and sustainable investments and 2) Develop and experiment with new practices in the municipality to enhance collaboration and communication.

The methods used to evaluate the contribution to sustainability were e.g. questionnaires and surveys to participants before and after the seminars. The contribution of the Urban Living Lab to environmental sustainability is presented here as an example. The impact of the workshop was evaluated by the number of people reached through the workshops. Besides the persons actually participating in the workshop, the invitations and the presentation materials distributed after the workshops reached a much wider group of people. The workshops were considered worthwhile participating and especially discussions were highly valued. The workshops were also regarded as a good way to enhance interaction and communication. The results of the questionnaires and surveys showed that the energy efficiency and life cycle perspectives are not well integrated into the current decision making in the municipality, despite of the goals and commitments of the city. This fact further emphasises the need for developing new ways to take these issues better into account in the future. Based on the discussions with the representatives of the City of Riihimäki some impacts of the workshops have already been noted, such as:

- Life-cycle projects will be taken to be considered in some upcoming investments
- PV panels will be included in some future alternatives
- Representatives of other departments have been invited to some meetings to enhance the flow of information in the organisation.

5. Discussion

This paper has concentrated on the evaluation plans of different Urban Living Labs. The impacts of each Urban Living Lab differ from each other and therefore impact evaluation has to be planned separately for each Urban Living Lab but also common elements have been identified. It is also challenging to evaluate the impact of one single Urban Living Lab as the city has several ongoing activities and sustainability goals having similar kinds of effect. Also, many impacts can be noticed and/or measured only after several years, as for example changes in attitudes and processes, which happen slowly and are simultaneously affected by several external factors. It is however difficult to identify at that point how an ULL has affected that development.

Key success factors for Urban Living Labs are the early and continuous involvement of the affected people, clear goals and expectations, and experimenting in real context instead of discussing. The methods must be adapted to the goals and participants. On the other hand, an intrinsic part of the ULL approach is that course of an activity may change during the process, based on the contributions and decisions among the participants. This further complicates the evaluation since the goals may be adjusted during the process. At its best, people can participate in the Urban Living Lab activities as a part of their other activities and see the effects of their participation shortly afterwards. The participants should have the ownership to the project, create content and express themselves (Brandtzæg et al. 2012).

There are different ways to realise Urban Living Labs depending on the stakeholder group, boundaries, and existing groups/networks in the neighbourhood. It is important to identify different types of existing development projects, networks and stakeholders, with which to link the Urban Living Lab actions as utilizing relations to other activities brings win-win advantages. Urban Living Lab should be planned to support broader development targets and projects in the municipality or area.

From a public policy point of view evaluation methods are needed for assessing a project's level of success and for being able to compare the project to its alternatives. Currently decision makers clearly need more evidence on the impacts and benefits of co-creation and co-design. How can we measure the impact and value of the learning process and show that the monetary investment has been profitable? The common factor in all Urban Living Labs is thus estimating the impact of co-creation, which lacks methods and indicators.

The preliminary evaluation results emphasize the need for careful planning of the measures and methods for evaluation but also the necessity to update them during the course of work, due to adjustments and changes for the scope of the work that often take place as a result of the contributions from the stakeholders.

Furthermore the results indicate that the value of using Urban Living Lab approach needs to be considered more extensively than the generally used quantitative measures, such as costs and number solutions that are taken into use. Benefits of engaging residents in developing and piloting solutions often follow from "avoided costs", such as early identification of non-working solutions or potential bottlenecks, improved acceptance of a new solution among the users, and faster start-up and active use of a solution. Additionally the approach intrinsically supports learning and self-efficacy among the participants and improves co-operation between the partners, and thus provides benefits that are not necessarily expressed as specific goals of the activity but nevertheless are valuable. Successful engagement as such should be weighted as a valuable result.

The preliminary evaluation results also emphasize that the motivation for using Urban Living Lab approach should be based on different kinds of criteria than simple cost-efficiency of implementing concrete actions. Engaging people and co-development processes require resources and take time but on the other hand the outcomes of all Urban Living Labs of the study were significantly affected by the participation: similar results could not have been achieved without the Urban Living Labs. Maybe even more importantly, the Urban Living Labs were seen to have numerous "secondary effects" on the participants and the area that would not have been accomplished without Urban Living Lab approach. Examples of these are learning, enhanced opportunities for self-expression, increased awareness of relevant issues in the area, improved collaboration between partners and feeling of being able to influence.

The set of evaluation questions formulated in this study provide a good basis for conducting systematic evaluation of an Urban Living Lab. Further development of methods and ways for assessing benefits of different scales in parallel are however still needed to be able to demonstrate convincingly the profitability of Urban Living Lab approaches.

6. Conclusions

The overall conclusions of the paper are following:

- It is vital to be able to demonstrate the benefits of Urban Living Labs and thus approaches for evaluating impacts systematically are needed
- The SubUrbanLab project with six different Urban Living Labs provides a good basis for developing a general evaluation "framework"
- This paper proposes division of evaluation into different categories and suggests questions that can be used as a basis for evaluating Urban Living Labs

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The paradoxical nexus between corporate social responsibility and financial performance in international construction business

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Abstract

This study aims to develop and test a paradoxical link between corporate social responsibility (CSR) and corporate financial performance (CFP): CSR may be detrimental to financial performance in the short-term term (e.g. by adopting carbon reduction schemes, or taking account of fair trade) but will be conducive to improving performance in the long term (e.g. by developing reputation, or improving business relationships). Using panel data of international construction companies derived from various sources, the hypothesis is confirmed. The traditional notion that CSR will have an immediate and unchanging impact on CFP is probably flawed. In the international construction business, a short-term, negative effect of CSR on CFP is witnessed, but a positive effective of CSR on CFP can be developed if effectively involved in CSR programme for long. It takes time to materialize CSR in terms of financial performance. This research helps explain the CSR dilemma, whereby business executives' hesitate to fully engage in CSR for long, given their pressure to effectively maximize profitability for shareholders. The research thus provides support to business executives who should be relieved from short-termism when devising proper CSR strategies in international business.

Keywords: Corporate social responsibility, Corporate social performance, Corporate financial performance, CSR-CFP relationship, International construction

1. Introduction

Since the phrase corporate social responsibility (CSR) was coined by Bowen and Johnson (1953), it has been and remains the subject of contentious debate. Friedman (1970), for example, famously argued that socially desirable goals, if at the expense of profitability, should be disconnected from a company's fiduciary responsibilities; "if managers used corporate resources for any cause other than profit maximization, it would constitute a form of theft". On the other hand, Porter and Kramer (2006; 2011) advocated 'creating shared value', which involves creating economic value in a way that *also* creates value for society. They advocated raising societal issues from the periphery to the core of a business. The two schools seem form a debate spectrum with Friedman on the one end while Porter on the other, although both share the same component to emphasize profitability of a business. The majority of the debaters tend to take an eclectic position in the spectrum by accepting that nowadays companies have an obligation to assume social responsibilities while pursuing business success (Lu *et al.*, 2014). This school of CSR thought reflects the changing social and political climate around the world, indicated by the decline of *laissez-faire*, the increase of government intervention, the vogue for stakeholder theory, the deepening of globalization, and the emergence of sustainable development (Green, 2009).

CSR has increasingly become the Quadruple Bottom Line (QBL) by broadening the traditional Triple Bottom Line (TBL), which requires societal, environmental, and economic reporting in business. This echoes with Porter and Kramer's (2006) observation that CSR has emerged as "an inescapable priority for business leaders in every country". Yet, the extent to which a company actually engages itself in this CSR trend is vigorously disputed. At times, business executives are allegedly myopic in assuming social responsibility (Painter-Morland, 2006). CSR needs to have a genuine economic foundation to be sustained in a competitive business world (DTI, 2002). Without evident benefits for companies, CSR may not continue to flourish as CSR programs are costly and detract from companies' limited financial resources (Wang *et al.*, 2008).

To provide this CSR legitimacy, researchers have endeavoured to search for a link between CSR and corporate financial performance (CFP). This CSR-CFP link has become a non-trivial issue that is widely debated amongst management theorists and business executives. Margolis and Walsh (2001) identified 95 empirical studies on the CSR-CFP relationship published since 1972. Orlitzky *et al.* (2003), in their milestone review, critiqued that Margolis and Walsh's (2001) study used the so-called 'vote-counting' technique, whereby studies are simply coded as showing significantly positive, negative, or statistically non-significant results, and conclusions are likely to be false. They used meta-analysis, viewing it as a more robust statistical method, and reported with greater certainty that CSR is positively correlated with CFP. Empirical research on the CSR-CFP relationship continues, irrespective of the call for a moratorium on it made by Margolis and Walsh (2001). Lu *et al.* (2014) identified 84 relevant empirical studies on the CSP-CFP relationship published during 2002 and 2011.

One notable research trend is that researchers have gradually recognized the CSR-CFP nexus as not being static but changing in a non-linear fashion, e.g. U-shaped curvilinear relationship (Barnett and Salomon, 2006; Park and Lee, 2009). The causality between CSR and CFP may occur in a certain time lapse. It is a significant advancement to consider time lags in the CSR-CFP nexus research, since decision-makings and resource allocation are time-consuming in practice. Though this kind of view is partly reviewed by Orlitzky et al (2003), convincing empirical studies remain few and far between. Inoue and Lee (2011) reveal that each decomposed CSR aspect had a different effect on both short-term and future profitability of companies in tourism-related industries. There seems to be two hypotheses, one positing the short term effect between CSR and CFP, and the other concerning the long term relationship. While contemporary researchers have acknowledged both hypotheses, no one, to the best of our knowledge, has attempted to integrate the two into a refined theory capable of accounting for their seemingly paradoxical dynamics.

The aim of this paper is thus to offer and test a refined theory on the dynamic and sophisticated relationship between CSR and CFP by considering time lags. The main hypothesis is that a paradoxical link exists between CSR and CFP: *CSR is detrimental to CFP in the short-term but will be conducive to CFP in the long-term.* The distinction between the expected short-term and long-term effects of CSR on CFP enables the falsification of the theory. The research in this paper has profound academic and practical values. Academically, the research provides fresh answers to the moot question regarding the CSR-CFP link. It helps divert researchers' attention from the allies-and-adversaries dichotomy to the paradoxical dynamics between CSR and CFP. It may lead to a breakthrough towards a refined theory of the CSR-CFP nexus. Practically, it could help explain some CSR dilemmas, such as executives' hesitation to fully engage in CSR despite the rhetorical exhortations of its benefits; back to the board room, they are under pressure to effectively maximize profitability for shareholders in short-term. The research provides support to business executives to be relieved from short-termism when they devise proper CSR strategies to achieve business success.

2. Constructs and measures

2.1 Corporate Social Responsibility (CSR)/Corporate Social Performance (CSP)

There is no agreed-upon definition on what is meant by CSR. Dahlsrud (2008) identified 37 definitions of CSR. Carroll and Shabana (2010) advised that there are many other academically derived definitional constructs. Carroll (1979) proposed four kinds of social responsibilities constitute total CSR: economic, legal, ethical, and discretionary (philanthropic) responsibilities; the CSR firm should strive to make a profit, obey the law, be ethical, and be a good corporate citizen. Carroll (1979) further suggested depicting them as a pyramid, which has been known by many scholars as the CSR pyramid. While a consensus of CSR definitions remains an issue, other similar concepts such as corporate social performance (CSP) have emerged. Many empirical papers reviewed by Margolis and Walsh (2001), Orlitzky *et al.* (2003), and Lu *et al.* (2014) actually examined the relationship between CSP and CFP. Although some researchers (e.g. Margolis *et al.*, 2007) use CSP and CSR interchangeably in empirical studies, others attempt to distinguish the two concepts (Lu *et al.*, 2014). According to Carroll (1991), CSR emphasizes obligation and accountability to society, while CSP emphasizes outcomes and results. Maron (2006) suggested that CSP is a way of making CSR applicable and putting it into practice. Beurden and Gössling (2008) pointed out that CSR is not a variable and therefore it is impossible to measure; CSP, on the other hand, though difficult to measure too, can be surrogated by the use of proxy measurable variables.

The proliferation of definitions makes it difficult to measure CSP. The challenge is to identify and measure CSR initiatives that are prevalent amongst companies. Carroll's (1979) CSR taxonomy provides the theoretical guideline from which CSR initiatives can be identified. Many companies also issue CSR disclosures, in which they explain their dedication to CSR and highlight successes. By following all these, CSR initiatives can be identified and measured. It is also noticed that studies that explored the empirical CSR-CFP link often circumvented the measuring problem by adopting a pragmatic approach. They used aggregated CSR indices that were established by other parties, such as the Council on Economic Priorities (CEP) index, the Kinder, Lydenberg, Domini (KLD) index, and the FTSE KLD 400 Social Index, or the World's Most Admired Companies, annually published by *Fortune* magazine, as a CSR index.

2.2 Corporate Financial Performance (CFP)

Performance means different things to different stakeholders. Nevertheless, in contrast to the pluralism of CSR/CSP, measures of CFP in academic research have largely converged into the trichotomy of CFP proposed by Orlitzky *et al.* (2003), namely, 1) market-based, 2) accounting-based, and 3) perceptual CFP measures. Market-based measures of CFP, such as price per share or share price appreciation, reflect the notion that shareholders are a primary stakeholder group (Cochran and Wood, 1984). Beurden and Gössling (2008) added more market-based measures in their review work, including stock performance, market return, market value to book value, and others. Alternatively, accounting-based measures consist of profitability measures, asset utilization, such as return on asset (ROA) and asset turnover, and growth measures. Cochran and Wood (1984) aruged that accounting-based indicators, such as the firm's return on assets (ROA), return on equity (ROE), or earnings per share (EPS), capture a firm's internal efficiency in some way. Lastly, perceptual measures of CFP ask survey respondents to provide subjective estimates of firms' financial performance (Conine and Madden, 1987). Amongst the three generic CFP measures, the accounting-based measures are objective and audited, market-based measures are partly objective, and perceptual are largely subjective based on the survey respondents' perceptions (Lu *et al.,* 2014). Given that both CSP and CFP are already broad constructs that are difficult to be measured, Lu *et al.* (2014) suggested a general principle of using more objective CFP measures and secondary data in future empirical studies. The selection of CFP measures is also subject to data accessibility, and their suitability to the characteristics of an industry within which companies are operating.

3. Hypotheses

To reiterate, the aim of this paper is to investigate the causality of CSP on CFP. Instead of trying to identify a static and linear positive, neutral, or negative causal effect between CSP and CFP, the main premise in this paper is that a paradoxical link exists between CSP and CFP. There are, in effect, two hypotheses: one that posits a short-term, negative effect of CSP on CFP, and the other that proposes a lagged, positive effective of CSP on CFP:

H_1: The link between CSP and CFP in the long-term is positive.

H_2: The link between CSP and CFP in the short-term is negative.

The intention is to identify how CSP affect CFP in the short and long-term. The hypotheses can be conceptually illustrated in Fig. 1.

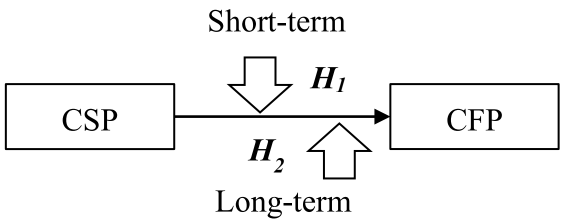

Fig. 1 Illustrated Conceptual Model

The hypothesized paradoxical relationship between CSP and CFP in this paper is different from those studies exploring a curvilinear (U-shaped) or an inversely U-shaped curve between CSP and CFP (e.g. Barnett and Salomon, 2006). For example, although Barnett and Salomon (2006) recognized that the basic issue concerns whether the costs of social responsibility are offset or exceeded by financial returns over some period of time, they hypothesized and tested the curvilinear relationship between CSP and CFP by using an ordinary least squares test without considering the lead-lag effects. The research is also different from those studies looking at the nexus between sustainability and financial performance, or in entertaining words 'when does it pay to be green'. The difference lies in the fact that the terms, CSR or sustainable development, are different, although when operationalizing the concepts, managers tend to treat them as similar, if not entirely identical (Lu *et al.*, 2014).

4. International Construction Business

The hypothetical paradoxical link between CSR and CFP will be tested within the context of 'international construction business (ICB)'. According to Ngowi *et al.* (2005), international construction is defined as the part of construction business that is undertaken by companies working on projects outside their home country; it concerns when a company resident in one country performs work in another country. Once seen as a local activity, the construction business today is fast becoming an internationally interdependent marketplace (Yang and Lu, 2013). To give an example of the scale of this business, *Engineering News-Record* (ENR) statistics show that the ENR Top 250 International Contractors (TIC 250) lodged US$511.05 billion in contracting revenue in 2012 from projects outside their home countries, along with US$813.55 billion in revenue from domestic projects (Tulacz, 2013). Advanced technology, fast transportation, convenient communication, effective knowledge transfer, integrated markets, and trade liberalisation have all helped construction companies transcend traditional national boundaries and enter the international arena (Yang and Lu, 2013).

When looked at in the context of CSR debate, probably no industry offers up as many paradoxes as construction CSR (Lu *et al.*, 2015). On the one hand, the construction industry has an inherent social responsibility; it materializes the built environment, making an important contribution to the national economy, and providing a large number of jobs (Hillebrandt, 1984). On the other hand, construction is intrinsically 'irresponsible'; it competes with the natural environment and can have an adverse impacts upon it, including land degradation, greenhouse gas emissions, resource depletion, waste generation, and various forms of pollution (Ofori, 1993). The conjunction of these paradoxes has brought CSR to the fore. CSR it is now growing in prominence as a core issue confronting the construction industry and its organizations (Murray and Dainty, 2008).

The above paradoxes relating to CSP-CFP nexus are particularly evident in international construction. CSR practices travel with international construction companies (ICCs) and influence other countries with the increasing globalization of construction business. Indeed, in analysing top ICCs' CSR disclosure trends and future prospects, Lu *et al.* (2015) discovered that the firms spent great deal of efforts on CSR when they conducted international business. Yet, the difference of cultural/institutional background between the home and host countries further complicated the paradoxes. ICCs from economically developed countries are normally required "central compliance". The ICB is certainly a positive development in terms of value creation, knowledge exchange, and resource configuration and optimization. However, the ICB is also criticized as being relatively irresponsible, given the embodied energy and the carbon emissions associated with mobilizing resources across continents. It thus provides an interesting lens through which the paradoxes of CSR can be fruitfully investigated.

5. Data, Samples, and Measures

The data used to test the hypotheses was collected from several sources. The initial sample came from the Environmental, Social and Governance (ESG) Intangible Value Assessment (IVA) index tracked by the Morgan and Stanley Capital International (MSCI). MSCI offers kinds of products and services indexes, such as the IVA indexes, to provide research and ratings of corporate management of environmental, social risk factors, and other CSR activities. Companies from industries related to construction were selected according to the Global Industry Classification Standard (GICS) developed by the MSCI. This included ICCs such as Hochtief AG from the construction and engineering industry, CRH plc from the construction materials industry, and Cummins Inc. from the construction and farm machinery industry. The MSCI began to rate ICCs in 2002. The amount of firms rated was small at the beginning bit it increased steadily. Our starting sample represents a balanced panel of 34 ICCs from 2006 to 2013, i.e. 34 ICCs over the period of 2006-2013 have been consistently rated in terms of their CSR performance by the MSCI and the data was realised via the ESG IVA index.

Secondary data was collected from various sources for measuring ICCs' CFP. Basic financial data for each firm were gleaned from their annual reports or financial reports. These reports were retrieved from their websites or other databases like Morningstar.com and Bloomberg.com, since most of the ICCs are publically listed companies in various stock exchange markets and they have to reveal data and maintain the integrity of the data to its shareholders to comply with the law. When we matched the financial data with the MSCI ESG data, we lost four firms due to missing data. This left us a final usable sample that is a balanced panel of 30 ICCs from 2006-2013.

CSP is used as a measurable substitution of CSR. The majority of CSP-CFP studies uses CSP databases developed by third parties, so does this study. MSCI rate firms' CSP based on three criteria: environmental, social, and governance pillars. For the environmental pillar, the MSCI considers carbon emissions, toxic emissions and waste, and opportunities for clean technology as the key issues. Corruption and instability, and health and safety are regarded as the key issues for the social pillar criterion. Key indicators of the governance pillar criterion include audit, board structure, shareholder rights, compensation, and transparency. The weights of key issues in each GICS sub-industry are set according to the industry's relative contribution to the externality of each issue, as well as the time frame to internalize these costs. According to the MSCI industry report of the construction industry, for example, the Construction & Engineering industry ranks above the 90th percentile of all sub-industries in terms of employee accident and fatality rates, which is thus categorised as a High Contribution (MSCI, 2015). Firms receive weighted average scores every year based on the performance scores and weights of the three criteria. The score range for a firm's CSP is within 0-10.

CFP measurement remains the subject of contentious debate in CSP-CFP nexus research. Orlitzky *et al.* (2003) list various CFP measures in 52 studies, and the widely used profitability measures include ROA (return on assets), ROE (return on equity), profit margin, EPS (earnings per share) etc. They converge the CFP measures into three broad subdivisions, namely market-based (investor returns), accounting-based (accounting returns) and perceptual (survey) measures. Following Lu *et al.*'s (2014) suggestion to use more objective CFP measures and depending on data availability, we selected accounting-based indicators, such as the firm's return on assets (ROA), return on equity (ROE) or earnings per share (EPS) and market-based indicators, such as the stock return (SR) or price-earnings ratio (P/E). Following many researchers, such as Waddock and Graves (1997), Barnett and Salomon (2012), we finally choose the ROA as the major CFP measure in this paper.

Control variables are needed for the CSP-CFP nexus analyses, given that CSP will not explain all the variations in CFP across companies. Andersen and Dejoy (2011) summarized that size, industry, risk, RD and advertising expenses are the most commonly used control variables in explaining the CSP-CFP relationship. Lu *et al.* (2014) found that capital structure is often adopted as control variable in the paper under their review. All the firms in the sample are from the construction industry so industry as a control variable makes little sense. Mainly for practical reason, firm size and capital structure are selected as the control variables in this study. Market capitalization of stocks is usually adopted as the measure of firm size. The stocks of large, medium and small companies are referred to as large-cap ($10 billion plus), mid-cap ($2 billion to $10 billion), and small-cap (less than $2 billion). We define debt/equity ratio as the firm's total debts divided by equity to control the capital structure of the firm. This ratio can reveal the managers' preference of financing as well as measuring the risk of the firm. In this regard, risk is also considered a control variable in this study.

6. Results and Analyses

The panel data model is analysed by R software (R Development Core Team 2008), which is an open source statistical analytical software program. The "plm" package in R software is chosen for the panel data analysis.

6.1 Stationarity test

Before the panel data analysis, the first step is to test the stationarity of the variables. A stationary process has the property that the mean, variance and autocorrelation structure do not change over time. If the data of the variable contains a trend, the results of regression could not be fully credibility without isolating the effects of the trend. Stationarity of the variables is tested by a unit root test (Maddala and Wu, 1999), which is one of the common ways to perform the task. Maddala-Wu unit root test model is chosen for this study. Maddala and Wu (1999) proposed that use of the Fisher (p_λ)

test which is based on combining the *p*-values of the test-statistic for a unit root in each cross-sectional unit. In *R* software, *purtest* implements several testing procedures that have been proposed to test unit root. The results are shown in the Table 1.

Table 1 Stationarity test of the panel data using the Maddala-Wu unit root test model

	Maddala-Wu unit root test						
Variables		***Chi Square***	***Degree of freedom (df)***	***Order***	***method***	***p-Value***	***Results***
CFP	*ROA*	*52.5334*	*2*	*0*	*trend*	*3.913e-12*	*Stationarity*
CSR	*CSP*	*49.4894*	*2*	*0*	*trend*	*1.793e-11*	*Stationarity*
Control Variable	*D/E ratio*	*29.7743*	*2*	*0*	*trend*	*3.425e-07*	*Stationarity*
	MC	*28.7758*	*2*	*0*	*trend*	*5.642e-07*	*Stationarity*

Notes: 1. ROA=return on assets; D/E ratio=debt/equity ratio; and MC=market capitalization. 2. Alternative hypothesis of test is stationarity.

The results in Table 1 show that Maddala-Wu unit root test with the method of trend is used and the null hypothesis is non-stationarity. Since the *p*-values for all the indicators are smaller than 0.001, they indicate that the variables in the panel are stationary and ready for the further analysis.

6.2 Results of long-run equilibrium relationship

To test *Hypothesis 1*, panel data models are used directly to estimate the equilibrium relationships between CSP and CFP in the long-term. The equation for testing the long term equilibrium relationship between CSP-CFP is shown as follows:

$$CFP_{it} = CSP_{it} \times \beta + DE_{it} \times \alpha + FirmSize_i \times \gamma + Z_i \times \theta + \varepsilon_{it} \qquad \text{Eq. (1)}$$

(i=1, 2… 30; t=2006, 2007… 2013)

where the subscript i indicates individual firm, t represents the time (years), CFP_{it} is the dependent variable (using ROA as the indicator), CSP_{it} is the independent variable, DE_{it} and $FirmSize_i$ are two control variables, DE_{it} is the Debt/Equity Ratio while $FirmSize_i$ is represented by Market Capitalization, β, α and γ are the coefficients of CSP_{it}, DE_{it}, and $FirmSize_i$, $Z_i \times \theta$ is the heterogeneity term, Z_i could be a constant term or a group-specific constant term or a group-specific random element, θ is the coefficient of Z_i, and ε_{it} is the error term.Various available panel data analysis models are compared using the results of the three tests (Lagrange Multiplier Test, f test, and Hausman Test) mentioned above. By strictly following Kunst's (2009) comparison method, the fixed model is tested to be better for estimating the impact of CSP on CFP, i.e., ROA in the long run. Results of the long-run equilibrium relationship using the fixed model are shown in Table 2.

Table 2 Results of long run equilibrium effects of CSP on CFP

Dependent variable: ROA (fixed model)				
	Estimate	*Std. Error*	*t-value*	*p-value*
CSP	*0.0056*	*0.0019*	*2.9000*	*0.0041***
D/E ratio	*-0.0009*	*0.0021*	*-0.4008*	*0.6890*
MC	*0.0013*	*0.0004*	*3.1651*	*0.0018***
R-squared: 0.1004 Adj. R-squared: 0.0866 F-statistic: 7.7014				
*p-value: 6.663e-05 Signif. Codes: 0 '***', 0.001 '**', 0.01 '*', 0.05 '.'*				

CSP is found to have a positive and statistically significant (*p*-value= 0.0041) impact on ROA in the general model with β equal to 0.0056, which means CSP in general would improve the financial performance, represented by ROA. Therefore, the general equation for the long-term equilibrium relationship between CSP and ROA (Eq. 1) can be written more specifically in *Eq.(3)*. The *p*-value of the long term model equals to 6.663e-05, which is much smaller than 0.001, showing good results in testing *Hypothesis 1*. The hypothesis that CSR will be conducive to improving corporate financial performance in the long term is thus supported.

$$ROA_{it} \sim 0.0056 * CSP_{it} + 0.0013 * FirmSize_i \qquad Eq.(3)$$
$$i = 1,2,\dots,30, t = 2007,2008,\dots,2013, CSP \in [1,10]$$

6.3 Results of short-run effects test

To test *Hypothesis 2*, interactive effects of CSP in each year are added into the panel data analysis, which indicate the effects of CSP in specific year on CFP. The equation is shown as follows:

$$CFP_{it} = CSP_{it} \times \beta_0 + \sum Factor(year) \times CSP_{ij} \times \beta_j + DE_{it} \times \alpha + FirmSize_i \times \gamma + +Z_i \times \theta + \varepsilon_{it} \qquad Eq.(2)$$

(*i*=1, 2… 30; *t*=2006, 2007… 2013; *j*=2007, 2008… 2013)

where the subscript *i* indicates individual firm, *t* represents the time (years), *j* represents the years using interactive effects (all years except 2006, which is regarded as the basis year), CFP_{it} is the dependent variable (using ROA as the indicator), CSP_{it} is the independent variable, $Factor(year) \times CSP_{ij}$ is the interactive items of each year times CSP, DE_{it} and $FirmSize_i$ are two control variables, DE_{it} is the Debt/Equity Ratio while $FirmSize_i$ is represented by Market Capitalization, β_0, β_j , α and γ are the coefficients of CSP_{it}, the interactive items, DE_{it}, and $FirmSize_i$, $Z_i \times \theta$ is the heterogeneity term, Z_i could be a constant term or a group-specific constant term or a group-specific random element, θ is the coefficient of Z_i, and ε_{it} is the error term. Various available panel data analysis models are compared using the results of the three tests (Lagrange Multiplier Test, f test, and Hausman Test). The fixed model is tested to be the best for estimating the impact of CSR on CFP (i.e., ROA) in the short term. Results of the short-run effects test using the fixed model are shown in Table 3.

Table 3 Results of short-term effects of CSP on CFP

Dependent variable: ROA (fixed model)					**Dependent variable: ROA (fixed model)**				
	Estimate	*Std. Error*	*t-value*	*p-value*		*Estimate*	*Std. Error*	*t-value*	*p-value*
CSP	*0.0053*	*0.0021*	*2.5326*	*0.0121**	***Factor(2011) *CSP***	*-0.0017*	*0.0010*	*-1.7219*	*0.0866`*
Factor(2007) *CSP	*-0.0002*	*0.0010*	*-0.2249*	*0.8223*	***Factor(2012) *CSP***	*-0.0024*	*0.0011*	*-2.2157*	*0.0278**
Factor(2008) *CSP	*-0.0002*	*0.0010*	*-0.2171*	*0.8283*	***Factor(2013) *CSP***	*-0.0034*	*0.0011*	*-3.1438*	*0.0019***
Factor(2009) *CSP	*-0.0030*	*0.0010*	*-2.9855*	*0.0032***	***D/E ratio***	*-0.0026*	*0.0021*	*-1.2531*	*0.2116*
Factor(2010) *CSP	*-0.0023*	*0.0010*	*-2.2350*	*0.0265**	***MC***	*0.0015*	*0.0004*	*3.5127*	*0.0005****
R-squared: 0.1887 Adj. R-squared: 0.15725 F-statistic: 4.6518									
p-value: 5.7636e-06 Signif. Codes: 0 '', 0.001 '**', 0.01 '*', 0.05 '`'***									

As shown in Table 3, all the interactive items, representing CSR in each year, show the negative impacts on ROA, which means CSR implementation in short-term is detrimental to CFP. Thus, *Hypothesis 2* is supported.

7. Discussions and Conclusions

Owing to its theoretical and practical significance, the intellectual debate on the nexus between corporate social performance (CSP) and corporate financial performance (CFP) is incessant. It is hardly new for existing studies to recognise the positive, negative, neutral or even the non-linear, dynamic, and multidirectional relationships between CSP and CFP. However, it seems that no one has attempted to integrate the CSP-CFP nexuses into a refined theory capable of accounting for their seemingly paradoxical dynamics. Originated on the both sides of the Atlantic, CSR has travelled with construction business when it traverses traditional national boundaries into the international arena. International construction companies nowadays use it as a 'soft power' for market penetration. This paper, by focusing on the international construction business sector, found that indeed CSR is slightly detrimental to CFP in the short term but will be conducive to CFP in the long term. At the beginning, CSR programmes are in the nature of competing scarce resources possessed by the firms, such as capital, entrepreneurship, manpower, time, and management efforts while the benefits might not be able to be cultivated in short term. After a certain period of time, the CSR programmes, though competing scarce resources too, may bring long-term benefits, e.g. after experienced the learning curve, by developing reputation, or improving business relationships.

The research provided a fresh perspective to the moot question regarding the CSR-CFP link. With the introduction of time into the equitation, the traditional negative and positive relationships are now conceived as complementary rather than opposing. It goes beyond the allies-and-adversaries dichotomy towards a theory of paradoxical dynamics between CSR and CFP. The research can also enrich the classic discussions of firm's boundary. Particularly, new institutional economics asserts that certain economic tasks, if add to the transaction cost, should be excluded from the boundary of a firm, and they should be performed by the market (Coase, 1930; Williamson, 1991). Given the fact that CSR does consume firm's resources, many scholars thus believe that CSR should be excluded from the boundary of a firm. Many have misunderstood Friedman, assuming he was against CSR as he famously argued that socially desirable goals, if at the expense of profitability, should be disconnected from a company's fiduciary responsibilities (Friedman, 1970). This research shows that with discretional management, CSR could reduce transaction cost, e.g. by developing a harmonious relationship with stakeholders so as to guarantee key resources, or by developing a reputation. Business executives should focus no more on "whether conducting CSR or not" but on how to properly manage CSR as the allies of CFP.

A significant practical use of this research is that it provides to business executives to be relieved from short-termism when they devise CSR strategies to achieve business success. Most contemporary firms are set up and governed based on old firm theories, such as profit maximization, and shareholders' profits are protected by law while stakeholders' benefits, though important too, are bound by 'social contracts'. With these firm-related ideology, it is a natural thinking for shareholders to emphasize maximizing their profit effectively and efficiently. In a competitive business world, this is translated to the perpetual burden of business executives to justify their CSR strategies with higher CFP. This research suggests that CSP may not immediately lead to higher financial performance. Instead, at the beginning, CSP may jeopardize a firm's financial performance. Shareholders should take a long-term stance to their CEO's CSR strategies.

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Building energy retrofits, occupant health and wellbeing

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Abstract

Occupant questionnaire data were collected both before and after retrofitting of 38 Finnish multifamily buildings and eight control buildings. One adult per apartment (an average of about five apartments per building) was asked to fill in a questionnaire about occupant perceived housing satisfaction, health and wellbeing, as well as occupant behaviour. A total of 234 occupants (response rate 94%) answered to the first questionnaire (baseline), and 187 (75%) answered to the second questionnaire (follow-up). In this paper, we aim to describe occupants' perceptions on their housing and self-reported health symptoms, and to assess the effects of retrofits improving energy efficiency of the buildings on occupants' perceptions if indoor environmental quality and health.

Keywords: apartment buildings, indoor environmental quality, noise, thermal comfort

1. Introduction

Collecting information directly from the occupants is an important part of building and indoor environmental quality (IEQ) assessments. Overall, collecting information from the occupants using structured interviews or questionnaires can be useful when assessing ways to improve occupants' satisfaction with their housing conditions, and also in larger scale population studies where sample size is sufficient for group level (statistical) analyses. Limitations of occupant surveys include that they provide subjective measures prone to bias (e.g., misclassification, self-selection bias), and dependent errors (Rothman et al. 2008).

There exist a few energy retrofit intervention studies, which have included assessments of health outcomes. In UK, a review of the impacts the Warm Front program provided evidence of that the home energy improvements conducted were accompanied by appreciable benefits in terms of use of living space, comfort and quality of life, physical and mental well-being (Gilbertson et al. 2006). In Germany, Frankfurt housing intervention study concluded that renovation and insulation activities did not appear to be in conflict with the health of residents (WHO 2008).

Outside Europe, a cluster randomised study was conducted to evaluate effects of insulating existing houses on health in New Zealand. It was reported that insulating houses led to a significantly warmer, drier indoor environment, and resulted in improved self-rated health, self-reported wheezing, days off school and work, and visits to general practitioners as well as a trend for fewer hospital admissions for respiratory conditions (Howden-Chapman et al. 2007). In addition, a recent study from the US assessed low-income housing development renovated in accordance with green healthy housing improvements, reporting improved self-reported general health among adults (Jacobs et al. 2015).

This paper focuses on results from housing and health questionnaires collected from Finnish apartments as a part of INSULAtE-project (www.insulateproject.eu).

2. Material and methods

Study buildings were drawn from several regions in Finland (Tampere, Hämeenlinna, Imatra, Helsinki, Porvoo, and Kuopio). Participating multi-family buildings were chosen among buildings with planned retrofits improving energy efficiency during the project (2010-2015). In addition, some control buildings, which had no plans for retrofitting, were included. Recruited apartments were selected from volunteering occupants, who did not receive any compensation for their time participating in the study. The study plan was evaluated and approved by the National Institute for Health and Welfare's Ethical Research Working Group in Finland.

About 80% of the buildings were constructed between 1960 and 1980, and majority of them had mechanical exhaust ventilation (<10% had natural ventilation). Most common retrofitting activities included changing windows, adding heat recovery to the ventilation systems, adding thermal insulation to the building envelope, and changing heating systems.

Information about housing and health was collected from the occupants by questionnaires developed based on previous studies (Turunen et al. 2010). The questionnaire comprised of 49 questions related to the building and living environment; physical, biological, and chemical conditions; hygiene; occupant behaviour, health and well-being; and background information. One adult per apartment was asked to fill in the questionnaire on two occasions: first at the baseline (corresponding to the situation before retrofits in the study buildings) and second (follow-up) questionnaire usually about one year later (corresponding to the situation after retrofits in the study buildings). A total of 234 and 187 people (response rates 94% and 75%) answered to the first and second questionnaires, respectively. In addition to the questionnaires, comprehensive IEQ assessments were performed by trained investigators, who conducted measurements in each apartment (data not shown). Table 1 shows some background characteristics of the respondents and their apartments.

Table 1: Questionnaire respondents' background characteristics.

	Control buildings					*Study buildings*				
	1st		*2nd*			*1st*		*2nd*		
	N	*%*	*N*	*%*	*P*	*N*	*%*	*N*	*%*	*p*
Gender, female	16	52	6	55	.87	127	63	101	63	.98
Smoking in the dwelling, never	27	90	10	91	.93	187	94	142	90	.15
Furry pets	6	20	3	27	.62	27	14	22	14	.90
Exercising several days per week										
Near dwelling	23	79	6	55	.22	125	65	98	67	.90
On the way to work	12	57	6	76	.89	43	39	25	34	.34
Elsewhere						52	43	50	53	.40
Percent of income spent for housing					.12					.42
< 15 %	8	26	1	10		42	22	26	17	
16–25%	10	32	4	40		62	33	39	26	
26-35%	1	3	2	20		37	19	40	27	
36–50%	7	23	1	10		33	17	30	20	
51–65%	4	13	0	0		10	5	10	7	
> 65 %	1	2	2	20		7	4	4	3	
Tenure status					.69					.28
Own	13	42	4	36		138	68	111	70	
Rent	17	55	7	64		65	32	46	29	
*Other**	1	3	0	0		0	0	1	1	
Balcony	21	68	7	64	.80	110	54	86	53	.88
Covered balcony	12	39	4	36	.89	**96**	**47**	**99**	**62**	**.01**
Mechanical exhaust	9	29	6	55	.13	62	31	49	30	.98
Mechanical supply	10	32	3	27	.76	**16**	**8**	**34**	**21**	**.00**
Trickle vents in bedrooms	8	26	2	18	.61	**31**	**15**	**66**	**41**	**.00**
Wood burning fire place / oven	3	10	2	18	.45	1	1	1	1	.87
Sauna	17	55	4	46	.59	**86**	**42**	**85**	**53**	**.05**

	Mean	SD	Mean	SD	P	Mean	SD	Mean	SD	p
Age mean	*47.5*	*18.6*	*49.6*	*16.1*	*.75*	*57.9*	*19.4*	*58.2*	*17.4*	*.88*
Years lived in the current dwelling	7.8	10.1	11.3	11.2	.37	13.0	12.5	13.2	12.5	.87
Number of persons in the dwelling										
Adults (18-65 yrs)	1.1	0.6	1.1	0.6	.79	1.4	0.6	1.4	0.7	.91
Children (7-17 yrs)	0.4	0.7	0.8	1.0	.39	0.8	0.9	0.8	0.8	.87
Children (<7 yrs)	0.1	0.3	00.0	0.0	.66	0.5	0.7	0.5	0.7	.99

*includes: employers' housing, right of residence apartment, and others

P-values shown in the tables are referring to the statistical testing of group level differences between first and second questionnaires using chi-square test. The test does not take into account the dependency between the samples, i.e. the fact that in most cases the respondents were same at the baseline (1st questionnaire) and follow-up (2nd questionnaire). Therefore, the test results are only used for screening purposes. With respect to selected variables, where significant differences were found on the group level, the results were further analysed using General Estimating Equations (GEEs). These multivariate models were fitted with unstructured covariance structure and binominal link-function. In the models, individual responders and buildings, as well as time of questionnaire were identified by the ID-, building-, and time -variables, and respondents' gender and age were included.

We also tested the differences between the control and study buildings using chi-square test, but these results should be treated with caution due to small number of respondents from control buildings. At the baseline (1st questionnaire), a larger proportion of the respondents in the study buildings were females, and kept furry pets indoor less frequently than the respondents in the control buildings. On the other hand, the respondents in the control buildings were significantly more often tenants, they were younger, and had lived in their current apartment a shorter period of time, and had less children living in their apartments. Mechanical air supply and wood burning fireplace were more common in the control buildings. At the follow-up (2nd questionnaire), the differences between study and control buildings remained significant for tenure status and number of children living in the apartments. In addition, the respondents from the study buildings reported exercising more frequently.

Based on the preliminary screening, the respondents from the study buildings reported higher proportion of apartments having covered balcony, trickle vents, and mechanical supply air after retrofits (2nd questionnaire) as compared to the baseline (1st questionnaire), which changes are corresponding with the targeted energy retrofit actions. Also saunas were significantly more common in the study buildings after retrofits.

3. Results

Results related to occupant self-reported thermal conditions are shown in Table 2. Occupants from the control buildings reported significantly less opening windows daily in the living room as compared to the occupants from the study buildings at the baseline (1st questionnaire), and a similar (non-significant) trend was seen in the winter. At the follow-up (2nd questionnaire), occupants from the study buildings reported significantly higher temperatures during heating season as compared to the occupants from the control buildings.

Table 2. Thermal conditions.

	Control buildings					*Study buildings*				
	Pre		*Post*			*Pre*		*Post*		
	N	*%*	*N*	*%*	*P*	*N*	*%*	*N*	*%*	*p*
Typical temperature during heating season					.35					.33
<18°C	0	0	1	9		3	2	0	0	
18-20°C	9	30	4	36		33	17	19	12	
20-22°C	16	53	4	36		108	55	96	61	
22-24°C	5	17	2	17		46	23	39	25	
>24°C	0	0	0	0		7	4	4	3	
Thermal conditions in summer										
Suitable warm	15	48	8	73	.16	111	58	92	57	.93
Too cold	0	0	0	0	-	2	1	3	2	.48
Too hot	14	45	6	55	.59	103	51	68	42	.11
Draughty	0	0	0	0	-	5	3	6	4	.48
Cold floor surfaces etc.	0	0	1	9	.09	5	3	2	1	.40
Thermal conditions in winter										
Suitable warm	17	55	6	55	.99	130	64	105	65	.82
Too cold	15	48	3	27	.22	45	22	36	22	.97
Too hot	1	3	0	0	.55	17	8	13	8	.92
Draughty	5	16	3	27	.42	58	29	34	21	.10
Cold floor surfaces etc.	8	26	8	36	.50	53	26	39	24	.68
Open windows daily in kitchen for temperature control										
Summer	10	32	7	64	.07	102	50	65	40	.06
Winter	1	3	2	18	.10	29	14	18	11	.38
Open windows daily in bedroom for temperature control										
Summer	17	55	8	73	.30	141	70	99	62	.11
Winter	7	23	4	36	.37	79	39	59	37	.66
Open windows daily in living room for temperature control										
*Summer**	9	29	5	46	.32	**110**	**54**	**66**	**41**	**.01**
Winter	2	8	2	17	.26	37	18	22	14	.24
Did not attempt to adjust thermostats in the past 12 mo.	18	58	4	40	.32	85	43	70	44	.86

* Further analysed with GEEs

In the study buildings, the respondents reported slightly higher indoor temperatures after retrofits as compared to the situation before retrofits, but the group level differences were not significant. Similarly, reporting too hot summer temperatures was less frequent among respondents from study buildings after retrofits, as well as reporting of draught during winter.

There was a significant pre - post retrofit difference among respondents in the study buildings in reporting opening windows daily for temperature control in summer in their living room. The difference remained significant in the GEE model including respondents' age and gender. The trend was similar for other rooms and also during winter in the study buildings, whereas an opposite trend was seen among the respondents from the control buildings.

Table 3 shows results related to dampness and mould, odours, lighting, and noise. At the baseline, respondents from the control buildings reported significantly less frequently odours related to food, and daily noise disturbance related to traffic or industry, as compared to the respondents from the study buildings. At the follow-up, respondents from the study buildings reported odour related to tobacco smoke significantly less frequently.

Table 3. Indoor environmental quality.

	Control buildings					*Study buildings*				
	Pre		*Post*			*Pre*		*Post*		
	N	*%*	*N*	*%*	*p*	*N*	*%*	*N*	*%*	*p*
Condensation on windows										
Summer	7	23	3	27	0.75	24	12	22	14	.60
Winter	14	45	7	64	0.29	75	37	52	32	.36
No know water damage	24	77	9	82	0.74	151	77	123	79	.48
No moisture or mould damage in the bedroom	26	93	9	100	0.56	184	100	151	100	.37
Odours										
Food	1	3	2	18	0.11	46	25	25	17	.07
Tobacco	**3**	**10**	**5**	**46**	**0.01**	**28**	**15**	**11**	**7**	**.03**
Mould	1	4	1	9	0.48	3	2	1	1	.41
Building materials	1	3	0	0	0.53	2	1	3	2	.50
*Stuffiness**	4	14	2	18	0.73	**33**	**19**	**12**	**8**	**.01**
Sewage	4	13	2	18	0.70	**31**	**17**	**13**	**9**	**.03**
Lighting defects										
In the dwelling	4	13	1	9	0.71	21	11	16	10	.82
In the hallways	3	10	2	18	0.50	18	9	10	7	.37
Outside	4	15	3	27	0.37	36	19	28	18	.89
Daily noise disturbance related to										
Dwelling (occupants etc.)	4	14	2	18	0.76	12	6	17	12	.08
HVAC systems	6	21	3	30	0.58	22	12	26	18	.10
Neighbours	10	35	4	36	0.91	46	24	42	28	.41
*Traffic, industry etc.**	2	7	2	18	0.31	**52**	**28**	**26**	**18**	**.03**

* Further analysed with GEEs

Reporting of odours appeared to become less frequent after retrofits in the study buildings. The group level differences were statistically significant for odours of tobacco, stuffiness, and sewage smell. The differences for stuffiness remained significant in the GEE model including respondents' age and gender. Daily noise disturbance related to the dwelling and HVAC systems appeared to become more frequent, whereas disturbance related to traffic or industry was reported significantly less frequently. These differences were statistically significant in the GEE models including respondents' age and gender.

As indicated in Table 4, occupants from the control buildings were more satisfied with indoor air quality (IAQ) and maintenance at the baseline, and they reported less upper respiratory symptoms and eye symptoms. They also related symptoms to home environment less often than the occupants from the study buildings. They missed days from work or school less frequently. At the follow-up, the differences between the control and study buildings appeared to diminish.

Table 4. Satisfaction with housing and health symptoms.

	Control buildings					*Study buildings*				
	Pre		*Post*			*Pre*		*Post*		
	N	*%*	*N*	*%*	*p*	*N*	*%*	*N*	*%*	*p*
Plans to move	8	26	6	55	.08	57	28	32	20	.07
Satisfied with dwelling	18	58	5	46	.37	82	41	82	52	.23
*Satisfied with IAQ**	14	45	4	36	.56	**42**	**22**	**65**	**41**	**.00**
Satisfied with maintenance	12	41	4	36	.56	**65**	**33**	**63**	**40**	**.02**
Health symptoms[a]										
General symptoms	4	13	3	27	.27	56	28	42	26	.75
*Upper respiratory symptoms**	6	19	3	27	.58	**75**	**37**	**44**	**27**	**.05**
Lower respiratory symptoms	3	10	1	9	.96	45	22	23	14	.06
Eye symptoms	**3**	**10**	**4**	**36**	**.04**	64	32	43	27	.32
Skin symptoms	9	29	4	36	.65	60	30	42	26	.46
Arthritis	6	19	2	18	.93	51	25	45	28	.54
Muscular pain	4	13	2	18	.67	40	20	34	21	.74
Diarrhea	2	7	1	9	.77	7	3	4	3	.59
Difficulties to sleep	7	23	3	27	.75	46	23	37	23	.94
Symptoms are related to home environment	**4**	**15**	**5**	**50**	**.03**	60	34	55	37	.53
Respiratory infections[b]*	8	26	3	27	.92	**62**	**32**	**34**	**22**	**.04**
Doctor visits	6	19	3	27	.58	56	29	30	20	.05
Antibiotics	6	19	3	27	.58	58	30	34	23	.10
Missed work or school	5	17	2	18	.91	33	21	17	13	.06

*[a] Daily / weekly [b] within the last 12 months * Further analysed with GEEs*

The respondents in the study buildings were significantly more frequently satisfied with IAQ and maintenance than before retrofits, and they were less frequently planning to move, whereas an opposite trend was seen in the control buildings. Respondents in the study buildings reported significantly less weekly upper respiratory symptoms and a similar trend was seen for lower respiratory symptoms. Reporting of respiratory infections, doctor visits and missed work or school days were also reduced. The differences with respect to satisfaction with IAQ and upper respiratory symptoms remained significant in the GEE models including age and gender.

4. Discussion

Drawing conclusions based on questionnaire data requires careful analyses and interpretation. Occupant self-reporting is subjective and prone to reporting bias. There are, however, some ways to increase objectivity: e.g. using questions that specifically ask about matters that can be validated, such as doctor diagnosed diseases, and missed work/school days due to illness.

Due to numerous factors that influence human health and well-being, a large enough sample size is needed to draw conclusions about the empirical relationships between housing conditions and occupant health. The required sample size is primarily based on the need to have sufficient statistical power. There are many methodological difficulties inherent in assessing the health effects of housing that need to be carefully considered. For example, response rates are often low, which can limit the possibility to draw conclusions and generalize the results.

On the group level, our sample size appears to be sufficient to detect relatively large differences (>10% difference in the prevalence values) between the sub-samples. However, group level comparisons may be inconclusive, as there are many confounding factors that have to be taken into consideration. It appears that our sample size with respect to questionnaire data may be limited with respect to drawing definite conclusions on the potential effects of energy retrofits on occupant health and wellbeing, but it could be used to develop tools to follow-up effects of national programmes and policies that are aiming to improve energy efficiency of buildings, particularly with respect to occupants' satisfaction. Future analyses will also provide additional information about associations between occupants' self-reported and measured IAQ, which can be used for validation purposes.

National Institute for Health and Welfare has also conducted so called "National housing quality, health and safety survey", where questionnaire data have been collected from random samples of 3000 household-dwelling units in 2007 and 2011 (Anttila et al. 2013, Pekkonen & Haverinen-Shaughnessy 2014). The results of the survey can be useful as reference material, regarding to housing and health conditions in Finland.

5. Conclusions

INSULAtE-project has developed a comprehensive assessment protocol aiming to demonstrate how improving energy efficiency in buildings impacts on indoor environmental quality and health outcomes. The protocol includes occupant questionnaires, which could be utilized when assessing the effects of improving energy efficiency of the housing stock. Changes were observed in occupant satisfaction with the dwelling and IAQ, perception of odours, daily noise disturbance related to HVAC systems and traffic or industry, as well as respiratory symptoms and missed work or school days, which could be related to the retrofits, although further studies are needed to verify the associations.

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Perspective of Social Usability in the Change Processes of an Academic Workplace

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Abstract

The goal of this paper is to provide an overview of the defensive and supportive projections of users towards perspective of social usability during the change processes of an academic workplace. The significance a university's staff attributes to relational aspects during the change process of a workplace was studied at the University of Jyväskylä, in a situation where a faculty and a research institute were moving into a new building. The workplace process was carried out through co-designing. An interview survey of the key persons (N=12) was conducted. These persons acted as mediators of information between employees, architects and designers. The results revealed several tensions relating to social usability and the importance of experiencing safety and trust during the process. Also professional identity is reflected during the workplace change. End-user satisfaction is closely related to the individuals' experiences of relational factors attributed to communication and collaboration. It is especially important in the change process of a workplace. Moreover, it is very culturally sensitive both to express and interpret who knows the needs of the users "best". Therefore, it is a very complex phenomenon: attempts to improve the culture of working needs those who lead the way of change. Otherwise it is too tempting to remain stagnant within a comfort zone. The agents of change partially exist inside the working community, but for the most part, the need for change can be found from the group consisting of the built environment professionals, the employer and the owner of the property.

An academic community is naturally accustomed to influencing its professional field but is much less so when dealing with factors beyond that field. Keeping this in mind, we must note that the arena of influencing the built environment that should reflect your professional expertise is a new one. Therefore, an academic community may at first have problems influencing these environments in an expedient manner. Research-based knowledge and a deeper understanding of the processes that build mutual trust are crucial. Therefore, a better base of knowledge and understanding of social processes is required.

Keywords: usability, user experiences, change within an academic workplace, co-creation

1. Introduction

Even though they carry the considerable weight of tradition, universities and academic workplaces are in a state of transformation. They must reflect and support the skills and attitudes needed in the 21st century. The requirements and need are not easily defined without the perspective of a future-orientated user. According to den Heijer (2011) the most important considerations that the campus of the future should incorporate/reflect are e.g. less individual territory and more shared space as well as considerations in terms of place independency: due to developments in ICT, people can work wherever is best for them. Various generic models are suggested for academic offices for example as 'studies, quarters, clusters, hubs and clubs' but that an appropriate workplace solution should be developed 'based on an in-depth understanding of the work activities of the people involved' in the workspace (Harrison and Hutton, 2014, 163).

Especially when considering the scenarios of the work and work environments of the future, the space should be seen as a multi-dimensionally structured one, containing social, emotional, physical and intellectual features. Existing spaces seldom support all these levels of work in the future. The future of academic workplaces needs dynamic communities that offer participative and collaborative spaces for knowledge sharing, creativity and learning. (See Jääskelä, Klemola, Kostiainen and Rautiainen, 2012; Rautiainen and Kostiainen, 2015.) Therefore, a fresh evaluation of usability of places from the perspective of social usability, meaning the usability of the social place, is worth to investigate: how the diverse features and artefacts of a built environment support emotional experiences and relational processes. The aim of this paper is to explore the defensive and supportive projections of users towards the perspective of social usability during the change processes of an academic workplace.

2. Theory

2.1 Perspective of Social usability

The International Council for Building Research and Documentation (CIB) working group on the usability of workplace (W111) has been exploring concepts, methods and tools, developed in the evaluation of all kinds of consumer products, applied to the built environment (Alexander, 2006; 2008; 2010). The intention has been to identify and evaluate how to design and manage the relationship between activities and space. Usability in the built environment is context dependent and related to user experience, social relations amongst users and to the interaction between users and facilities. Usability has found to be strongly related not only to relationships between people and physical settings, but also to clarify strategies for the organization regarding work and the use of facilities. Usability is 'a cultural phenomenon that can only be improved through better understanding user experience, considered as situated action in a specific context' (Alexander, 2008, 6). Usability is social by its nature and the perspective of social usability focus on user experience and understanding the relationship between individual, place and social community connected to the context. Language and communication are important factors in studying the user experience and understanding the social layout of the place (Airo 2014; Airo, Rasila and Nenonen, 2012).

2.2 The social dimension of work

Finnish organizations and university campuses are increasingly building multifunctional spaces (e.g. Future Campuses, 2011; Ruohomäki, Lahtinen, Haapakangas and Reijula, 2014). When considering the perspective of social usability of the workplace – especially the sense of community, knowledge sharing and meanings given to it – it is noticed in previous research that multifunctional spaces increase social interaction (Davis, Leach and Clegg, 2011; De Croon, Sluiter, Kuijer and Frings-Dresen, 2005; Vos and van der Voordt, 2002) and perceptions of forthcoming workplace changes also seem to focus on spaces where collaboration is supported (Ruohomäki et al, 2014, 709). The social dimension of the work and the meaning of interaction, collaboration and competence in communication become clear when we examine how work is performed in today's knowledge-intensive work culture. Academic work that is based on shared expertise, knowledge processing, networking, mobility and globalisation, poses a serious challenge to the meaning and relevance given to a social dimension of the work: communication and collaboration are not merely a tool – they are rudimentary requirements for work.

Jobs require comprehension and control of processes that are fundamentally communicative: collaboration is how work is done - e.g. work is done through teams or networks, or is performed interactively. Knowledge and understanding is created and shared and the work result - instead of concrete products or performance – is increasingly in the form of pooled ideas, and is the outcome of collaboration (e.g. specialised problem solving). Work no longer speaks for itself (work is not a material product), and an employee must be able to uphold the "results" of his or her work, often consisting of abstract ideas or shared processing of data (see Kostiainen, 2003). The origination, distribution and approval of common meanings - and learning what is new - are based on interaction, so that work performance requires multi-faceted familiarity with and confidence in collaborative processes both nationally and globally (e.g. Curtain, 2000; FinnSight 2015, 2006). However, collaborative orientation to work does not 'transfer' with employees from old environment to new or form an essential part of the work employees do, unless its meaning becomes relevant to them. Although interaction is permanently part of employee routine, it is too often taken for granted that people at work can communicate or collaborate, and is rarely given profound consideration. Therefore a fresh perspective of social usability of the workplace and its evaluation - meanings university staff attribute to collaboration and knowledge sharing – is called for in the studies concerning the forthcoming changing of the workplace.

3. Method

3.1 Research questions and data description

Previous research on usability has used case-studies in order to define the concepts of usability and to support the process of usability research (e.g. Alexander, 2008, 7-8). This case-study aims to improve the understanding about defensive and supportive relational processes and defining concepts related to the perspective of social usability of workplace. This study seeks to answer the following questions:

1) What are the defensive and supportive projections towards relational processes and experiences during the design-phase of the new work space?
2) What phenomena could explain the perspective of social usability?

An interview survey of the key informants (N=12) was conducted. The study included a total of ten interviews (two pair-interviews) with people from the University of Jyväskylä. The interviewees were chosen as module co-ordinators by the facility team consisted of faculty administration and construction team. All module co-ordinators had been involved in the planning of their own module (dice) - the section of the new building where the particular group of employees were placed. They were acting as key persons who were mediators of information between employees and architects and designers.

The interviews were carried out as semi-structured qualitative interviews using an interview guideline with about 25-30 questions divided into seven themes: (1) the overall expectations as well as expectations related (2) to work, (3) to the new building and space, (4) to collaboration, (5) to wellbeing and enthusiasm, (6) to the image of their own organization and (7) experience of possibility to influence. Questions were framed as open as possible. All interviewees were asked the same questions, but ordering the questions was flexible and followed the progression of the conversation. Additional questions were asked dependent on what interviewees brought into question. Each interview lasted about one hour and were recorded. Blakstad et al (2010, 23) states that in order to gain useful information about the usability of the building it is important to relate the users' experiences to certain space or place and to specific physical surroundings. In this case study, the new building was under construction and some of the future users had had an opportunity to visit the construction site. In the interview situation, all interviewees had a copy of a floor plan where they and their colleagues are going to move within one year. Just before the interviews the employees had got information about their placement in the new building.

3.2 Data analysis

The thematic analysis frame of Braun and Clark (2006) was used in data analysis. The data was analysed step-by-step consisting of three interactive sub processes. The first, data reduction phase consisted of generating initial codes where the process of systematic coding (Miles and Huberman, 1994) was applied. The second phase of the analysis was searching for themes and all the codes were collated into potential themes. Also the comprised themes were reviewed against the first phase initial codes' themes. Finally, defining and naming themes and the drawing of conclusions were implemented (see Table 1). In the first, data reduction phase the qualitative interview data was reduced into a manageable form by generating initial codes by using an ATLAS.ti analysis program. The codes were used as the units of organizing the qualitative data in a way that the initial codes were formed through the re-reading of the data. The data was coded according to defensive, supportive and neutral projections concerning social usability. After categorizing the data into these three dimensions the qualitatively different ways of experiencing the phenomena either positively, negatively or neutrally were the more detailed units (e.g. sentence or phrase) of analysis (see Marton, 1994). As a result of the first analysis phase altogether thirteen sub-code categories were created to which interviewees' experiences were interpreted as connecting (see Table 1).

Table 1: The phases of analysis

Phase 1: Generating initial codes			***Phase 2: Searching and reviewing themes***	***Phase 3: Defining and naming themes***
Supportive projections	*Defensive projections*	*Neutral projections*	*Thematic tensions between experiences and expressions*	*Interpretation, identifying the central findings*
Social orientation, collaboration			*Need for change – the claim/concern of stability* *The sense of ownership – the sense of detachment* *Efficiency – inefficiency* *The sense of being heard – the sense of being dismissed* *The sense of being valued – the sense of being valueless* *Rationality – sensibility* *Social – privacy*	*Experience of safety (high – low)* *Experience of trust (high – low)* *Professional identity (individual – collective)*
New possibilities, innovations				
Clean and healthy work environment				
Enthusiasm				
Privacy, peace and quietness	*(Lack of) privacy, peace and quietness*			
The sense of ownership	*(Lack of) ownership*			
Stability	*Stability*			
Status, hierarchy	*Status, hierarchy*	*Status, hierarchy*		
Informing, instructions	*Informing, instructions*	*Informing, instructions*		
Work practices	*Work practices*	*Work practices*		
	Various fears, anxiety			
	Placement	*Placement*		
	Physical space, layout			

The first phase analysis revealed that the same matters, occasions or events could have both supportive and defensive as well as neutral projections. Although the interviewees experienced certain matters either largely positively or negatively it was apparent that in the same interview the same matters could be expressed both defensively or supportively. As a consequence of this finding, the thematic tensions between experiences and expressions were studied in the second phase of analysis. Analysis revealed in total seven thematic tensions. Finally, in the third phase defining and naming the meta-themes was the systematic process of interpretation, identifying the central findings, the conclusion drawing of the organized data. Three meta-themes behind the thematic tensions were identified as experience of safety (high-low), the experience of trust (high-low) and the professional identity (individual-collective). These cross data findings – the thematic tension between experiences and expressions (Chapter 4.1) and interpretative meta-themes (Chapter 4.2) are reported in the results.

4. Results

4.1 Social usability as supportive and defensive tensions

The interview survey of the key informants who were mediators of information between employees and architects and designers revealed several tensions relating to social usability in the process. These tensions could be named to following themes: 1) Need for change – the claim/concern of stability, 2) the sense of ownership – the sense of detachment, 3) efficiency – inefficiency, 4) sense of being heard – sense of being dismissed, 5) sense of being valued – sense of being valueless, 6) rationality – emotionalism and 7) social – privacy.

Need for change – the claim/concern of stability. The analysis of the data raised either the need for change or the claim of stability. Also those who wanted some changes expressed their concern about excessive stability. They saw that the possibility to change is maybe not utilized in its possible entirety. Both desire for change and fear for change are essential elements which generate experiences of feeling comfortable at future work and work space. Therefore it is important to take these opposing orientations into consideration. The need for change and the concern of stability are shown in the next exemplars:

> ”I also believe that they are sort of burdened by tradition. I think that they should gather an outside perspective on things and switch things up accordingly. It should be the basis for trying new things bravely. We should try to find ways to save some space if it helps in keeping a few more people employed at the location. I don't think the concept of saving always has to mean that things are taken away from you. It can also be the spark for trying out new and different things.”

> ”I probably somehow disagree with the notion that the work of a researcher requires a peaceful atmosphere for thinking. If we consider the kind of phenomena that we're researching and the direction we're heading to, I think we need […] a sort of shuffling of ideas. A kind of collision of minds. Meetings where different ideas are tossed around. Then after such meetings, there are places for you to kind a withdraw to […] where you can mull over your own thoughts. But the thought of going through an entire process like that in isolation, that 'I came up with this research idea, I'm going to look into it, I will advance and I will develop'...no way, such thinking belongs in the past.”

> ” I don't think it's going to become any better or worse than what we've had here or anywhere else.”

”If I had to say one word, for me it would be, like, an opportunity to do something differently. But unfortunately I have to ask that has it also been a wasted opportunity? I mean, it's still somewhat possible, but it also carries the danger of getting too comfortable and safe.”

The sense of ownership – the sense of detachment. The data also revealed a tension between the ownership and sense of detachment. Users' expectancies mirror the idea that the users themselves mould the new space to be their own. Some of them could already express that 'this is my place here' (pointing out one spot from the floor plan) or this is going to be 'our get-together space'. Experiences related to at least some level of ownership create the feeling of safety. Next citations exemplify the joint or personal feeling of ownership:

”On the other hand, I feel we're not even expecting to get everything, like a physiotherapy station […]. So our wishes display the atmosphere that we would want there. […] If there won't be an egg chair, then there'll probably be an exercise ball or something else then. There's a drive present, that we're going to make this great.”

“At least my own feelings about the building are really positive. My kids are utterly tired of hearing about it when we drive past it. Like look, there's mommy's house! The entire building is so beautiful already.”

Other hand, there are also uncertainty originating from the sense of detachment and 'free-floating'. Within the co-design process all the users were not always certain were their planning the space for themselves or for some more undefined user. Also, the placement of users lived during the process and experiences of ending up with someone else's ready-made plan was frustrating. Moreover there is lots of speculation whether there is an own or a changing working place or whether it is possible to bring any material of their own and personal things or not. Moreover there is uncertainty whether the forthcoming working community is familiar or re-formed of stranger people. The elements of the sense of detachment emerge in the next quotations:

”So in a way, for quite a while it was designed for the needs of people who are not here anymore. We are no longer interested in what was being taken there but now we are going to live with the decisions that they made on our behalf.”

”Somehow I feel that there won't be a kind of personal space for me or anyone else. The reality will probably be that, considering how few people we have overall, in the end we will designate personal desks for everyone. So those will be the personal spaces where you can bring your own photograph or potted plant if you feel like doing so. But during the planning phase the overall picture we have received has been quite impersonal, that everyone is going to switch places constantly and you don't really have this little space of your own.”

Efficiency – inefficiency. One essential tension expresses the desire to be efficient and productive in the new work space. This tension was mainly connected to the discourse involving the private rooms or the working area in an open space. Especially the conditions where people do not have their own space were seen a great threat to efficiency. The following statements exemplify this approach:

”But if we look at the nature of this job, we have people who are doing eight to ten hours of work daily at their own work station in their office. I think it is a difficult proposition to place those individuals into an open space like this and expect that the efficiency of their work doesn't suffer.”

”Well, there are a lot of doubts connected to these developments. If everything that has been suggested during the planning phase is implemented, I believe that overall well-being will suffer. That not having a space of your own will immediately increase stress levels. […] In any case, this change of scenery, this big moving project will at first disrupt the working rhythm people have developed. I guess after six months or so we may begin seeing these factors settle down.”

Also, an opposite impression can be seen which is considered productive ways of doing work. For part of the users, the threat of working alone or placement in a private room would be more ineffective. The next exemplar illustrates this point of view:

> ”So how much do we know about ergonomics. How much do we know about creativity, producing new ideas and the importance of cooperation? I think it's a genuinely dreadful thought that I should go into a box, inside four walls, to work by sitting in that same spot.”

The sense of being heard – the sense of being dismissed. One of the most discreet tensions addressed the problem the sense of being either heard or dismissed in different phases of the co-design process. Some of the users find that their ideas and thoughts have been taken into consideration very well. Also the awareness of different experiences seems to be shared especially in informal discussions. The next quotation reveals the comparison of different experiences of being heard:

> ”And a trusting feeling, there's this notable feeling that this group […] trusts that they will be heard in comparison to these others. I mean, if we haven't been heard, we have designed this die but it doesn't turn out in practice according to those designs, somehow this feels different. I could of course be wrong, but maybe we have a more decided feeling of being heard here.”

The experiences of being dismissed are usually connected with assumptions that the decisions are fixed on in advance and there are not any possibilities to influence. Moreover users think that they have been promised certain solutions (e.g. private room) or things (e.g. extra walls) and these promises are not heard and taken into proper consideration. The following statements exemplify these thoughts:

> ”Somehow I feel that there's not much use discussing anything here. These things have already been decided. [--] I think at least in our dice the final conversations will revolve mainly around fighting for who gets to be in a smaller room and who in a bigger open space, etc. Or maybe fighting is too strong a word, but people will try to make their cases for needing exactly a certain type of work space.”

> ”Then the negative feelings that relate to our dice or that may not even be connected to any of the dice in particular, but to my feeling of how poorly we've been listened to. Even though we were promised the opposite. We assumed that we would have a bigger influence on this process and we are disappointed because we didn't.”

The sense of being valued – the sense of being valueless. Also the sense of being valued or valueless is one of the crucial features when evaluating the social usability of work space. Part of the users feel extremely privileged in the situation of having a brand new building and allowing to be part of the exceptional co-design process. Experiences of being valued are expressed in the following statements:

> ”Well, I feel it is like, once in a lifetime. A brilliant, but probably also a very rare, opportunity to be designing your own future work spaces.”

> ”I think that at least having this great building, at such a beautiful location, it makes me feel that it'll be nice to invite in guests from other universities or such places. That the building is a great business card of sorts, that we can proudly display to others.”

The sense of being valued or valueless can be fastened on an individual level as well as on a professional level or it can be fastened on status. Part of the users find it highly dismissing if their own work or opinions seem not to be valued during the process:

> ”What has kind of happened here, in my view, is that the work of the designers has been shifted onto us. That we could somehow nicely refine the most important questions and deliver them to the architects so that their valuable working hours wouldn't be wasted. […] Thinking about this inversely, this may mean that our working hours aren't the most valuable ones around.”

> ”This process has somewhat clarified the fact that the statements of some are valued more than the statements of others, because they tend to follow the basic ideas that the architects have set out. Those statements tend to be valued more than the ones that have criticized those basic ideas. […] It's obvious that some people are listened to more than others, I feel it's blatantly obvious.”

Rationality – sensibility. The data did not reveal any extreme expressions of happiness or satisfaction towards the new working space or its social climate. When users brought out some positive aspects or features even then they described the awareness of critical atmosphere and siege mentality at the same time. Quite a rational and moderate attitude was usual when describing the new work space and the ways of working there:

> ”I think that this is a common mission for us all. […] I relay the information and wishes and organize what is needed, but if folks are not going to get on board, I don't feel like it's my responsibility to lure people in. We're all grown-ups here. […] Whoever comes in, comes in [to the design meetings] and their opinions will be included in the decision-making process. Everyone else will simply adapt.”

> ”People have had a long while to digest this move to [the new building]. They have seen the blueprints, they know approximately what awaits them and thus should know how to ready themselves. I don't believe there will be any notable problems beyond that.”

Where there was not a noticeable enthusiasm in users talk there was considerable amount of negative toned emotions towards the new working space and the interpersonal relations there or even towards the location of the property itself:

> [Is there something inspiring there?] “It's terribly depressing if you say no, but in my mind it's just a space we occupy. I don't think there's anything particularly inspiring in that.”

> [What is the negative feedback centered on?] ”It's centered on the other staff members. People seem to fear the thought of an open workspace, figuratively sitting like chickens on a roost where everyone can see and hear what you're doing with no personal peace for your work. Maybe this fear is based on not knowing what this transition to something new will lead to, leading at first to negative feedback.”

> ”The property that [the new building] is built on is absolutely horrible, what with all the motorways crisscrossing around it. When you take a look at any of the university buildings, none of them are on such an inferior property.”

Tensions between social – privacy. Further, the tension between social and privacy was evident in users' expectations. Especially the entrance hall and lobbies on each floor were expected to function as various social encounters, more than their own working spaces. The wish for various social happenings and the chance for fruitful random and casual encounters were expressed:

> ”I think people should arrange all kinds of events in the main lobby, such as christmas parties or something more regular. It could work as a great meeting place, so I think it could also work as an event space for the townspeople.”

> ”I was actually allowed to visit the building back in August and in my view, the shared spaces and the ground floor and the entrance, right by the cafeteria and the large lecture hall, I think they're going to be brilliant. The entrance looked really nice. And I absolutely loved the cafeteria!”

> ”This dice in itself isn't all that important. What's much more important is the space in between the dice. I can imagine that in that space lots of happy or even random gatherings can take place. ”

The tension between social and privacy was often expressed through the talk of quietness and peace. The privacy-talk was mainly attached to the wish to have a decent peace to work. The concern of losing the ability to concentrate was very evident at the expense of those possibilities the new building could offer. There was even a very strict demand for being silently which causes also distress:

> ”There's a lot of talk about arranging the workspace culture in a way that gives people silence when they need it. I would have personally maybe wanted more discussion about how to co-exist while also frequently talking to our colleagues. [--] Silence, silence and calmly and silently like mice within the walls and you should never say anything or make any sounds. Even if you start eating your lunch, you should try to make sure you don't rustle any papers or otherwise cause noise in the process.”

> ”The biggest issues have revolved around peace for working. I think the demand for this kind of peace and silence has drowned out attempts to innovate and bring in new ideas and viewpoints concerning our jobs.”

4.2 Social usability as an experience of safety, trust and professional identity

As a result of the third analysis phase three meta-themes behind the supportive and defensive thematic tensions were identified: 1) experience of safety (high-low), 2) experience of trust (high-low) and 3) the professional identity (individual-collective). These phenomena and their relations can in part be attached to explain the concept of social usability. The relations between these meta-themes can be placed at a fourfold table as seen in Figure 1.

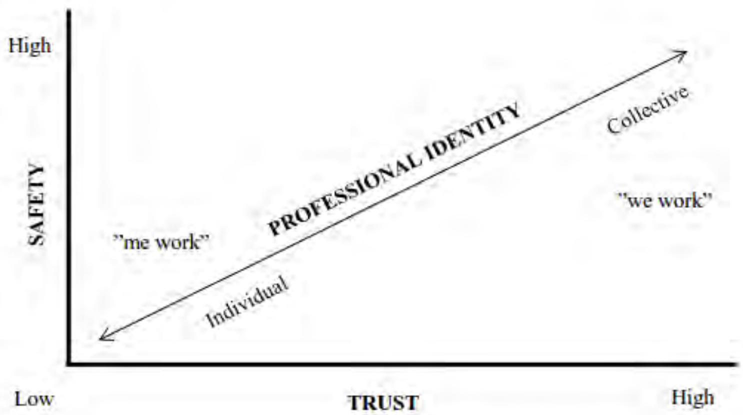

Figure 1: Relations between experiences of safety, trust and professional identity

It seems that during the change process of an academic workplace the experiences of individual workers can fluctuate in the continuums of experiencing low trust to experiencing high trust as well as experiencing low safety to high safety. The trust (e.g. experience of being heard and valued) is not only experienced at an individual level but it is a shared feature – what you hear and assume others to think and behave moulds also subjective experiences. Further, experience of safety seems to be attached to relational factors, how and to what degree an individual expects he or she is able to preserve ones privacy as well as factors connecting with ownership to ones' work and various personal things. Experience of low trust and low safety can be erupted into high defensive emotionalism. Moreover this can have a link to the fear of low productivity which emphasis is apparent in an academic work. At the same time, the professional identity can be seen either more individual or collective or the desire to be more one or the other remains either quite stable or varies depending e.g. on the new placement and its possibilities. Experience of high trust and high safety can predict desire to work more collectively.

5. Discussion

In the workplace change process it is very culturally sensitive both to express and interpret who knows "best" the needs of users and therefore it is a very complex phenomenon. In the transition phase and especially just before the concrete change – in our case before moving into a new building – the suspicious and defensive projection tend to be overpowering compared with supportive and trusting projection. However, being aware of this emphasis attempts to improve the working culture needs those who lead the way of change, otherwise remaining in the comfort zone is too tempting. The transition from customary or traditional work culture towards something new is not easy and it is crucial to understand how users are able to make the sense of the change (Bean and Eisenberg, 2006, 210). Employees' expectancies and prejudices tend to colour their mental image of forthcoming work space (whether physical, social or virtual in nature), have an impact on motivation and wellbeing and therefore non-instrumental, especially social needs must be better understood, defined and operationalized (e.g. Airo, 2014; Kojo and Nenonen, 2012; Hassenzahl and Tractinsky, 2006). During the change process it can be considered if a place and perspective of social usability can be understood as an interactive product: interactive processes should be planned carefully both before, during and after the workplace change.

We need to notice that an academic community is naturally accustomed to influencing its professional field but is much less so when concerning factors beyond that field. Keeping this in mind, we must note that the arena of influencing the built environment that should reflect your professional expertise is a new one. Therefore, an academic community may at first have problems influencing these environments in an expedient manner. Partly the agents of change exist inside the working community, but for the most part the need for change is displayed by built environment professionals, employer and the owner of the property. In academic settings there is a long tradition to be or to move in ready-built environments. Nevertheless when there is a possibility to influence not only in ones' professional field but also in the built environment which should reflect your professional expertise it is a new arena to express the expertise. Therefore understanding the processes building mutual trust are crucial.

6. Conclusions

The results revealed several supportive and defensive tensions relating to the perspective of social usability during the change process of an academic workplace. Eventually, the experience of trust and safety and the perception of being heard and valued during the change process seem to be essential.

Experiences of trust and safety mirror the satisfaction among the users and support the trend that more qualitative indicators are needed in real estate business (e.g. den Heijer, 2011; Kärnä et al, 2013).

End-user satisfaction is closely related to the individuals' experiences of relational factors attributed to communication and collaboration in the workplace (Airo, Rasila and Nenonen, 2012; Kivimäki et al, 2000) and especially in workplace change processes (Laframboise, Nelson and Schmaltz, 2003; Qian and Daniels, 2008). Further, experience of trust and safety can enhance the collective professional identity, which is seen to support the skills and attitudes needed in the 21st century. In all, research-based knowledge and deeper understanding about the processes building mutual trust are crucial.

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Review of end users' role in facility management in university environment. A basis for a complementary approach to enhance interaction between end users and professionals

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Abstract

The aim of this literature review is to explore ground for including institutional and socially constructed understanding of the end users' role in facility management processes. This is applicable especially in strongly institutional settings, such as universities.

In facility management of universities, economic efficiency and effectiveness, such as utilization rates and appropriate use of premises, is a recognized object for development. The usual attempts are to survey end users' needs and satisfaction, or to establish interactive bodies and processes between facility management, organizational management and the end users. However, the interaction between the facility managers and the end users is still a challenge.

This research is carried out by a literature review of current study about the role of end users in facility management. The literature review is focused on university buildings' internal end user groups, students and staff, but includes a wider overview of service buildings in general.

First, previous study shows needs for development and implementation of practical methods of interaction between facility management and end users. Secondly, there is a lack of recognizing the need for inclusion of end users in the everyday practices. Thirdly, there is an insufficient understanding of the end users as definitive stakeholders, that have their own concepts and understanding of the facilities they work and study in. Fourthly, in dynamic university campus environments, the connection between the facility management and its' added value function in academic outcomes is recognized, but hard to measure.

Since facility management can be defined as a type of workplace management, a different interpretation of the environment should be considered on the side of the technical and the service-business-oriented view. Socially constructed understanding of the institutional settings is already a common approach in the field of organizational studies. This approach can facilitate interaction and improved understanding between the professionals and the end users. Higher level of mutual understanding can contribute to the value adding function of the facility management.

Keywords: end user, facility management, interaction, university

1. Introduction

The aim of this literature review is to explore ground for including institutional and socially constructed understanding of the end users role as stakeholders in facility management processes. This is applicable especially in strongly institutional settings, such as universities. The literature review concentrates on current research papers on the end users' role in facility management.

Chapter two presents end users' role in whole cycle of construction design and use. The objective is to find out how end user involvement in this cycle is presented in the literature. Facility management has a value adding function for the core operation. The end user is one key actor for this value adding function.

Chapter three reviews current research of end user role in facility management in university environment. Research of the subject can be divided in two groups: first the research concerning end user satisfaction, and secondly the research concerning campus management processes.

Chapter four reviews research papers concerning current practice in the facility management research, as well as a few recent academic openings that aim for understanding users' original definitions in the field of facility management.

Chapter five discusses the findings and introduces the idea of socially constructed and institutional understanding as a complementary approach in the field of facility management research. Chapter six present conclusions of this literature review.

2. End users' role and involvement in facility management

2.1 End users in design and using phases

In facility management of service buildings, economic efficiency and effectiveness, such as utilization rates and appropriate use based on core functions and individual and social needs, are often a challenge. The practical developmental actions are for example to survey end users' needs and satisfaction, or to establish interactive bodies or processes between the professional facility management, the user organization management and the end users. The common factor between these different tools is the need to increase interaction. However, often not the whole process from design to actual end use is covered. The using phase and the actual outcome of the design process is not necessary the object of concern. (Hansson et al. 2010, 37.)

In Scandinavian countries, based on the democratic welfare-state-ideology, hearing of citizens is a part of official processes in land use and urban planning. In the house building industry this is not regulated and thus not a practice. However, in the design phase of buildings, end users seem to be involved increasingly. Reasons for this are both practical and political. There is a genuine need to obtain information as the base for technical solutions. Another reason is to overcome differences in values and interests, as well as resistance for change, to reach commitment of the parties involved (Pemsel et al. 2010, 24). Literature presents a number of different methods to include end users in a design process. It is still uncertain, how well these methods are used, and also, how well they can be adopted in real life projects (Pemsel et al. 2010, 24; Hansson et al. 2010, 37). Many of the methods are also criticized for not offering guidance for how to act upon the outcome from the method (Hansson et al. 2010, 13). Different methods tend to seek increasing communication between the stakeholders, and to improve the understanding of end users' real needs and requirements. However, they are built on quite complex systems and based on data gathering and analysis (ibid.) Methods seem to be built on professional base of knowledge and concepts of the industry.

In previous research about end user inclusion in both public building projects, as well as in private office building environment, the writers argue that a traditional cost-based property management doesn't still acknowledge end users' level of awareness of for example sustainability factors or long-term maintenance cost (Nousiainen & Junnila 2008, 275; Wihlborg & Laurell 2011). In public building projects end user inclusion in the process in early states benefits society's cohesion and decision-making processes (Wihlborg & Laurell 2011, 367). End users knowhow and interest seems to be underestimated.

Social and cultural barriers between the professionals and the end users cause communication failure and hinder the effectiveness of the planning tools used, even though some methods are based on interaction (Pemsel et al. 2010, 25). The end users are still seen merely an obstacle, than a stakeholder of great importance in design phase, which causes setbacks and conflicts in hand-over phase (Lehtiranta 2015, 571). Understanding operational performance of the project should be a combination of technical focus in construction and emotional basis of customer experience (ibid. 573–574). There is a need for a better understanding of issues like cultural and social habits and highlight the importance of putting effort into ensuring a productive and trustful relationship and communication among all participants (Pemsel et al. 2010).

2.2. Value adding function of facility management

Few tools that concentrate on the end users, even though used in design phase of construction projects, cover the whole cycle and different phases from the user point of view (Hansson et al. 2010; Lehtiranta 2015). In using phase of the building, the professional body present is the facility manager. Facility management should have an elementary relationship with the strategic core of the operation, since it organizes and maintains the whole physical environment of peoples' work and other operative actions (Barrett 2000). Even though design phase has major impact on the quality and functionality, few decisions are totally irreversible (Finch 1992). Facility manager is in key position to make adjustments, both in risk management as well as to improve functionality, safety, aesthetics and overall satisfaction of end users.

Based on the strategic positioning of facility management, with relation to the core functions of the organization and operational core, facility management should be suited to the environmental characteristics rather than adopting a universal best practice (Chotipanich 2004, 367; 371). Both internal and external factors should be considered in the management practices (ibid.). This is due to the understanding of facility management as a strategic and a value adding function to the core operations, rather than just a cost factor (Anker Jensen 2010). Conceptualizing the value adding impacts, four different stakeholders for added value for the organization can be defined: society, customers, staff and owners (ibid. 182). It is also important, that facility management professionals are capable of explaining the benefits of their actions to their clients, customers and end users of the services they provide (ibid. 186). Facility management should be acknowledged as relationship management. The value of the function is produced in these relationships and is subjectively dependent of the other parties' experiences. So it is important to take into account the views and interests of different stakeholders, including the significant groups of end users in the facilities. (Anker Jensen et al. 2012, 211–212.)

This paper is concentrating on internal end users in university facilities, which are students, academic staff and administrative staff. By an end user in facility management can be meant "a person receiving facility services" (Coenen & Kok 2013, 343). In public buildings, like universities, where there are a groups of everyday end users, like staff or students, as well as groups of persons that receive facility services on more random base, such as visitors, this should be more focused. End user can be defined as a person within the core organization receiving facility services. The ideas about added value by facility management (Anker Jensen 2010; Anker Jensen et al. 2012) are based on this grouping, dividing internal (staff, students) and external (visitors) dimensions.

Facility management is in charge of organizing the physical settings for the operational needs of end users. In addition to physical needs, the purpose of the facilities is also to provide for a social setting where people meet and interact. The physical setting provides cues for social situations and communicates meanings. Thus, facilities management can create value for organization by setting the physical environment according to organizational goals and desired behaviour by the end users. (Coenen & Kok 2013, 345.) For that, not only organizational goals, but also actual personal understanding of the facilities functions are required. Cross-functional cooperation between different end user groups and facility management can create balanced setting for the operation, as well as help the facility management in their service function (Kok et al. 2015).

Considering end users as a significant factor in a facility management process can influence both the satisfaction of the end user, as well as their actions, in a profitable way (Junnila 2007; Awg Husaini & Tabassi 2014). The end users should be involved in the process of shaping their workplace environment. People occupy workplace as their territory. If they are involved in the processes of management and maintenance of that physical setting, they will commit themselves also to changes required. (Kaya 2004, 251.) Too often in practice the appearance of the facility management happens and is interpreted as a sudden, uninformed and unwanted change by the end users. This causes non-communication and misunderstanding. (Rayle 2006, 54.) If the end user responses were understood better, it would be much easier to develop effective and efficient processes (Rasila & Gersberg 2007). If changes are planned together beforehand, stress could be decreased and changes carried out with less time and resources.

Even though the end user involvement is considered in some tools of design the whole process and using phase is left out for less attention (Hansson et al. 2010). Based on the idea of facility management as strategic and value adding function for the core operation (Anker Jensen 2010; Anker Jensen et al. 2012; Valen & Olsson 2012; Coenen & Kok 2013), there is a need for further development of assessment tools that include the evaluation of added value and how the user experience the buildings (Valen & Olsson 2012, 298–299).

3. End users and facility management in universities

3.1 End user satisfaction

In university environment, research seems to concentrate especially on students' comfort and satisfaction. Student surveys about facilities' technical quality and functioning show that the students do understand and articulate such concepts as sustainability (Nousiainen & Junnila 2008; Lehtiranta 2015).The aim is to point out the significance of end users as stakeholders in process of sustainable facility management (Hebert & Chaney 2012, 469). A survey applying customer satisfaction model to the research on campus facility management showed that both students and university staff emphasize overall appearance, tidiness, as well as safety. Indoor air quality is also an essential factor for satisfaction. (Kärnä, Julin & Nenonen, 2013.)

About space use and learning environment, students see informal settings and ad hoc spaces for learning important on the side of the formal learning environments and situations. Technology access, as well as collaborative space are important for students. (McLaughlin& Faulkner 2012, 148.) The most effective strategy to improve student satisfaction with the space management would be the emphasis on the social areas, such as auditoriums and libraries (Hanssen & Solvoll 2015). Also, facilities, as physical environment, seem to have some impact on student choice of university (Price et al. 2003).

There are differences between students and staff satisfaction factors. Public spaces and campus accessibility are in an essential role for the students. For academic staff, factors related to teaching and research facilities have the main contribution to the satisfaction. (Kärnä & Julin 2015.) For research staff, possibility to carry on working without interruptions caused by moving or other facility changes seems to be of importance (Hebert 2012). Considering the ongoing pedagogical change and virtual access requirements in the universities, expectations of the end users are that physical and virtual access is flexible and that facilities will reflect what is available in other aspects of students' lives socially, professionally and personally (Todhunter 2015).

However, it seems that the articulation of the needs and key issues addressed to the facilities, by the individual end users, is not clear. There are different views between individuals, and there is not necessary a clear and common articulation of organizational visions and strategies, as well as pedagogical approaches, to lean on. (Todhunter 2015.) There can also be a lack of recognizing facilities as strategic issue in organizational level, usually caused by lack of information and representation, or by managements' viewpoint of facilities as operational cost rather than strategic issue (Kamarazaly et al. 2013, 143).

3.2 Campus management

Campuses are physical working and studying environments that are arenas of interaction between different groups, as well as objects for a constant change. Therefore, a process perspective including both internal and external influences has to be considered. Social, physical and virtual facilitation should thus be seen as a systemic entity. Rather than seeing the campus as a set of stable facilities, the emphasis should be on managing flows and communities. (Rytkönen 2015.) There is a demand for a holistic approach for facility management to create learning environments of today (Rytkönen et al. 2015).

This holistic approach sets pressure to new methodologies and approaches involving end users as stakeholders in university environment, in addition to surveys and interviews, such as referred previously in this chapter. One approach could be to include experience-oriented methods that look the facilities also from the user's perspective from both technical, social and virtual viewpoints. (Rasila et al. 2009.) Another suggestion is to implement future-oriented modelling tool, which can provide a systematic and a collaborative design approach (Rytkönen & Nenonen 2014).

The added value structures of facility management are space quality, efficiency and utilization, quality of education and research, as well as collaboration-competition aspect (Rytkönen & Nenonen 2014, 148). This suggest that facility management has influence upon academic achievement (Kok et al. 2011, 260). The added value of facility management in educational environment can be conceptualized by defining facility services and coordination as settings, knowledge transfer as process and educational achievement as an outcome (ibid. 256). However, the route from optimizing facility services (the settings) the best way, to achieve the best possible academic achievement (the outcome), is still unclear. Subsequent research is required on the subject. (ibid. 259-260.)

4. Challenges in facility management research

The specific object of facility management defines it as a service business that has focus on workplaces and their management (Tay et al. 2001, 361; Jughans & Olsson 2014). According to a review of academic research of facility management (2007), researchers emphasize the need for valid quantitative data analysis techniques, as well as rigorously conducted qualitative research. It is also suggested that in order to develop, the field of facility management should exploit both approaches and theories of such fields as social science and human resource management. (Ventovuori et al. 2007, 235–236.) Within the Nordic countries, the main trends and development challenges in the field of facility management seem to differ significantly between the four countries (Anker Jensen et al. 2014). In Finland, the facility management research is influenced by the recent innovation policy that emphasizes the needs of customers in product and service development, the systematic use of economic incentives, as well as the participation of end-users in the innovation process (Nenonen & Sarasoja 2014, 65). In a Swiss research is was stated that, from the value adding point of view, more empirical evidence of economical, ecological and social aspects is required to develop facility management further (Windlinger et al. 2014).

A few researchers have approached towards qualitative and socially constructed understanding of facilities, in terms how people define the change in the physical environment in discourse (Airo et al. 2012.) There is no clear difference whether the space people discussed about was actually physical or symbolic, but it is stated that the method of discourse analysis could be more widely used in the field of facilities management. (ibid. 299.) The methods of narrative and discourse analysis are not very widely used in research of general workplace management. The use of linguistic methodology could help to reach a holistic way of studying and developing workplaces. (Airo & Nenonen 2014.)

The concept of space in the field of organizational studies and the facilities' role in workplace management can be approached in the light of organizational creativity. The way of organizing the physical space plays a significant role in the emergence of organisational creativity. As a concept, aspects related to physical space and the organisational culture are brought together. (Kallio et al. 2015.)

Engineering and management, in terms of both research and practice, tend to lean towards procedural concepts and leave declarative approach for a smaller emphasis. On the other hand, from the end user's point of view, the challenge is to understand why something is done and what the consequences are. The importance of qualitative data and approach is also important to reach such taxonomic and ontological concepts that can reach this declarative dimension, in addition to the procedural (Rasila et al. 2010; Che Hassan 2013, 111).

5. Discussion: Opening for an institutional approach

There is evidence of social and cultural barriers and communication failure between the professionals and the end users (Pemsel et al 2010; Hansson 2010). There are also challenges with the tools used in these processes. Tools and practices, as well as the recognition of the importance of the end users, seldom reach beyond the design process into using phase of the buildings (Pemsel el. al 2010, 24; Nousiainen & Junnila 2008; Hansson et. al 2010; Lehtiranta 2015). Thus, the first challenge of recognizing end users in the field of facility management is the lack and applicability of suitable tools of interaction between the professionals and the end users.

The value adding function of facility management understands end users' significance for the process. End users can be defined by terms of external (for example clients) or internal (for example staff or students). (Chotipanich 2004; Junnila 2007; Anker Jensen 2010; Anker Jensen et al. 2012; Coenen & Kok 2013; Awg Husaini & Tabassi 2014; Kok et al. 2015.) Still, there are challenges of how well the end users are included and informed for example in projects of change. Thus, lack of commitment from the end user side occurs (Kaya 2004; Rayle 2006; Rasila & Gersberg 2007). The second challenge is the real inclusion of the end users in everyday practice. This could also be seen as a consequence of the first challenge.

End users in university environments are often considered as customers, whose satisfaction factors are surveyed and interviewed in order to develop service practices (Price et al. 2003; Hebert & Chaney 2012; McLaughlin& Faulkner 2012; Kärnä, Julin & Nenonen 2013; Hanssen & Solvoll 2015; Kärnä & Julin 2015; Todhunter 2015). There are also openings towards more explanatory, individualizing research (e.g. Hebert 2012; Todhunter 2015). The third challenge is the still insufficient understanding of the end users as definitive stakeholders, that have their own concepts and understanding of the facilities they work and study in.

There is a lean towards a holistic approach to campus management practices, due to dynamic aspects of todays' campuses (Rasila et al. 2009; Kok et al. 2011; Rytkönen & Nenonen 2014; Rytkönen 2015; Rytkönen et al. 2015). The roots of this holistic view about university campuses are also in the pedagogical field. The connection between the facilities and the academic outcomes, in terms of added value, is recognized, but not easily measurable. The fourth challenge is the difficulty to show the complicated structures between the physical environment and actual efficacy in academic outcomes.

Mainly due to the value adding function, field of facility management is recognized as a type of workplace management (Tay et al. 2001; Ventovuori et al. 2007; Jughans & Olsson 2014; Nenonen & Sarasoja 2014; Windlinger et al. 2014). Workplace management can also be attached to the field of organizational studies. There is a recognized understanding of organizations and workplaces in a cultural and institutional context, together with other approaches (e.g. Morgan 2006; Hatch & Cunliffe 2006; Czarniawska 2008). Having facility management understood as workplace management, some recent attempts to approach that tradition of social constructionism (Berger & Luckmann 1966) are to be found (Rasila et al 2010; Airo et al 2012; Che Hassan 2013; Airo & Nenonen 2014; Kallio et al. 2015). However, based on both the writers' own statements, as well as the theoretical frames used in the articles, these studies are merely testing and exploring the cultural and constructionist aspect in the field of facility management, rather than applying the cultural and socially constructed frame in the research as such.

There is also an indisputable understanding of universities as strongly institutional organizations (e.g. Millett 1962; Weick 1976; Brubacher 1978; Becher & Trowler 2001). As such, they are built on regulative, normative and cultural-cognitive basic framework (Scott 2008). By definition, this means that institutional setting and these basic structures direct the actions and reasoning of the people working and studying in them (Berger & Luckmann 1966, Weick 1995; Czarniawska 2008).

The challenges and recognized state of the art in facility management found in the literature suggest that opening the door wider for cultural and institutional based understanding in the field of facility management could be an additional new approach. Exploring this possibility could help with the challenges of interaction between the facility management professionals and the end users.

6. Conclusions

Four different challenges that cause problems in end user and professional facility management interaction were defined based on literature research. First, lack and applicability of suitable tools of interaction between professionals and common users. Second, mistakes in understanding of end users as occupants in their own territory that have also knowledge of their physical surroundings, and lack of recognizing the need for inclusion and interaction in the processes. This can be caused by the lack of tools. Third, still insufficient understanding of the end users as definitive stakeholders, that have their own concepts and understanding of the facilities they work and study in. Fourth, in dynamic environment, such as university campuses, the connection between the physical environment and its' value adding function for academic outcomes is hard to measure and show.

Studies of the facility management show the nature of the discipline as a branch of workplace management. In addition to widely implemented approach of service process development, there could be other directions of organizational management research applied. Some recent attempts have been taken towards cultural and socially constructed understanding of facilities as space for social interaction. Exploring this approach in future research could give a new insight and ideas to the development of interaction and interactive tools between the professional facility managers and the end users. As strongly institutional environments, universities would be a fruitful ground to start to conduct such research.

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Spatial borders and affordances of a temporary school building – Enhancing the school engagement and learning experience

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Abstract

In the recent years several Finnish school buildings are facing renovation needs, which force municipalities to relocate the activities of schools to temporary facilities. Often the problem is solved with container schools. The usage of the temporal space may last for several years, therefore it is essential to design them as functional as possible. Furthermore, the temporary settings can provide a platform to develop new knowledge practices and promote school engagement.

The aim of this paper is to identify the spatial borders and affordances, which affect school engagement and learning experience in temporary container school. This is examined in a case of a temporary upper school facilities. The spatial effects on school engagement and learning experience of pupils were researched by mixed method -approach, which included survey, four workshops and a user journey observation with the employees and the pupils of the school. The result were analyzed with FOA-framework consisting of three components of flexibility, ownership and accessibility of space.

Spatial borders and affordances from the perspective of the school engagement were identified and labelled under the major components. The results of this study can be directly utilized in the design of future type temporary school concept but also in designing complete new school buildings.

Keywords: Learning Environment; School Engagement, Learning Experience

1. Introduction

In Nordic countries the school buildings are in desperate need of renovation. Temporary facilities are used in order to maintain the basic education standards. While the actual building stock is going through extensive rebuilding, the pedagogical needs are faced in temporary facilities.

Simultaneously the emphasis of primary education is shifting from teacher-centred education, towards inquiry-based and student-centered forms of learning (Kumpulainen et al, 2010; Litmanen et al., 2012; Lonka, 2012; Lonka, 2015). Accordingly learning processes have become more collaborative and activating including a variety of different forms of working and ICT-based knowledge practices (Hakkarainen, 2009; Lonka, 2015). This puts the traditional and rigid learning environments truly under test. The contemporary learning activities challenge the physical learning environments by knocking on the doors and bouncing from wall to wall (Lonka et al, 2013).

While the new views on education are faced in the old premises of school, a clash of cultures are about to take place. As the renovation of old facilities forces the users of school to relocate to temporary premises, an opportunity to test different kinds of spatial solutions emerges. This provokes the question: what kinds of spatial solutions enhance the new needs of learning and teaching?

In this paper the effects of temporary spatial solutions to school engagement and learning experience are investigated. The following questions are asked

1. What is the role of temporary space in learning experience
2. How does the spatial design effect to school engagement
3. What kind of spatial solutions enforce the positive learning experience and school engagement.

The results of this paper give insights to the design of future type temporary school concept but also in designing complete new school buildings, which enhance the new ways of learning.

2. School Engagement and Learning Experience

Despite the flattering PISA-results in Finland (OECD, 2013), there seems to be a worrying lack of school engagement and positive learning experience. Latest research indicates, for instance, that school exhaustion (Salmela-Aro & Tynkkynen, 2012) and school-related cynicism and inadequacy has increased among students on an academic track (Salmela-Aro et al, 2008). Furthermore, in the latest measurement by OECD (2013) the students' school engagement in Finland fell exceedingly beneath the OECD average. This is one crucial factor why improving learning methods and environments are topical as they can promote pupils' motivation and wellbeing.

The concept of school engagement can be defined in three ways: to behavioral, emotional and cognitive. The behavioral engagement draws on the idea of participation; it includes involvement in academic and social or extracurricular activities and is considered crucial for achieving positive outcomes. Emotional engagement encompasses positive and negative reactions to social sphere, school and is presumed to create ties to an institution and influence willingness to do the work. Cognitive engagement draws on the idea of investment; it incorporates willingness to exert the effort necessary to comprehend complex ideas and master difficult skills. (Fredricks et al, 2004).

As Fredricks et al claim the engagement is seen more of a mental issue. Its' connection to physical space and the experience of space is still an unknown territory. However the school engagement and learning experience are connected not just to social but also to physical gathering of things. (Airo, 2014). Wang and Holcombe (2010) state that adolescents' school engagement can be seen as school participation, school identification and use of self-regulation strategies. In this research particularly the school identification is discussed in connection to spatial attributes of learning environments.

Measuring actual learning and experienced learning can differ. However there is a body of evidence that relationship of the two is positively correlating. It is stated that learning is enhanced through active involvement in personally meaningful experiences accompanied by processing for meaning and future use (Luckner, et al 1997).

3. Learning Environments

Learning environment is a wide concept that consists of multiple dimensions from which the context of learning emerges. Usually at least three dimensions are acknowledged: physical-, social- and digital (Lodge, 2007; Nuikkinen, 2009; Piispanen, 2008). Also cultural and pedagogical dimensions are mentioned (Manninen, 2007; Kuuskorpi, 2012). However, it's not about how we divide the concept in pieces but how we form a functional and engaging unity out of these dimensions, so that the surroundings and its multidimensional affordances really promote 21st century learning. In addition, the school's organizational culture and leadership practices plays a huge role in pushing the educational practices toward 21st learning and thus utilizing the corresponding learning environments (Vaara, 2014). Furthermore, this cultural shift also set its own demands on learning environments: new co-working and communal practices require more informal and flexible spaces to foster straightforward collaboration (Vaara, 2014).

Self-determination theory (SDT) assumes that the degree to which students perceive that the school context meets those psychological needs determines the level of students' engagement in school (Wang, 2010). In this sense the perceived school environment also in physical sense, would enhance their engagement to school and learning experience. In addition the physical design of the school has been seen both as an enabler and prohibiter in pupils learning process.

Physical school environment also reflects the policies of governments' pedagogical views. They are political and public places, which often lack private rooms and enclosed space for pupils. It has been quite critically stated that sometimes school buildings resemble hospitals, factories or even prisons, in which the individual does not have a freedom for privacy or individuality.
(Vuorikoski & Kiilakoski 2005, 312–313.) In addition the traditional classroom represents hierarchy between teachers and pupils. Teacher is allowed to move and control the space, whereas the pupils are forced to sit still (Gordon 1999, 106–107.).

School and learning environments are not just restricted to internal spaces. Also the yard and network of learning places can be seen part of the learning environment. School is often separated from the other cityscape by fences etc. The aesthetics of the external spaces have been seen as important part of the pupils' wellbeing. However they often contradict with safety regulations and ideals, which would acknowledge the needs and behavior of young pupils (Gellin et al, 2012, 143).

In this paper the school engagement, learning experience and learning environments are defined always in relation to the spatial design and its' features. The actual learning outcomes are not discussed. Neither is the overall school experience other than its relation to the temporary school facilities.

4. Flexibility, Ownership and Accessibility of school environment

The school engagement and the learning experience in temporary school facilities was investigated with a so called FOA - framework, in which the concepts of flexibility, ownership and accessibility of space were used to both gather and to analyze the data. Flexibility of space refers to the range of usage of the space. That is how well does the space alter to variety of usage. The ownership refers to identity of the space. In other words, how well do end-users, the staff and pupils identify with their school and how much they have a freedom of using it. Accessibility refers to usability and comprehensiveness of the school building and infra.

The FOA-framework was derived from literature focused especially to the research of usability of built environment. The researchers argue that usability as a core concept for managing organisational ecology (Alexander et al 2013). It is stated that usability is a cultural phenomenon that can only be improved through a better understanding user experience, considered as situated action in a specific context" (Alexander, 2008). A building's performance can never be seen or understood in isolation from an organisational and technical perspective.

Alexander (2010) argues that school facilities should be considered in the context of the communities they serve and as a prime means of transforming education. Effective learning environments successfully combine appropriate social and digital environments with the physical environment (Beard, 2012). Creating quality learning environments, which are more broadly accessible in the community, can also play a catalytic role in regeneration.

Usability evaluations are based on different user's experiences and assessments on how well the buildings perform regarding different parameters. The dutch standard NEN 8021:2014 (Valuation of User Requirements and Performance of Non-Residential Buildings) defines nine usability criteria: which are comfort, safety, sustainability, flexibility, use of space, representativity, services and accessibility. NEN 8021 helps both the users to determine their needs and wishes regarding the building and also helps providers to compare their products to it (Anon 2014).

In this study the concepts of usability defined by NEN8021 were applied in forming the FOA-framework by focusing in flexibility including the use of space, representative especially from the perspective of ownership of the space and accessibility. The other criteria like comfort and safety where also discussed but the three parameters were the most significant for this research.

The flexibility, ownership and accessibility i.e. FOA-framework was applied in analyzing both quantitative and qualitative information. That is, the discussions, answers and observations were placed in the thematical FOA-framework. In addition the different kind of data (qualitative and quantitative) were cross analyzed in a matter of how they correlated or differed. In addition it was looked are they any extra data, which would differ from the original FOA-concept.

5. The Methods

The temporary School environment was investigated with mix-method approach, that is both qualitative and quantitative methods and data were utilized. The qualitative methods included four workshops and a user journey observation.

Self-report questionnaire

To map the prerequisite for the co-creative learning environment intervention a preliminary self-reported questionnaire was conducted among all seventh graders of the school (n =100). The seventh grade was chosen, because of potential follow up-measurements in close future, since the seventh graders would stay at the school for two further years and therefore also experience the school's transfer to the new school building in fall 2016. For this purpose a questionnaire including 22 statements about the conceptions on learning environment and school work was prepared by applying partly statements used in the self-report questionnaire of the Mind the Gap Between Digital Natives and Educational Practices -project (2013-2016) funded by the Academy of Finland (Mind the Gap, 2014, Hietajärvi, 2014).

However, more specific statements concerning learning environments were invented and added to the original Mind the Gap *How do you experience your school and schoolwork?* –instrument, which was a learning environment centered section in the self-report questionnaire. This decision was made, because the orginal Mind the Gap instrument included only a few more general statements about learning invironments, for example *my school feels safe* and *the learning environment of my school feels comfortable*. Therefore, more precise statements concerning physical learning environments were added, for example *my school building is comfortable from the inside* and *the spaces of my school help me to focus on the current task*. Furthermore, the statements in the questionnaire were set in an order that would reflect the daily cycle of pupils' school experiences, by starting with statements about entering the school area, then proceeding to the interior design of the school building and finally to more general school experiences (see table 1).

This so formed Flexible Learning Spaces-instrument (see table 1) was then set in a 5-point Likert-type scale. The statements were set in an order that's in line with the users' daily cycle of observations: starting with statements about entering the school environment, proceeding to the inner surrounding, first in more general and then in more specific, and then measuring the users' overall conception about their school.

User journey-observation

Part of the qualitative data was gathered with user journey observation. Observation tells something about the things that people actually do, not what they think they do. Conceptualizing of a space is based on user actions and researcher's interpretation. Spaces as such are not conceptual entities but they become one when combined with human reasoning and action (Lefebvre, 1974). Thus both the users, their actions and the space were observed.

The actual observation was based on Dale Cobb's (2008) customer journey framework. The idea of Dale Cobb's customer journey was originally an idea of a conceptual journey becoming a customer. Observation applied a model of the different concrete "journeys" users make in the building and in the space. The researchers observed the school building and the yard by all the functions that took place in school such as entering school, acting in breaks, eating in cafeteria and being in the class room. The observations were conducted both from the teachers and from the pupils' point of view. This was done by walking first with the teachers throughout the school facilities. The pupils' perspective was first investigated in workshops and later with taking the observation walkthroughs with the pupils.

Workshops

During the project four workshops were arranged: the first workshop focused on user experience about existing physical spaces and surroundings of the school and the thus collected data were then combined with results of the user-journey observation. Later one workshop was then arranged to participate the users, both pupils and teacher, into the design process of a new engaging learning space which was supposed to demonstrate the key findings and principles of the project and offer a testbed for the school to adopt new educational practices to foster 21st learning. In this later workshop pupils sketched preliminary spatial layouts which were then reviewed and improved by the teachers and researchers.

Additionally two workshops were executed to introduce new digital solutions to the pupils and teachers. The aim of these workshops was to foster the integration of ICT into the learning environment and learning processes, which is an important factor in 21st century learning. Furthermore, it was to make sure that the new devices provided by the project would successfully blend into the daily practices performed especially in the new learning space.

6. The Results

The aim of this paper was to identify the spatial borders and affordances, which affect school engagement and learning experience in temporary container school. Based on mix-method approach following key results can be identified.

The results of the self-report questionnaire indicates that the physical learning environment in the temporary school settings are not experienced by the users as comfortable or engaging (see table 1, 8.2, 8.3, 8.4). However, the results indicate that the overall working culture and communality is seen as rather engaging and positive (table 1, 8.11, 8.17,). The pupils also felt the overall school environment safe (table 1, 8.1.). Furhermore, the results show that the pupils experienced their work at school as activating, collaborative and the teachers' guidance supportive (table 1, 8.9, 8.12, 8.14). In all, the pupils considered the role of their working environment as significant (table 1, 8.16).

Table 1. Results of the self-report questionnaire.

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
a8.1 My school area feels safe	100	1,0	5,0	4,070	,9239
a8.2 My school yard is comfortable.	98	1,0	5,0	2,357	1,1238
a8.3 My school building is comfortable from the outside.	99	1,0	5,0	2,242	1,0888
a8.4 My school buiding is comfortable from the inside.	99	1,0	5,0	2,697	1,1469
a8.5 The spaces of my school foster collaboration.	98	1,0	5,0	2,592	1,0633
a8.6 The spaces of my school foster my own learning.	99	1,0	5,0	2,828	1,0977
a8.7 The spaces of my school help me to focus on the current task.	99	1,0	5,0	2,626	1,2002
a8.8 The classrooms enable a variety of different working forms.	98	1,0	5,0	2,837	1,0619
a8.9 During the lessons the pupils have an active role.	99	1,0	5,0	3,667	1,0102
a8.10 It's peaceful during the lessons.	97	1,0	5,0	2,866	1,1513
a8.11 The pupils in my class enjoy being together.	97	1,0	5,0	4,041	,9345
a8.12 During the lessons the teachers encourage me to express my opinion.	99	1,0	5,0	3,636	,9944
a8.13 The teachers are interested in how I'm doing.	98	1,0	5,0	3,378	1,0890
a8.14 The teachers treat us pupils righteous.	99	2,0	5,0	4,051	,8497
a8.15 I feel that the school's ICT helps me to learn.	98	1,0	5,0	3,367	,9238
a8.16 The surrounding working environment plays a significance role.	97	1,0	5,0	4,021	1,1178
a8.17 There is a good atmosphere at our school.	98	2,0	5,0	3,816	,9454
a8.18 It's easy to work in my school.	99	1,0	5,0	3,667	,9476
a8.19 I feel my school's spaces as my own.	98	1,0	5,0	3,276	1,1468
a8.20 I know how I can influence the matters at my school.	97	1,0	5,0	3,278	1,0776
a8.21 I feel myself happy in this school.	99	1,0	5,0	3,717	1,0789
a8.22 I'm proud about my school.	98	1,0	5,0	3,367	1,1158
Valid N (listwise)	86				

6.1. Role of space in learning experience

The results of the qualitative approach complimented those of quantitative. Based on observation and workshops the effects of spatial attributes to learning experience were often concentrated to physical hindrances of the temporary container school.

> "The classrooms are noisy. It is impossible to listen the teacher, when it is raining and the water hits the ceiling so hard" Pupil 15 years.

The hindrances were mostly connected to audio, such as the noice of the rain, ventilation or to the light structures of the facility. It was also claimed that the trembling of the facility and its' vulnerability to external factors such as passing cars or slamming doors affected to concentration of the pupils.

It was not only the physical structures, but also the temporary gathering of the spaces that impacted to pupils overall spatial experience and behavior. Walls, visibility and access to different spaces affected for instance to the amount and grouping of students and teachers in certain places:

> " There is gasstation across the road. All the pupils are running there all the time. I can't see all the students all the time, since the yard does not have a shared area and the containers are sort of a labyrinth" Teacher

and

> "All the pupils are gathered in front of doors under the rain shelter, like penguins" pupil, 13 years.

These comments illustrate how certain corridors or lack of them affects to the way pupils are teached, managed and taken care of. Also they affect to the social order of the groups. Who is going where, who is the first in line, who has to stay out in the rain etc. Of course similar structures can be seen in every school building and built environment in general. However, the temporary schools this is rarely acknowledged.

6.2 Spatial effect to school engagement

Spatial design has both straightforward causal effects on engagement and indirect effects which are connected to overall experience of school building and wellbeing within the school. For instance dysfunctional basketball field may arouse constant discomfort of the students, which accumulates to misbehavior within the classroom.

> “ The older pupils govern the whole yard by playing basketball in the center. It is hard to cross the yard to other side without interfering the game and causing annoyance” pupil 13 years

On the other hand the common distress of the students and teacher unites them and enforces the engagement to the organization. In this sense it is challenging to separate the role of space in overall experience of the school.

> “ This is our school. This is the only memory I will have about my school, when I grow up. When I am an adult I don’t have my school anymore. I can’t say to my children that, there is the school, where your mom went to” Pupil, 14 years.

Based on these aforementioned findings the spatial design of the school building whether temporary or permanent solution should acknowledge the identity of the school by either creating new symbolic artefacts or bring old ones from previous premises.

> “We have this old counter, which is the designated place for 9 graders. My dad asked, do we still have. He also used to have it when he went to same school” Pupil 13 years

The temporal nature of the space affected to school engagement also by lack of certain key spaces such as gym hall.

> “we do not know where to go, if we have a party. We do not even have a gym hall. We always have to go somewhere else and it takes time” Pupil, 13 years.

In addition the fractured nature of container school in small and bigger perspective affects to time management within the school life. If pupils have to go far for eg. gym lessons, they do not have time to come back to next lessons, which generates pressure to curriculum plans.

7. Conclusion

The borders and affordances of temporary school facilities can be categorized in terms of flexibility, ownership and accessibility. Learning experience and school engagement is affected in following ways:

The temporary school facilities such as container schools are often ready made mass products, which lack the quality of the permanent school. On the other hand, as not being so fixed they can and especially should be adjustable to differing needs for learning.

The results of the preliminary self-report questionnaire also indicates that the positive and safe atmosphere and collaborative school culture, at least in the context of this study, could foster an experimental approach into co-creating new pedagogical practices and adjustable learning environment solutions to turn the otherwise non-engaging temporary environment into an engaging testing ground of new kind of learning.

The ownership of the temporary school is endangered by its temporary nature. As indicated in work shops it appeared that no-one cares to take responsibility of a school that is not permanent. On the other hand the shared experience of the temporarity strengthens the engagement to the community. The lack of quality in physical conditions contribute to school engagement and identity by bringing the staff members and pupils together. The accessibility of the container school is often overlooked, which creates unusable and almost dangerous situation in school yard. On the other hand the lack of internal spaces such as corridors, forces pupils to move and interact with each other and within the space.

Based on results it can be said, that whether in design of a temporary school or a permanent school following suggestions should take into consideration, when planning new learning environments: Facilities should be planned primarily in terms of functions they could gather avoiding for instance the setting of different disciplines. Utilization of gamification as part of the learning and working (eg. Avatars, listing their achievements, gathering experience points, immediate supportive feedback). The school can be a interface of learning in itself.

Sets of furniture are such that they can be easily grouped into different forms to support and control the gathering of spaces. This can be also supported with a rhythm of curtains and other movable space dividers between the various rooms. Private spaces should move towards public spaces: the user should feel intuitively the nature and purpose of the different spaces and is able to act accordingly. The building should be easy to expand, if necessary, outside the classrooms, eg. In the lobby, courtyard, or in some other open environment. Spaces are teaching platform in their self: for example, green walls, showrooms, solar panels.

The interaction between the users and the environment, strengthens the school engagement (eg. events, concerts). The border of a temporary school building is often a lack of communal space. This is a weakness in formulating the engagement. Various events increase ownership and promote the takeover of the operating culture and spaces. Creating a themed space with a variety of identities, which are suitable for different learning processes give the users feeling of freedom and creativity. The engagement can be supported artifacts which encompasses a certain meanings.

Users should be included in the design of new environments and be given the opportunity to customize their own environment. Projects made together: for example, the wall paintings as part of the arts exercises, school logo design contest. The ownership of the building encourage students to move out of the recess. The external space of courtyard is extremely important and should be acknowledged. The gathering of spaces guides also the gathering of groups and social order.

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Integrated learning for students in the Built Environment

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Abstract

The purpose of this study is to assess the transformation of integrated learning in one course related to the built environment. Research on college teaching and learning provide evidence active learning and collaboration is more effective than traditional lecture (Kuh, Kinzie, Schuh, & Witt, 2005; Pascarella & Terenzini, 2005). Applying this research to improve undergraduate education a transformation is occurring by incorporating more effective pedagogical techniques across disciplines. This paper will outline the changes which have been applied to one course that includes many different majors connected to the built environment. Data collected in this course and at the university will show if the integration changed the students' perception of learning climate, basic psychological needs or knowledge transfer. The results of this study will show the impact of the different elements of active learning in a classroom across disciplines.

Keywords: Assessment; Active Learning; Integrated Learning; Transforming learning

1. Transforming Education through Integrated Learning

Decades ago, King (1993) in his research, encouraged faculty to move from being a ‘‘sage on the stage’’ to more of a ‘‘guide on the side’’ in their teaching approaches. A university wide transformation program took this concept and applied current pedagogy to develop faculty training to change one course at a time. To improve higher education pedagogies, Instruction Matters – Purdue University Academic Course Transformations program (IMPACT) was based on research in pedagogy to improve student learning. The mission of the program is “to improve student competency and confidence through redesign of foundational courses by using research findings on a sound student-centered teaching and learning” (IMPACT Management,, 2014a,b,c). Through the development it was shown that redesign of courses needed to include innovation, implementation and assessment to be successful (Arthur & Zelda, 1987; Levesque-Bristol, Weaver, & Parker, 2012). The experts leading this initiative created tools for assessment based on The Self Determination Theory. This tool was used in all courses associated with IMPACT. One course that was transformed is an introductory course in the built environment (BCM10001). The transformation included the development of new learning outcomes, utilization of an active classroom and creation of active learning modules. Data collected over three semesters show the impact of the all courses at the university and the specific course related to learning climate, psychological needs and perceived knowledge transfer.

2. Review of Literature

2.1 Curriculum Development

Curriculum development was based on the research related to student success. One beginning set of tools includes the seven principles of good practice in undergraduate education by Chickering and Gamson, 1987. More current research includes the evidence of collaboration / team work and active, student-centered learning as increasing student success (Kuh, Kinzie, Schuh, & Witt, 2005; Pascarella & Terenzini, 2005). Blooms taxonomy was used to transform the learning outcomes into more students centered objectives (Anderson, L. W., Krathwohl, D. R., & Bloom, B. S. (2001).
John Dewey is believed to be the father of experimental learning and it is from his ideas that researchers have developed the self-determination theory (SDT). Each course transformation was unique, but it was important to have a common assessment tool. The experts leading the university wide curriculum researched leading publications and found the Ryan and Deci model was not only proven to be valid and reliable, but also aligned with their mission statement. This tool is utilized to measure students’ perception of learning climate, basic psychological needs and knowledge transfer (Ryan & Deci, 2000b). Self-determination theory has the potential to address learning problems such as student attrition in the active learning environment (Chen & Jang, 2010). As Neimiec and Ryan (2009) stated in their research, the STD higher learning can be improved by helping a student develop interest to want to learn because of interest in developing their own knowledge. This theory is based on the ideas that there is a need for autonomy (self-choice), the need for competence (mastery learning), and the need for relatedness (related to real world) (Ryan, Connell, & Deci, 1985). Figure 1 illustrates the concept of moving students towards self-determination and increasing

their intrinsic motivation to learn. The transformation of courses was based on this type of theory and as an assessment tool was developed to measure the effectiveness.

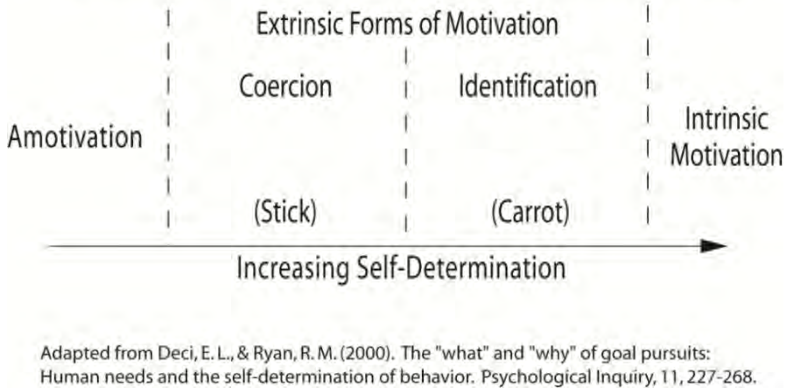


Figure 1: Continuum of Self Determination Theory

The goal of the project is to develop instructional pedagogy that engages students in learning activities that apply knowledge but also allows them to develop higher levels of cognitive learning. The activities create an engaged student that work at their own pace and continually grow as information is interpreted and applied to authentic interactions in the classroom (Grabinger & Dunlap, 1995; Prince, 2004).

2.2 Learning models

The IMPACT program was designed to utilize active learning through different course transformations techniques. There are three main models that were introduced to faculty to assist in their course transformation. The goal is to make a more student centered learning instead of the traditional lecture model where students listen and take notes during the entire class time. A supplemental model adds materials online which assists the students in applying the knowledge of the course. This could be videos over current events related to the class that assist the students in transferring the knowledge from the classroom to life. The idea is that when the students are in class, there can be activities integrated into the lecture to assist the students in applying knowledge and building cognitive skills.

The next method is the replacement model where parts of the lectures are replaced by online content to allow for more in class time for activities. Students come prepared for class and have reviewed materials which allow them to expand their participation in the class. The final method is known as the flipped method. This can be used for a fully online course or can be developed to eliminate the need for lectures and create a fully active student-centered teaching. For example, students read and do homework before coming to class and then review assignments in class instead of listening to a lecture that they were not prepared to hear. They read material and view videos on the assigned chapter before coming to class and then engage in active learning strategies such as debates on current issues during class (Gilboy, Heinerichs, Pazzaglia, & Chester, 2014). The idea that students must be self-motivated to learn before coming to class and that class time is used more for clarification of information. A hybrid model of this would be when some information is given in class like a mini lecture but still utilizes the class time more as a work period.

The supplemental model is the middle ground between the fully flipped and the traditional lecture. These types of pedagogical approaches have been utilized to transform classrooms.

Figure 2 illustrates the connection to active learning and the increase in student success measured by a lower Drop, Fail or Withdrawal (DFW) rates and increased GPA in courses. The ultimate goal is to increase retention and decrease time of degree completion to ultimately lower overall cost of education.

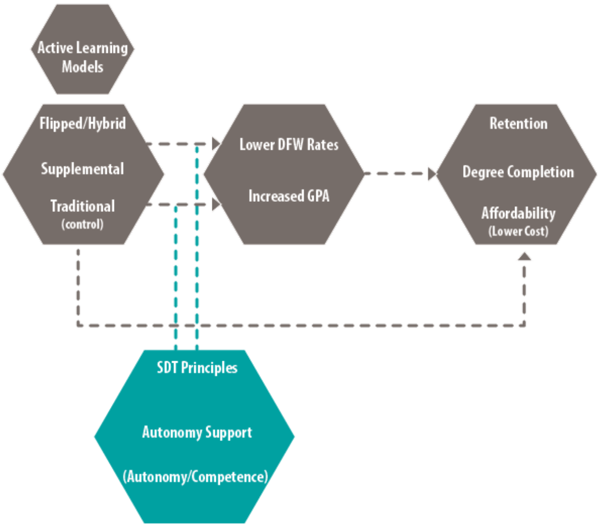


Figure 2: Active Learning Model Measurable Outcomes.

3. Specific Pedagogical Changes

The BCM10001 Introductory course was first transformed in spring 2013 with assessments collected in fall 2013, and spring and fall of 2014. The instructor has made the following changes to the course:

- Met in an active classroom with moving tables and chairs (shown in Figure 3)
- Developed an online textbook with pre and post tests for each chapter
- Implemented modules with pre work and in class activities
- Created community based group service project to apply knowledge.
- Instant feedback in class tests
- Limited lecturing with emphasis on activities in classroom

This university allows faculty to own the curriculum for each course while outside accreditation agencies validate each program. The outcomes of courses are required to be measurable for assessment purposes of each department. The changes in this course have evolved with continuous improvements added after each semester. The initial major changes were developed with the guidance instructional designers, literacy professionals and information technology experts.

Figure 3: IMPACT Active Classroom

3.1 Transforming Outcomes

The initial learning outcomes for this course were based on the American Association of Construction Education (AACE) accreditation standards. As these standards are moving towards outcomes based assessment, it seemed logical to also align courses to follow these standards. The original outcomes were as follows:

1. Introduce students to the Building Construction Management (BCM) department including: Faculty, staff, concentrations, program, history, career opportunities, student opportunities, and department events.
2. Review the history of the construction management industry through the current trends for the future. (LEED, Sustainable, Green)
3. Evaluate the campus resources available for students' success (Online writing lab, libraries, Academic Success Center (ASC), College of Technology Tutoring, BCM Mentors, etc.)
4. Identify and define materials, methods and construction vocabulary related to the CSI divisions by numbers.
5. Explain the various sectors of the construction industry and career opportunities for the students.
6. Utilize computerized software to overview topics including: project delivery types, contract documents, plan reading, bidding, estimating, pre-planning, scheduling, codes, and safety.
7. Reveal the roles and of the major players in construction industry and how they work as a team.
8. Identify the general concepts and applications of Building Information Modeling / Management (BIM) to construction plans and specifications.
9. Expose the opportunities for lifelong learning in the construction industry (certification programs per state, CPC, AIC, Site Supervisor Cert. etc.)

Over the semester long IMPACT workshop, the faculty and team refined the outcomes for the course to include only these four main points:

1. Review the past, present and future of the construction management industry.
2. Identify resources for student success and lifelong learning at Purdue and beyond.

3. Demonstrate competencies in using computerized software to overview topics in Construction Management.
4. Differentiate between material uses and applications on a construction project.

Each outcome for the course were then aligned with objectives which were mapped to an assessment technique. Table 1 shows a sample of two objectives related to outcome # 1. The first objective uses exam questions to assessment the recall level of Blooms. The next objective is assessed through a project and expects the student to analyze this topic area.

Table 1: Mapping of BCM10001 Course objectives to Blooms Taxonomy

	Remember/ Recall	Understand	Analyze	Apply	Evaluate	Create	Activities
1.a.i Define construction related technical vocabulary	x						Exam questions
1.a. ii Differentiate between LEED, Sustainable, and Green using materials as examples			x				Project

Further improvements in the course were created based on the pedagogies introduced in the classes. As replacement model of course design was utilized. Improvements to the course aligned with Checkering's principles of increasing student success in the classroom. The physical space of the classroom with rolling tables and chairs that can be configured into endless configurations assist the faculty and student connections. This allowed students to collaborate and work in groups and have the faculty walk around and sit with the students. Activities related to the built environment include: design process, team building, scheduling, estimating, communication, and professional development. Modules which include professional development assist the students with understanding how their career path integrates into the built environment.

One specific example of an active day is a mock career fair that occurs each semester during classtime. It is one part of a career development module that begins with a resume review. The Mock Career Fair was developed to increase the self-efficacy of students related to interaction of industry partners. Students are given information on how to dress, what to say and specific companies to research. Typically 6 – 9 companies with 1 – 3 representatives for each company attend the mock career fair the class before the real department career fair. Students are required to dress appropriately and interact the company representatives as if it is a real career fair. They received points by reporting out on the feedback, positive or negative, from the industry partners. Feedback from this has been positive from the student's and the industry partners. There is an overall belief that this class increases students' confidence and preparedness for the larger career fair event.

Some of the larger more technical course projects include a mini design project. This project has been done as an individual and group activity. The students are applying knowledge of roles in the built environment by finding flawed designs and outlining the major players in the owning, design, building, or maintain the particular infrastructure issue on the campus.

After this identification, the students had to come up with a plan on how to fix the design flaw thereby encouraging creative thinking as well helping students apply the knowledge obtained.

To understand project scheduling, students are required to bring a list of activities that they do in preparation for getting ready for school each morning. During class time, a full class discussion is facilitated by the instructor to help the students understand if each of the items on their list is actually an activity. Does it take up time or resources? After this discussion, students are introduced to a bar chart format for visualizing the data. They then work individually, but can talk with each other, to make each of the bar charts for this daily tasks. It is then that the students begin to understand concurrent and predecessors and successor types of activities. The goal of this assignment is to assist the students in understanding basic concepts of scheduling. Additional assignments included interpreting an actual construction schedule and developing a schedule related activities assigned.

4. Data collection to assess course transformation

Students in the course represent many areas of the built environment including designers and management. Table 2 below shows the typical distribution of majors attending the class. This course fulfills the requirements of a general education elective for the university and therefore is taken by all majors across the university. It is a required course for all students in the School of Construction Management majors and minors. The exploring students are undecided in a career choice and have not declared a college major.

Table 2: *Demographics by Major Typical for Course*

College Major	Typical Percentage in Class
Construction Management	51%
Liberal Arts	9%
Engineering	4%
Management	6%
Exploring	15%
Science	4%
Technology	11%

The diversity of the class allows for richer experiences for students to work in groups and share information. As an introductory course, there is a higher number of first year students, but also students who are upper level. Figure 4 shows the typical distribution by years enrolled in college.

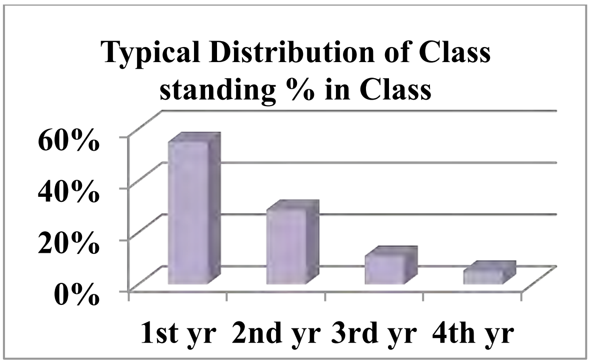


Figure 4: Typical Demographics of Class by Year

4.1 Methodology

Data was collected by the IMPACT team using an online survey instrument made up of questions on a Likert scale ranging from 1 (Strongly Disagree) to 7 (Strongly Agree). The survey instrument was made up of sections that aligned with the outcomes for the assessment (learning climate, psychological needs and perceived knowledge transfer). The survey instrument based on the STD research explained in the review of literature is one which has been proven over many years of research. This version of the survey has been utilized in all of the transformed courses since 2010. Some of the details which have been included in the questions are outlined below.

Learning Climate questions are used to determine the students' perception of the active learning. Sample questions include:

My instructor understood my perspective.

My instructor encouraged me to ask questions.

My instructor listened to how I would like to do things.

Basic Psychological Needs pertains to the extent to which students are confident about mastery of content material as well as the feelings of being connected, intellectually and emotionally, to other students in the class, as well as to their instructor. They include the areas of autonomy, competence, relatedness, and self-regulation questions listed below:

I am free to express my ideas and opinions in this course.

I feel like I can pretty much be myself in this course.

I have been able to learn interesting new skills in this course.

Most days I feel a sense of accomplishment from this course.

Perceived Knowledge Transfer is the student perception of if the course content is important to their future learning or life. Sample questions in this area include:

I feel confident in my ability to apply the course material in my professional life.

I feel as if the material covered in this course is relevant to my future career.

Information learned in this course will inform my future learning experiences.

I believe that it is important for me to learn the information included in this course.

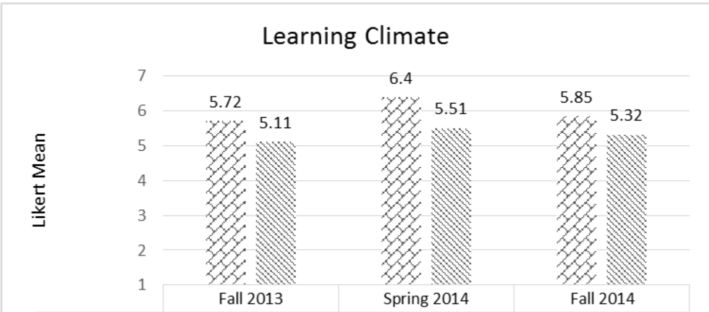
4.2 Results

The goal of this study was to examine the effects of infusing active learning elements and integration into a course related to the built environment. The results will show the individual semesters that were surveying. The instrument consisted of three sections that align with the objectives of the study:

1. Learning Climate
2. Basic Psychological Needs
3. Perceived knowledge transfer

Descriptive and inferential statistics and selected variables were used to explore the research. Analyses were conducted to examine the experiences of the students who had chosen the course.

1. Learning Climate refers to students' perceptions of the student-centeredness of the learning environment. Results for the course and overall campus numbers are shown in Figure 5. Fall 2013 semester was lower due to being the first semester and having the least amount of activity. It is logical that as the faculty member becomes more familiar with the new pedagogy it would improve the learning climate. The lower numbers in Fall 2014 are probably because of a new online textbook that was implemented for the first time.



	Fall 2013	Spring 2014	Fall 2014
BCM 10001	5.72	6.4	5.85
IMPACT Mean	5.11	5.51	5.32

Figure 5: Comparison of average Learning Climate score

2. Basic Psychological Need is based on the Self Determination Theory as mentioned earlier. Figure 6 illustrates summary data for SDT in area of autonomy, relatedness, and competency as determinants of motivation. The highest learning climate provided the lowest Basic Psychological Needs satisfaction although the result was not significantly different from that of Fall-2014. This is finding is in accordance with Niemiec & Ryan's research and indicates that the infusion of active learning elements into learning climates can possibly undermine the Basic Psychological Needs of the students (Niemiec & Ryan, 2009).

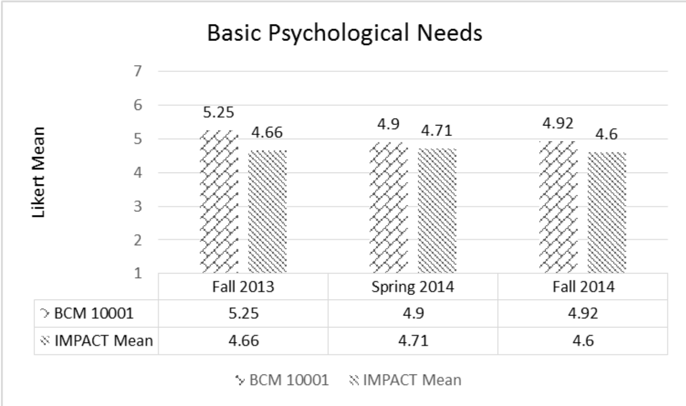


Figure 6: Comparison of Average Basic Psychological Needs Score

3. Perceived Knowledge Transfer is the engagement in higher levels of Bloom's taxonomy may improve the students' perception of knowledge transfer (King, 1993; Mazzolini & Maddison, 2003). Upon comparing the results of Fall-2013, Spring-2014 and Fall-2014, it was found that there was no significant difference in the way the students perceived their knowledge to be transferred. Figure 7 shows the overall comparisons for each semester.

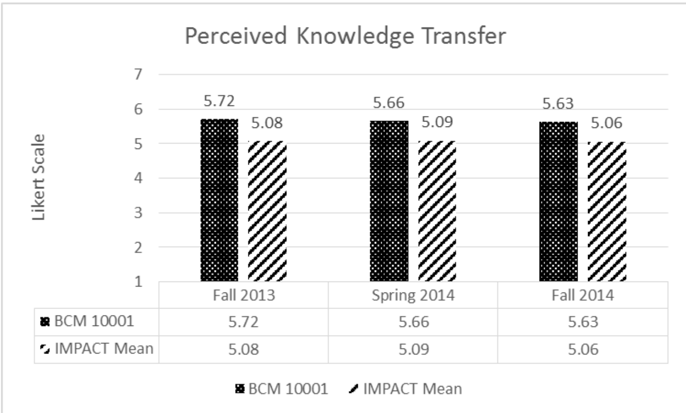


Figure 7: Comparison of average Perceived Knowledge Transfer Score

5. Conclusions

Overall the changes to the course showed to be very positive. Since the changes have been made to the course, the number of students taking the course has doubled. Industry partners are now commenting on the maturity of the students as the becoming employees in areas of the built environment. The active learning modules create a platform by which students learn materials, but also grow more motivated and excited about the career path and college major that they have chosen. Real world activities create an autonomous environment which increases student interaction. A gallop poll done in 2014 with over 30,000 college graduates around the United States showed that the top 6 outcomes align with the transformation ideas:

1. I had a professor who made me excited to learn (63%)
2. My professors cared about me as a person (27%)
3. I had a mentor (22%)
4. I worked on projects (32%)
5. I had an internship (29%)
6. I was active in extracurricular activities (20%) (Paul, 2015).

Unfortunately, only 3% of those surveyed had experienced all 6 areas. Those who were reporting were also reporting success in the workplace to further show that the extra effort by faculty to create an integrated learning environment might that transfers to lifelong learning. Figure 8 shows a summary of the three semesters for this course in comparison to the overall average for the campus. With n=170 for the course and n=7,000 for the overall campus, this gives a good indicator that the research of active learning is supported by this course.

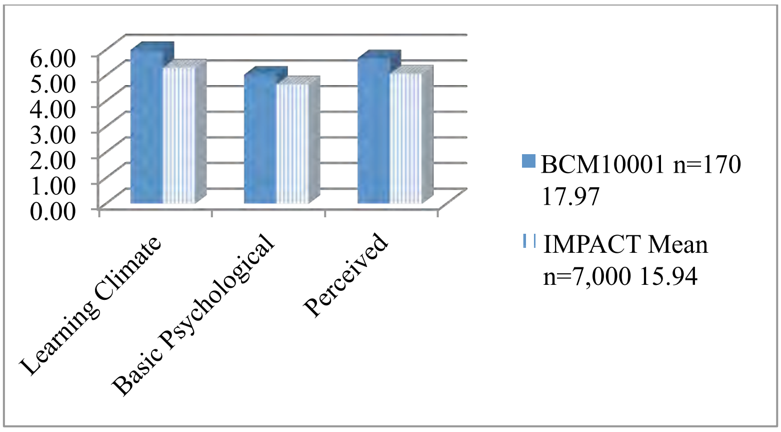


Figure 8: Overall Comparison of course and campus.

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Campus Retrofitting (CARE) Methodology: A Way to Co-Create Future Learning Environments

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Abstract

The future learning environments are not based on standardized design solutions like lecture theatres for 100 persons or classrooms for 40 persons. As new technology and new ways of studying are being developed new demands are put on university environments. At the same time utilisation of resources in form of both teachers and university facilities is challenged by development of integration of learning, teaching and the spaces where it takes place. The challenges are shared among users and owners of campus, where retrofitting is needed too. This paper aims to describe Campus Retrofitting (CARE)- methodology for user-centric and co-creative campus retrofitting processes. The campus development research in Nordic countries and co-creation in retrofitting processes are discussed. The campus retrofitting cases in different countries are described by emphasising especially the methods they used. Based on the analysis of the methods the framework for Campus retrofitting (CARE) - methodology is presented and discussed. CARE-methodology is a tool to capture new logic to learning environment design. It has three key activities: co-creating, co-financing and co-evaluating. The integrated methodology and the formulation of the guiding principle of the CARE-way of sustainable retrofitting of university campuses opens up an agenda for investigating a new methodology for sustainable urban retrofitting in a Nordic context.

Keywords: universities, space management, facilities management, space design

1. Introduction

The Nordic countries have much in common, historically, culturally and linguistically. They have had a common labour market and strong co-operation in many areas for many years. The Nordic welfare state model is based on the rights of individuals to a decent life and equal opportunities for social promotion, often achieved through education. Higher education is a part of their large public sectors and has been influenced by a powerful nation-state in which regional policy considerations and the social thesis of equal educational opportunity have played an important role (Fägerlind et al. 2004). Nordic countries have a strong research and development drive in campus development. The challenge is to apply the research results to campus retrofitting practices: how and what kind learning environments to develop. Nearv et al. (2010) claim that the intelligent estates director, from a position of blindly reacting to academic demands and maintaining the existing stock, has taken a pro-active role in contributing to the academic and business planning process by presenting options, identifying under-utilised resources, and mapping out pathways to achieving academic aspirations. Also Nielsen et al (2012) emphasise the significance of interactive co-creation between an actor and stakeholders surrounding the actor as a way to develop future learning environments and in particular for sustainable retrofitting of universities.

The future learning environments are not based on standardized solutions. Universities are under pressure to expand, change and find greater efficiencies. They have recognised the value of their estate both as a real estate asset and vehicle to open up opportunities for innovative teaching. All Nordic university property management organisations emphasise, that their operations need to be sustainable from economic, environmental and social perspective. There is a need to preserve the cultural heritage, since the university properties are often culturally valuable and reflect the society in general (Anon. 2010).

This paper aims to describe Campus Retrofitting (CARE)- methodology for user-centric and co-creative campus retrofitting processes. First the campus development research in Nordic countries and co-creation in retrofitting processes are discussed. Then the campus retrofitting cases in different countries are described by emphasising especially the methods they used. Based on the analysis the framework for Campus retrofitting (CARE) - methodology is presented and discussed.

2. Campus Retrofitting

2.1 Need to Retrofit Learning Environments

A university's campus is seen as a huge learning environment, which creates possibilities for learning – also across the university's academic environments (Anon. 2013). The last thirty years have witnessed dramatic developments in higher education. In Danish literature it is stated that an important parameter in world-class universities is a vibrant and challenging physical research and study environment. Physical planning is of great significance to the quality of the study and research environment at and around universities. (Anon. 2009) New methods of learning, new creative work environments, internationalisation, digital possibilities, and not least urban development and more stringent energy requirements continually increase the demands concerning the physical setting (Anon. 2013). In Norway thirty projects, which address such issues as the future of the prototypical greenfield campus were collected in order to understand how inner city campuses are transforming the urban context and include prominent corporate enclaves and their ideological underpinnings (Hoeger and Christiaanse 2007).

In Sweden Karolinska Institute and Stockholm County Council (SLL) had a research and development project about Future Learning Environments in 2010-2012: How Space Impacts on Learning. They used the concept of the learning landscape to explore the range of learning environments needed at multiple scales to better align with changes in the medical education curriculum. Four key scales that correspond to important types of learning spaces are identified: the classroom, the building, the campus and the city. "In- between" spaces were identified as growing in importance given changing patterns of learning and the use of information technology. The focus from singular spaces to networks of inter-connected virtual and digital environments was considered as a critical shift. The need for higher levels of engagement of faculty, administrators and students in defining the briefs for the design of new kinds of medical education environments was highlighted (Nordquist and Laing 2015). By using more sociological perspective (Leijon 2012) states, that space shapes interaction, but interaction also shapes space; thus, it is essential to consider space in relation to negotiation and transformation (Leijon 2012). According to Nenonen and Lindahl (2014) inter professional interactivity and boarder zones between the traditional hierarchy, space segments and organisational structures as learning environment need to be identified, especially in the context of medical education.

Similar topics were touched in Finnish research about academic identity. User identity has a significant effect on how users experience a campus area and its buildings. Despite this, user identity does not necessarily meet the image of the organization. The strategic planning of spaces need to be done without forgetting the history and own identity of the users. (Airo and Rytkönen 2015). This finding has been published as a part of the large research and development program The Future learning environment 2011-2014 led by University properties of Finland. The learning environments of the future were investigated from the perspectives of campus co-operation, sustainable development, co-creation and multi-disciplinary learning. In the begin of the research program the expectation was to collect the new typologies for learning environments but at the end of the project it was found out that that equally important as the new solutions are the processes how they are realized together with users. E.g. the transition to sustainability is often seen as a top-down governing challenge, but it can include pioneering bottom-up ways to create change. Bottom-up actions in innovation should be given recognition and nurturing, as the bottom-up initiatives often challenge systems that resist change (Pulkkinen and Staffans 2005).

The existing premises of campuses possess a huge potential to be turned into lively urban centres that support learning and research of the future. Hence, the existing buildings can be seen as platforms for novel architectural solutions and stages for presenting the universities' state-of-the-art education and research. Radical, extensive changes would most likely create the biggest impact on behaviour and functionality. However, not all changes need to be massive and expensive. Like acupuncture, which releases energy by the point of a needle, so could the campus spatial structure be energized through small changes, which have a bigger impact than their size (Poutanen et al., 2015). According to Eriksson et al. (2015) retrofitting as technical and spatial solutions covers only part of the process. The activity-based retrofitting consists on multidisciplinary collaboration and learning processes where the diverse users have different roles during the retrofitting process. This will be discussed in the following chapter in terms of co-creation.

2.2 Need to Co-create in Campus Retrofitting Processes

Campuses are pioneers in facing the built environment challenges. The retrofitting processes are the additions of new technologies, features and functions to existing built environment systems. In university campuses this means the development of embedded learning environments, new space typologies, variety of platforms (both digital and physical) supporting collaboration within the university and in connection with diverse stakeholders. It means upgrading or replacing technical elements but also the changes in user activities and practices. Nevertheless it is connected also to service concepts and the new ways to produce services. (Eriksson et al., 2015) The purpose of user involvement in retrofitting processes means making fuller use of user knowledge and experience. Action and use of facilities is strongly related to experiences of the users and thus their possibility and will to perform. People create their own places in the facilities – they are socially constructed. Both technical and psychosocial systems are important when retrofitting campus. Co-creation allows and encourages a more active involvement from the users of the campus to create a value rich experience. Interpretation and analysis of the built environment and support services based on how it is socially constructed will enable integration of organisational use and the facilities provided to arrive at an understanding of usability of built environment (Alexander et al., 2013). The question is how retrofitting processes are conducted.

Sanders (2008) has been investigating the history of co-creation and stated that in Norway, Sweden and Denmark the Collective Resource Approach was established to increase the value of industrial production by engaging workers in the development of new systems for the workplace. The approach put together the expertise of the systems designers/researchers and the situated expertise of the people whose work was to be impacted by the change. The approach, thus, built on the workers' own experiences and provided them with the resources to be able to act in their current situation. In the broadest meaning of user participation it could be called "collective design" which was launched in early 1990´s. Collective design is something more than contributory influence and just participation. It is a process where knowledge and values confront, complete and modify each other leading to something new. All actors in the process are regarded as experts and their participation is therefore based on their relevant knowledge rather than on their roles as representatives for different interests. (Granath et al., 1996) Over the past ten years, together with increasing attention to the importance of front-end activities in general (Ryd, 2008; Blyth and Worthington, 2010), new interest in user involvement is emerging; though a change in focus is noticeable. The purpose of user involvement has shifted from mere participation to co-designing, making fuller use of user knowledge and experience (Sanders and Stappers, 2008; Erikson et al., 2014).

CIB Work Group 111 on Usability of workplaces - with a significant amount of Nordic researchers and practical case studies - has been exploring concepts, methods and tools, developed in the usability of built environment, including also learning environments. A key product of the Nordic research project REBUS (User- oriented Benchmarking for Usability in Real Estate) was a process description, detailing how building owners and facilities managers can gather user experience from existing buildings as a basis for improving them, as input when designing new buildings, or as a reference when choosing new premises. (Lindahl et al. 2011). The universities comprising of the students, researchers, professors, lectures and other staff are the users of the universities properties. The university occupiers' needs vary from other commercial properties (e.g., offices) with needs regarding, i.e., lecture halls, laboratories and other special space. The university properties are often relatively large, made for a special purpose and can be difficult to convert to other usage. (Alexander et al. 2013)

To sum up it seems to be crucial to understand more the characteristics of co-creation methods in campus retrofitting processes in order to find out the ways for constant, future-orientated way to develop learning environments. Leaning on Nordic tradition on user-involvement we make the following analysis of campus-retrofitting cases.

3. Nordic studies about Campus Retrofitting

Campus Retrofitting (CARE) -project focused on innovative retrofitting of Nordic University Campuses. The goal was to develop and demonstrate scalable retrofitting, CARE-concepts for sustainable built environment management. The emphasis was in developing the systematic and continuous Campus retrofitting methodology, which is a system of broad principles or rules, from which specific methods or procedures may be derived to solve campus retrofitting problems in the context of developing future learning environments.

In Sweden, Denmark and Finland the Campus retrofitting studies were connected to developing new concepts for learning environment especially by understanding the diverse needs for informal learning. In Norwegian studies as well as in some Finnish studies the emphasis was in evaluation of the retrofitting concepts. In Norway especially in terms of the use of energy efficient solutions and in Finland in terms of the usage rates, indoor environment quality and user satisfaction of the solution.

The Danish study aimed to develop future learning environment together with users. The method used in Danish study was participatory workshops in DTU (Danish University of Technology) Campus Service – building client function for developing future learning environments. Instead of the usual approach: study tours they wished to get inspiration from ”learning researchers”. They conducted an action research process in spring 2015 with four workshops and participants were campus service representatives, teachers, students and users of Learning lab. The themes for the workshops were: Dream learning environment; What do we know about learning spaces and what are the new typologies; Relations between learning space, technologies and learning and Performing University Spaces. The outcome was a new and different dialogue, which was engaging, strategic, open. It opened the bigger picture for participants and created the idea of a ”longitudinal community” to supplement existing organisational structures. The facilitators and experts of the workshops represented e.g. anthropology and business sciences. The approach was multidisciplinary by its nature.

The Swedish study aimed to build meeting places within the university designed to create and implement social responsibility and sustainability framework of Chalmers Real Estate Ltd. The method used in this study was based on best practice mapping by using the approach of human geography and urban sociology. They developed a manual for the meeting place builders called “Building Meeting Places - an introduction to strategic inter structure supply”. In parallel with the manual also a digital tool for inventory and analysis of the meeting places have been developed. Additionally the training of staff was part of the project. An inventory of meeting points on the Chalmers campus has been made during the spring of 2014, which formed the basis for future development with the physical environments. The manual includes a reviews of the meetings and venues evolved historically, trends that are relevant to today's and tomorrow's meeting place realization, models and theories to analyze and describe the meeting places' anatomy and character, as well as a number of concrete strategies and tools to develop and strengthen the different types of meeting places. The first demonstrations were made during the Campus Retrofitting process.

The Finnish study included 26 demonstration projects on different campuses of Finland, conducted by University Properties of Finland. Co-creation, realization, co-inesting and finally evaluation of activity based, multifunctional learning, research, and working environments were typical for the demonstrations. The retrofitting in case Musica, a building at Jyväskylä University Campus dedicated for education and research of music, aimed to plan a living room and learning/research spaces for the students by using Charrette-method. During the five day Charrette-process the new end-user goals were recognized and linked with the strategic principles of the facility department of the university, and the needed planning documents were created. Small scale campus retrofitting demonstrations concerning future learning and working environments in universities was the effective way to test new, unknown solutions and concepts. The costs were shared between user and property owner. (Naaranoja et al 2015)

In Tampere University of Technology, Finland students were in active role when redesigning under-used lobbies into a lively social and informal learning space. The halls and corridors, which are located in popular areas on campuses, have great potential as redesigned into novel social and informal learning spaces. Learning spaces located in circulation spaces reach students from all faculties, which also intensifies the use of the spaces as those compose typically up to 22% of the total floor area of Finnish university buildings. Campus-wide Wi-Fi and the culture of Bring Your Own Device (BYOD) enable all secondary spaces for informal and social activities. The three cases were novel learning spaces created in a lobby, a renovation of a campus café, and co-created learning spaces in an academic library. All of these demonstrations were successful in both attracting people and increasing the popularity of the space. Also the indoor environment measurements provided evidence of sufficient comfort factors. Economically the demonstrations were inexpensive due to the fact that they were made by innovative student projects. Traditionally the renovation budget is used to return the facilities to the same level than they used to be – campus retrofitting demonstrations focus on developing the facilities for responding to the needs of future. (Poutanen 2015).

The Norwegian study focused on energy-efficiency improving methods for non-residential buildings and linked master student education with an on-going research project on energy efficiency improvement of non-residential buildings. They mapped the implementation in Norway by developing and conducting a MINDER survey with focus on existing methodologies. They learning environment was extended to visit and study energy-efficient buildings in its real life context. The students were invited to visit the buildings, analyse building documents, conduct interviews with practitioners and meet in the university classroom to present and discuss their findings. Best practice examples represented the most relevant building types and user organisations towards energy-efficiency improvement and were selected from the local municipality's energy-efficiency award. The students developed and presented findings with focus on innovative solutions for energy-efficient buildings' management. The aim was to analyse and improve the methods for innovative approaches for energy-efficient operation of energy efficient buildings. The survey cooperation with practice contributed to getting information and develops a deeper understanding about user-behaviour in energy-efficient maintaining of buildings next to technical facts and figures.

Additionally a Living lab case study have been followed up. The case was a single-family house at NTNU Gløshaugen campus in Norway with a gross volume of approximately 500 m^3 and a heated floor area of approximately 100 m^2. The house consisted of traditional residential spaces such as living room, kitchen and two bedrooms and it was used as a living lab. The ecological drivers for activities were low energy demand, passive and active use of natural resources and independency from the energy grid and lowering the environmental impact of the second home sector. Living Lab was developed in cooperation with industrial partners inside the Research Centre on Zero Emission Buildings (ZEB). The design included a wide range of components that can be adjusted according to users' needs and desires, functional program distribution and climatic context (envelope, furnishing, and technical system). The users interacted with buildings characterized by high indoor comfort conditions and low energy demand. The monitoring system of the use of the building has been designed in order to be flexible, expandable and easily reconfigurable. In addition sensors have been integrated in the building as it would be in a real house and chosen among those that can be installed in a real-world application - i.e. on- purpose-made sensors have been avoided as much as possible. The Living lab involved students, researchers and industry partners to develop sustainable solution and behaviour. (Finocchiaroa et al. 2014)

The analysis of the methods used in different Nordic studies was made by comparing the following aspects: How the users were involved to the studies and demonstrations, how the campus retrofitting process/project was realized in practice and economically and how the demonstrations were evaluated. The summary of analysis is presented in Table 1.

Table 1: Summary of campus retrofitting methods

Analysis focus \ Country	*Denmark*	*Sweden*	*Finland*	*Norway*
User involvement	*Active role in workshops – source of ideas and information*	*Staff trained to meeting place manual*	*Active role in workshops – source of ideas and information*	*User behaviour in testing focus*
Realization	*Longitudinal community for on-going development was established for creating the future learning environments*	*Inventory of meeting points in campus and development of meeting place strategy for campus*	*Future learning environment demonstrations with co-funded budgets of owner and user. Partly realized as student projects*	*Producing and testing energy efficient solution with focus on user interface*
Evaluation	*Not yet*	*Not yet*	*Sensors for indoor environment, interval cameras, observations, user feedback surveys*	*Testing user-interface in Living lab Case studies on using and maintaining the energy efficiency of buildings*
Other remarks	*Trans disciplinary approach*	*Trans disciplinary approach*	*Diverse participatory methods*	*Integrating master student education and research*

4. Results

Based on the analysis the campus retrofitting methodology includes the following elements:

1. Active user participation and co-creation process: Campus retrofitting methodology indicates the importance to understand users and their needs as well as diverse activities, which set requirements for the future learning environments. The user was in all cases the main informant and also co-creator. The users were challenged to provide insights about their activities now and in the future. They were set to the active role also in designing the solutions. This activity based understanding is the basis of co-created and co-designed solutions.

2. **Commitment to share economical costs among stakeholders - co-financing:** The active stakeholders in Danish, Swedish, Norwegian and Finnish studies were the property owners or facility managers. They need to provide good university facilities and at the same time take care of the economical issues in order to achieve sustainability, sufficient usage rate of university facilities and efficient use of spaces. The economical structure was based on co-financing the projects by the university and by the property owners. The engagement of user and owner create cost-efficient ways to retrofit campus facilities.

3. Follow-up measurements - co-evaluation: Evaluation together with users and owners as by using diverse methods (e.g. user surveys, using sensors, interval camera and user feedback, user interface testing) to ensure the success of demonstrations was important in all cases. Co-evaluation provides evidence about effectiveness of the solution and material for learning and developing. It provides a longitudinal perspective for retrofitting processes and solutions.

The qualitative methods in connection with more traditional quantitative and objective methods together provided the valid process for proof of evidence in Campus Retrofitting (CARE)-demonstrations. The Norwegian study included survey, where the intention was to combine the technical data with the user data and enlarge the scope of fully technical approach to energy efficiency. In the Living lab case the user interface was the in user-test and both technical and user-data was gathered. The Finnish studies connected to campus lobby demonstrations included the measurements of usage rate and user satisfaction provided also quantitative data. In Danish, Swedish and other Finnish cases the methods were more qualitative by their nature including e.g. participatory workshops.

It was notable that the besides the different stakeholders the use of multidisciplinary approach was typical for the cases. E.g. Finnish charrette-process is based on method used traditionally in urban design. In the Swedish study the manual was based on human geography and urban sociology approach. In the Danish study anthropology and business sciences, e.g. management were part of the content of the workshops. The synergy between different disciplines and different actors provide material for new solutions.

5. Discussion

CARE-methodology has three key activities: co-creating, co-financing and co-evaluating. CARE-methodology can be framed and illustrated with the following Figure 1.

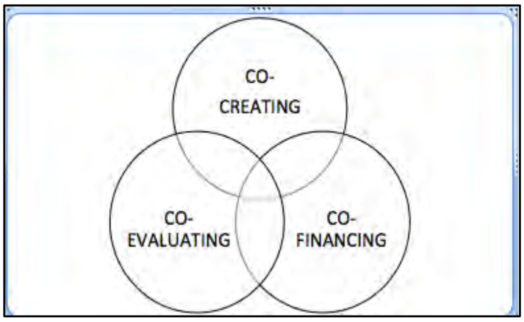

Figure 1: CARE-methodology

CARE-methodology consists on sharing: the vision, costs and results of retrofitting are shared between users and owners of campus in order to develop the future-orientated and sustainable agenda. The iterative processes of campus retrofitting differ from traditional linear technical projects. The activity based campus retrofitting is the on-going process and not limited to the certain phase of the retrofitting as a financial or technical process.

The Nordic studies provided material of planning itself but also new ways to provide continuity for the development of learning environments: it is important to provide proof of concepts and to engage different stakeholders. In order to use the CARE-methodology in practice the following steps are recommended: 1. Set the vision for the retrofitting process. 2. Identify the diverse actors for sharing the vision. 3. Define the budget among diverse actors and agree about the shared economy 4. Involve users to co-creation by using different methods. 5. Update user needs continuously, not only in the one dedicated, often predefined phase like e.g. specification of needs. 6. Decide and realize the user-centric evidence collection of the process and the solution. 7. Learn and develop continuously: there is not such a thing as "finished solution".

CARE-methodology can be a tool to capture new logic to learning environment design. The Nordic studies were chosen because they represent new and actual on going, experimental co-creating strategies at the universities, and we expected to gain new insights from these innovative processes, where the universities deviated from their standard practice. This has led to identification of new methods and contributions to the current literature on retrofitting of universities and learning environments. The two-year long project did however not allow longitudinal studies beyond one year or further co-creation processes. And this we recommend for future studies.

6. Conclusions

Nordic universities have been investigating campus retrofitting case-studies, which include a wide spectrum of methods how interaction and co-creation between students, teachers, researchers, real estate and FM staff as well as industry can take place in campus retrofitting processes. The wide user group represents a broad cross section of perspectives and experiences and provides a platform for fruitful discussions of the studied demonstration projects. The applied methodologies and the formulation of the guiding principle of the CARE way of sustainable retrofitting of university campuses could be applicable in the larger context of urban retrofitting. The methodology is not depending on learning environment or university campus context as such but it seems to be more transferable by its nature. It opens up an agenda for investigating a new methodology for sustainable urban retrofitting in a Nordic context.

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How to Manage Corporate Real Estate and End-Users Engagement into Smart Workplace Change Strategies: A Case Study

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Abstract

Progressively, the spacial demand of workplaces is modifying, together with the habits of workers. How can companies react to the change of perspective that is affecting the traditional ways of working? What does 'Intelligent Built Environment' mean for corporations?

For several years at international level, it has diffused a new conception of the office: flexible spaces, shared desks and informal areas that can accommodate different activities as needed. Even in Italy this phenomenon is spreading rapidly: some firms have started to abandon cellular offices and open-plan offices, and to experiment with flexible work settings. A new demand is emerging with specific characteristics. The most significant drivers seem to be economic efforts (big and expensive buildings affected by low daily occupancy) and organizational reasons (teamwork, part-time work, teleworking, network strategies, etc.). Nevertheless, even external factors such as competition, globalization and corporate image can influence the motivation for change.

The authors have collected data on new ways of working and workplace change strategies in the brand new Italian headquarters of a company active in the technology hardware & equipment industry, with around 1,000 employees. The investigation involved both quantitative and qualitative research methodologies. By matching the results obtained, it has been possible to elaborate some considerations regarding benefits and risks of flexible workstations and the way of integrating smart working into corporate real estate strategies. What kind of data is valuable to retrieve about the use of workspaces? Which methodologies would be the most suitable for such a scope? When and how should consultants support their clients? And, most of all, to what extent can an 'intelligent building' support human activity in daily life?

The knowledge acquired can be useful to companies, both for managing the functioning of existing buildings and for orienting future projects towards the objective of becoming more 'intelligent'.

Keywords: Smart Working, Employees' Satisfaction, Workplace Change Management, Corporate Real Estate, Intelligent Office Building

1. Introduction

More than 30 years ago, Ronald Goodrich (1982) was considering that "now, as a result of the growing importance of office work, the introduction of office automation, the changing character of work, and the economics of office buildings, the office environment is becoming more intimately linked to the psychological needs, performance, and well-being of its users." The same consideration, with the due differences, seems to be valid today as well. The importance of office work has now partially been revised, office automation is evolving everyday, new ways of working are rising, office buildings are changing their form and function, and the office environment requires being linked more than ever before 'to the psychological needs, performance, and well-being of its users'. New working activities, new technologies with which we do them, new organizational structures and new ways people work together generate new requirements from the users' side, that reflect on the space, the building and the built environment.

The opportunities, offered by a world that is more technology-driven everyday, lead to new ways of communicating, informing and networking affecting life and work style (Corso, 2005). Due to the advancements in the Information-Communication Technology field, some main consequences are emerging: a) new ways of communicating and expressing likes/dislikes are diffusing; b) new ways of working are developing; c) new data is available and suitable to create value. These aspects converge in the workspace that should, therefore, change and evolve taking into account people expectations. This probably means that, along with the workplace features, configuration and layout, even the methodologies currently used to assess the workplace quality might be adapted. As the most recent RIBA 'Plan of Work 2013' suggests, the fine-tuning of building quality against users' requirements, expectations and opinions is recognized as a fundamental part of the construction process and the users are important stakeholders within it (RIBA, 2013). But, despite the many Post-Occupancy Evaluations that have been conducted worldwide, it seems there is still the need to find a way to transfer that process into a form that can be meaningfully put into everyday practice (Mallory-Hill, et al., 2012). Moreover, it is fundamental to make the user-centered approach (Vischer, 2008) more widely diffused – e.g., in Italy there is still lacking circulation in the academia and a shortage of applications in the professional sector.

For these reasons, there is growing interest in studying the interactions between the working environment and users' perception. What features should characterize the workspace according to the new ways of working? How can we assess them? How is it possible to fine-tune the quality of the workplace? These questions affect all the stakeholders taking part in the process. Among them, Corporate Real Estate departments are particularly interested in those issues, since they are in charge of workplace change management, together with the Human Resources and Facility Management. Companies are taking up new ways of working in order to attract and retain talent, be competitive and successful in the globalized world (Heather, 2003). Architecture and built environment can be the enabler for the competitiveness of regions and cities, the success of companies and the well-being of workers and citizens. How is it possible for an office building to take the role of enabler? What is an 'intelligent office building' meant to be?

2. Background

Corporations that need new buildings should pay attention to creating solutions that correspond to real requirements, in order to obtain major cost savings with the best quality. Moreover, it is important to fine-tune building performances continuously, according not only to corporate strategies, but also to pragmatic human experiences. By involving the end-users of office buildings, in fact, it is possible to build an effective decision making process. For these reasons, an integrated approach to the design, delivery and management of buildings and built environments is necessary nowadays. The objective is to reach the best results in terms of employee commitment, satisfaction and productivity (Miller, et al., 2014).

To this end, an international company was interested in conducting a post-occupancy study on their brand-new Italian headquarters. The firm had recently invested in the construction of new premises. The initiative entailed a radical re-layout of the work settings, according to the smart working approach (Methodos, et al., 2015) and looking at the 'Intelligent Building' model – i.e. high-tech building with flexible office space and advanced control technology (Preiser & Schramm, 2002). The application of a hot-desking solution (Knight & Haslam, 2010) was embraced in order to optimize space utilization and encourage employees' interaction. Only 30 employees out of almost 1,000 can use an enclosed office, different business units are grouped in some open-space areas, which are dedicated generically to one organizational function, but nobody has an assigned workstation. A proportional number of meeting rooms, varied for capacity (from 4 to 25 seats) and equipment (projectors, screens, teleconference and videoconference tools, etc.), concentration rooms and phone booths are located on each floor, beside some free space for informal meetings, breaks etc.

The study began 6 months after the move in, in order to allow the occupiers to start using the space and get accustomed with the new way of working. The previous workspace setting was arranged as a traditional open plan, with fixed workstations and a very low density rate. Therefore, the working experience radically transformed in the new building and some resistance to change emerged among employees. The objective of the management, including Corporate Real Estate (CRE), Human Resources (HR) and Facility Management (FM) departments, was to accompany the employees through the workplace transformation, to verify the pre/post-transfer impacts and to harmonize the new spaces with their requirements.

3. Research Methodology

The investigation involved both quantitative and qualitative research methodologies, in line with the approach suggested by Jick (1979) and referring to Post-Occupancy Evaluation techniques, as recommended by Costa (2014). The first methodology implied processing on quantitative data provided by the company and a questionnaire administration. The qualitative approach consisted of a field observation campaign, some semi-structured interviews with the management team and a few focus groups with employees.

As the exploratory phase began, a large documentation was revised about the characteristics of the building, completed by a non-structured observation with the walk-through of one of the HR managers. In addition, numerical data concerning the accesses of employees to the building and meeting rooms' reservation was analyzed. Actually, FM and HR departments pick up this data on a daily basis, but leave it at a raw stage of elaboration, so it needed cleaning and preparing before use.

Semi-structured interviews with the management team, including CRE, FM and HR managers, were conducted, with the goal to bring together impressions, intentions and sentiment from the stakeholders responsible for fine-tuning real and perceived building performances.

The structured observation was carried out on 2 different workdays, considered representative of the standard ones, given the firm's characteristics and different business units' habits. This methodology was applied to map and monitor the way people use spaces, according to the behavioral mapping approach typical of environmental psychology studies. In addition, qualitative considerations about where and how workers performed several activities were annotated and later compared with workers' perception. Four researchers, in two groups, walked through specific zones of the building (selected as a representative sample of the whole premises), making sure to observe each space once per hour. Overall, 62% of the workstations and 87% of the meeting rooms were observed. Supported by a detailed checklist, the observers punctually registered the number of:

- employees seating at desks;
- personalized desks;
- employees occupying the meeting rooms;
- employees using concentration/phone booths;
- people present in the break areas.

These records have been intersected with:

- total number of accesses;
- total number of desks;
- capacity of the meeting rooms;
- number of phone booths;
- number of break areas.

In the end, 3 focus groups were organized to directly meet with the employees and listen to their thoughts. The HRs selected the 50 people sample – divided into smaller groups. The sample represented overall almost all the business units inhabiting different zones of the premises. A questionnaire was administered during the sessions, with the aim of systematically collecting some information and better organizing the meetings, since they involved a large number of employees. This covered several aspects and was composed of seven questions about workers' perception, four of which, more in detail, regarded – see Appendix (Survey questionnaire):

1. their doubts or worries before the move compared to their feelings after the move;
2. their presence at work during the 'typical working week' (time spent in the office building);
3. their activities at work during the 'typical working day' (time spent on different activities and in different areas of the building);
4. the level of importance and relative satisfaction they attribute to some factors that affect work quality and effectiveness (on a typical Likert scale from 1 to 5).

The questionnaire was used as a template for open discussion. After answering one question, the people were invited to talk about the same topic and discuss between each other. The interviewers wrote down several annotations during the conversation, suitable for further comments. Finally, information gathered through the application of the methodologies above mentioned have been matched together.

4. Findings

Useful findings have been built up thanks to the integration of several methodologies, none of which can bring trustworthy results if taken in isolation. Quantitative data retrieved about the use of the workspace (e.g. number of accesses per day, employees sitting at the desk, personalized desks, employees occupying the meeting rooms, employees using concentration/phone booths, people present in the break areas) need to be verified against qualitative information. Only through this integration, is it possible to get 'what' is happening and explain the reasons 'why' this is going on and, therefore, find a strategy to correct eventual mismatches.

The chapter will summarize the main insights obtained on flex office implementation, workspace management and employees' satisfaction, with respect to the move in process and the brand new office layout.

4.1 Pre/post Transfer Impact

With regard to the employees' issues about moving to the new premises, most of the focus group participants found their worries were ill-founded. Out of 49 interviewed employees, between 60 and 70% confessed they:

- were afraid of wasting time while they were looking for a free work station;
- were concerned there could be problems in working relationships with colleagues;
- suspected they would lose their normal efficiency in their daily work activities.

Overall, they found that these matters were not a problem. Respectively, 100% of them were satisfied with finding a free workstation, 85% of them were fine with working relationships and 78% had no problem with work efficiency. In more detail, during the open discussion, specific reasons for concern in work efficiency emerged, which lowered the employees' level of satisfaction. Among these reasons, the main ones were associated with noise and distractions in an open space setting, sense of privacy, and climatic discomfort. Regarding these problems, a deeper understanding has been provided thanks to the field observations and the further points faced in the focus groups, where additional issues connected to the quality and effectiveness of the daily work came to light.

4.2 Adaptation to flex office

Even though the majority of the people who were afraid of wasting time while looking for a free workstation admitted to having no problem in this instance, some complaints about contract conditions arose. Against expectations, indeed, contracts require most of the employees to work in the office (*"I thought flexible space meant a more flexible management of work. I thought I would really be able to work from home, but this is not happening now"*). The ratio of people who have a telework contract and employees with a traditional contract is very low (*"about 1:9"*) and in some cases has been further reduced compared to the previous situation (*"many colleagues had a 3-days-at-home-2-days-in-the-office contract. Now contracts are renewed in the opposite sense"*). As a result, the risk of overcrowded spaces increases proportionally with the rigidity of contracts. Besides, there is the threat this company policy is upsetting employees, who perceive a considerable lack of alignment between architectural/layout choices (*"it is all in flexible logic"*), on the one side – which aims at establishing a model of flexibility in settling and working, and contract conditions, on the other – which are perceived as working against that model. In this regard, it is noted that a good workplace strategy should be managed with the full involvement of the human resources and real estate functions, that should work in an integrated manner (Martin & Black, 2006).

In addition to this consideration, the questionnaire shows that most of the interviewed employees can represent their working hours in a 'typical working week', where over 90% of them say their daily work is performed in the office. Only a very small minority believes their activity does not follow a regular pattern and admits they are often away from their work desk. This minority includes employees of those business units that are typically more mobile, such as the customer service unit and the marketing department in particular.

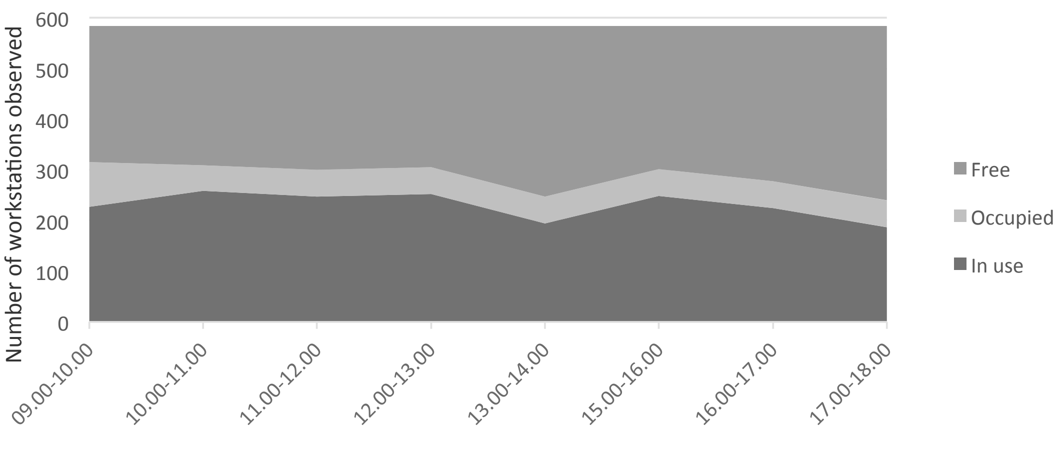

Figure 1. Number of workstations in use, occupied and free (source: observation)

Comparing the issues that emerged during the focus groups and the questionnaire answers with the numerical records retained by the HRs and the field observations, it is possible to correctly weigh the accuracy of the statements reported by some workers. According to them, in certain conditions it is difficult to find a free desk (*"on some days there is not enough room for everybody, teleworking does not fit in properly"*). The quantitative data obtained from monitoring badge swipes at the entry turnstiles, during the period January-June 2015, reveals that the average attendance level of the total number of employees is around 75%, reaching 81% as its highest value. Therefore, employees' perception about their daily presence in the office doesn't correspond to real data. Moreover, field observations reveal that the percentage of attendance at the workstations is even lower (Figure 1). Only around 40% of workstations were in use (an employee was physically present at the desk), on average, and 15% of them were occupied by an employee being not physically present (he/she could be involved in a meeting, conference call or other activity). Therefore, almost 50% of the workstations resulted in being effectively free.

This kind of count is actually more accurate than the mechanical count performed by turnstiles activated by badge swiping, because it detects the continuous presence of an individual in a building. However, a margin of error is possible because of eventual misinterpretation of traces on the workstation at the time of observation. Although, numbers make it evident that it is unlikely for employees to encounter real difficulties in finding a free seat.

Furthermore, with regard to the multiple-choice question "Which of the following statements best describes your work station in your company?", most employees answered that they worked in an open space setting, whereas only 13% specified they worked in different, non-assigned work stations. This means that most employees do not perceive they are hot-desking. They still have a more traditional concept of open space, which they conceive as a collective space shared with colleagues, in which everyone has the exclusive use of one workstation. This feeling explains also the tendency to 'sedentism' and personalization that affects their behavior. During observation rounds, on average 1 workstation out of 4 was marked in some way with personal objects. This trend might compromise the flex office model, but it is not equally distributed among all the functional areas. In fact, some business units tend to mark the space less strongly than others do. These correspond to those functions that are more suited to a flexible workstyle, for example the sales areas. On the contrary, some business units are more settled as a vocation, such as finance, legal, procurement, quality and others. Not surprisingly, it is exactly here that the most numerous territorial signs, e.g. identity-oriented markers (Brown, 2009), have been found. It is also significant that almost 20% of those desks not assigned to any business unit, i.e. theoretically free from personalization, presented some marks. The objects typically found on the desks may affect more or less significantly the image and functionality of the workstations. Among them it is worth mentioning: toys, photographs and posters; calendars, post-its, reminders; plants; pen holders; documents. Coherently with the trend registered, according to the questionnaire, 44% of interviewees would appreciate the possibility to personalize the desk in order to feel more comfortable at work.

4.3 Work Activities and Spaces

Beside more traditional activities such as 'PC, reading, writing' and 'talking/meeting', that employees estimate can take up, respectively, around 45% and 15% of their typical working day, other activities such as 'phone' and 'conference call' seem to be very significant, as revealed by the questionnaire, occupying 27% of the typical working day. This is coherent with recent research saying that thinking, talking and brainstorming create the most value for an organization (Colpaert, et al., 2014). Today, the time spent at work in some type of conversation is up to 50-80% of the overall working day. It is common belief that by talking together, people come up with new solutions in the shortest time that probably neither single person could have developed alone. The key activities in today's work are both concentrated (solo) and collaborative (together). On one side, concentration, observation, research, imagination, testing and planning require concentration. On the other hand, brainstorming, interviews, workshops, co-creation, debate and delivery require collaboration. These attitudes impact the traditional features of the workspace and how people perceive it.

Referring specifically to the employees' assessment, the activities performed in a typical working day can be carried out collectively or individually in the following proportion:

- collectively or in groups, 40%;
- individually, 47%;
- both collectively and individually, 13%.

It is therefore possible to claim that the distribution of the workstations in the new headquarters is correctly planned; in fact, the number of open space workstations and the number of workstations in meeting rooms is almost the same.

When considering the above, it is necessary to bear in mind the importance of the spaces and technological facilities used to manage meetings and calls. It is crucial to implement the appropriate measures to disturb as little as possible other employees who are involved in activities that require particularly high levels of concentration (e.g., PC, reading, writing).

4.4 Strengths and Weaknesses

Focus group participants were asked to express their opinion on the importance of, and satisfaction with, a number of factors that can affect the quality and effectiveness of their work (on a scale from 1 – not at all important/very dissatisfied, to 5 – very important/very satisfied), regarding physical (Roeloofsen, 2002) and psychological (Alker, et al., 2014) issues (Figure 2)

It is interesting to read the weight of the difference between the level of importance given to one factor and the corresponding level of satisfaction. In this way, it is possible to become aware of the most critical issues and establish intervention priorities accordingly.

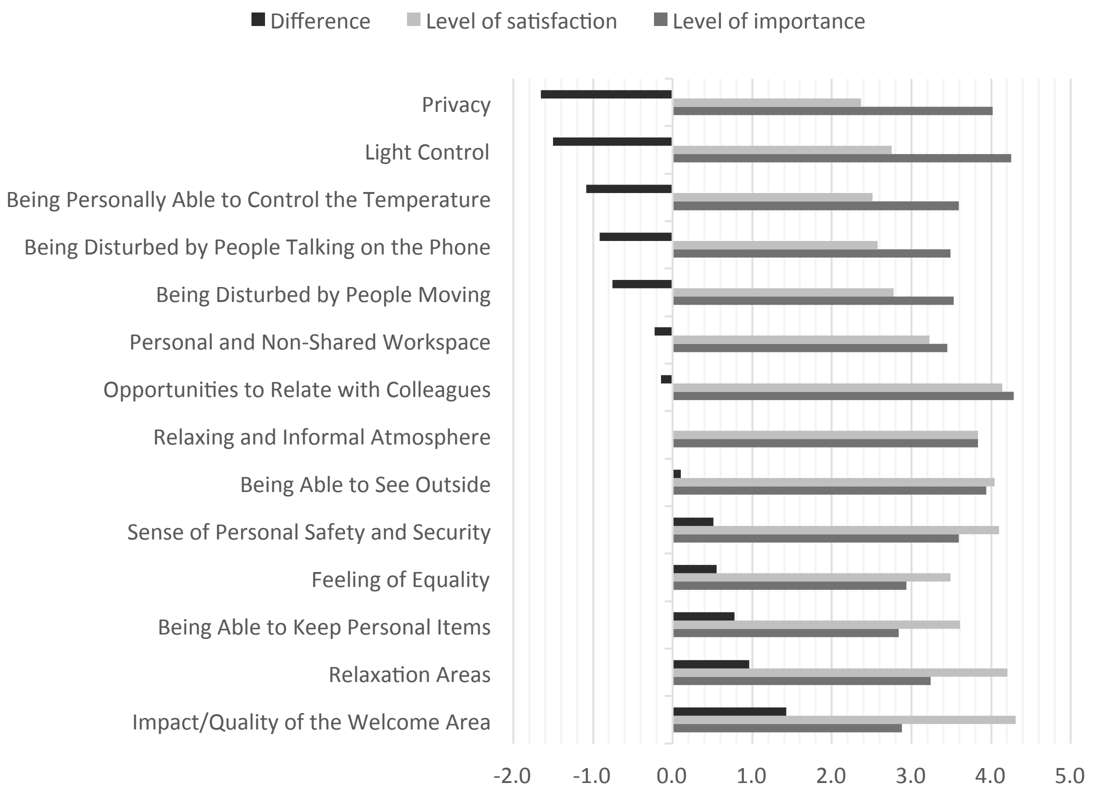

Figure 2. Level of importance/satisfaction regarding the factors that affect work quality and effectiveness (source: questionnaire)

The factors that received the highest score (≥ 4 points) for importance include: opportunities to relate with colleagues; control of light; privacy.

With regard to satisfaction, the highest ranking factors (score ≥ 4) include: impact/quality of the welcome area; relaxation areas; opportunities to relate with colleagues; sense of personal safety; being able to see outside.

It is important to note that for some of the listed factors the level of satisfaction is equal to or exceeds the given level of importance. These factors can be considered 'strengths' (Table 1). On the contrary, in some cases, there is a significant deviation regarding the level of satisfaction (< 3 points), so these factors must be interpreted as 'weaknesses' (Table 1), which require urgent intervention measures.

Table 1: Strengths and weaknesses

Strengths	*Weaknesses*
- *impact/quality of the welcome area* - *relaxation areas* - *being able to keep personal items* - *feeling of equality* - *sense of personal safety* - *being able to see outside* - *informal and relaxing atmosphere*	- *privacy* - *control of light* - *being able to personally control the temperature* - *disturbance caused by the use of mobile phones* - *disturbance caused by people moving around*

Lastly, there are some aspects that have a slightly negative difference but the related level of satisfaction is good or excellent (≥ 3 points), e.g., personal and non-shared workspace. In this case, it is reasonable to suppose that the changes in working conditions have had a certain impact on employees, who have yet to absorb it all. It is likely that over time the level of satisfaction may increase, even without making significant changes to the surroundings, simply as a result of people becoming used to the new conditions.

From the direct discussion about factors listed above it is possible to claim that the general sentiment seems to be very positive ("*I like it here*", "*it is a 100 million times better than in the past*", "*everything is much more efficient*"). In most cases, the expectations regarding the new open space layout are positively satisfied ("*before joining this company I worked in an open space setting. In the old premises I felt I had taken a step back, now I feel things are normal again*"), and in some cases they have actually exceeded improvement expectations. About one third of interviewed employees have switched from a closed office to an open space layout with a generally favourable attitude (*"I had a closed office but I have grown used to it - now there is more contact with colleagues"*). It is clear that the opportunities for social interaction, for exchange and for establishing new relations have increased (Blakstad, et al., 2009), which everybody considers a positive aspect ("*we know each other better, we have met new colleagues*"). Among other things, this element was considered the most important factor (score of 4.3) that can affect the quality and efficiency of work ("*The new layout improves interaction among colleagues and helps us feel more part of a team*").

The outward image of the premises is considered one of the best factors. The architectural features employees are most satisfied by are the equipment in the meeting rooms, common areas for guests ("*the company image has gained a lot*", "*I always receive compliments from guests*") and quality of light (not be confused with 'control of light', which is related to the quantity of light and being able to manually adjust its intensity). On the contrary, the inward image seems to have some issues, especially regarding the feeling of equality ("*we were told we were going to the new premises so we would all be equal, 'Break down the barriers, no more status quo!', then it turns out not to be true*"). Some employees complain about disparity caused by closed offices assigned to people who do not actually need them ("*there is a problem of equality,* *actually there are closed offices for colleagues who could integrate with everybody else*"). However, these considerations can be rated as 'overcome' by the answers recorded in the questionnaire completed by the focus group participants, who on the whole gave the feeling of equality a positive assessment in terms of satisfaction (3.5), which actually exceeded the expectations compared to the given level of importance (2.9).

5. Discussion

The study has demonstrated the success of the project in terms of overall employees' commitment, satisfaction and productivity, as declared by themselves. The new workspace features have been introduced in order to react to the change of perspective that is affecting the traditional ways of working. The update of the office setting according to the new trends – including hot-desking, encountered the favor of building occupants, despite initial doubts. Thanks to occupants' consultation, it was possible to assess the appropriateness of the new configuration and to fine-tune the quality of the intervention. The users gave warnings of discomfort during the focus groups, so that some technical problems emerged, such as the control of light and temperature. These were reported to the management who planned a prompt intervention. About work efficiency, most of the concerns could be attributed to incorrect or improper habits on the users' side (disturbance caused by the use of mobile phones, disturbance caused by people moving around and privacy related issues). These are likely to be resolved simply as a result of people becoming used to the new conditions and thanks to a good communication and education strategy implemented by the HRs.

Particularly crucial to this extent was the phase of reporting findings. At a first stage, a written report was delivered to the management, providing all the details about research methodologies, conclusions and possible actions to implement with indications for prioritization, in order to support the decision-making process. Afterwards a presentation was organized, inviting all the employees who took part in the focus groups. Here the main outcomes of the research were explained in an understandable way, trying to focus on those behavioral aspects that could positively affect the working experience. Moreover, the real estate and facilities managers introduced the actions they were going to undertake in light of consultants' recommendations. Involvement of employees in decision-making is likely to foster a sense of common identity and to promote motivation and commitment. In this phase the evaluator assumed the role of mediator, helping communication and negotiation of consensus (Preiser & Schramm, 2002).

In the end, it was confirmed that the most important worries troubling the employees before the move were mostly inconsistent. No waste of time while looking for a free workstation, no problems in relations with colleagues, and no loss in normal work efficiency was seriously detected. In fact, many free desks are always available and enhanced relationships with colleagues are reported as one of the most satisfactory factors. The risks of implementing flexible workstations with open-space and hot-desking were positively faced and brought benefits in terms of interactions, feeling of equality and informal working atmosphere. All these aspects characterize the new ways of working and should be endorsed by the office environment. This is the extent to which an 'intelligent office building' can have a meaning for corporations. It should be able to adapt every time to the changing necessities of the company that it hosts and to provide the occupants with the right backing for their multiple activities. Then, of course, an office building is not intelligent by itself, just for its architectural configuration and technical infrastructure, but it is primarily the way it is managed that makes the difference.

6. Conclusions

The present research should be considered one of the few efforts in the post-occupancy studies conducted in Italy. Therefore, it represents one of the actual best practices in workplace change management in an Italian context, which will contribute to building a cross-cultural framework of evaluation data on building types like intelligent office buildings. Moreover, hopefully it will encourage the evaluative stance throughout the building delivery process. The implementation of a post-occupancy study is important both for verifying the results of a project after its completion, which is needed in building management, and for gathering data suitable for further interventions. Particularly, the phase of reporting findings to the end-users brings the immediate outcome of making them feel important stakeholders within the office building and to keep them well-informed about the objectives of the project and its results. This process itself enhances engagement and satisfaction among workers. In addition, it is an important occasion for communicating messages able to turn behaviors into positive attitudes and good habits. The related consequences will be visible after some months, when, for that reason, it will be important to perform further surveys.

With regard to this specific case study, the main objectives to accompany the workers through the workplace transformation and to verify the pre/post-transfer impacts towards the harmonization of the new spaces with their requirements were met.

An external consultant's job can be important for helping companies switch from a traditional way of working to a smart working model and conveniently match the workspace with the organization's new objectives and values. Ideally, this accompanying function should last from the very beginning of the project until the delivery of the building, and even afterwards with a continuous monitoring activity. Through the whole duration of that period, it is possible to understand the initial intents and to verify them against the everyday operation of the workspace. This long and complex process is the only means to fine-tune the quality of office buildings. Most of the time, because of a lack of resources or motivation, it is not possible to carry on this preferential relation with the company. Nevertheless, it would be useful, at least, to retrieve some data about the use of the workspaces, since they are suitable for keeping the building value under control. Going into more detail, it seems valuable to monitor space occupancy rates, employees' habits concerning their ways of working (presence during the week and activities during the day) and occupants' perception on how the workplace affects work quality and effectiveness. These are the main variables that reflect if an office building is working properly or not. Some professionals should be in charge of collecting them and to promptly adopt the best measures for adjusting the space features according to these changing variables. Today, thanks to sensors and portable devices it is not difficult to gather some of them. Nevertheless, some room for innovation exists especially where occupants' involvement is required – in light of the new ways of sharing likes and dislikes – and in assembling qualitative shades with quantitative assumptions. More research would be interesting to understand how to combine this information in everyday practice.

In fact, on the basis of our experience, while relying on only one source of information could have produced misleading results, matching both quantitative and qualitative data through the triangulation of different methodologies helped obtain consistent outputs. On one side, it is important to remark that the role of a consultant needs to be supported by internal sectors. On the other, it is evident how different skills (the consultants' know-how, with the CRE, HR and FM experience) have collaborated to generate key insights valuable for driving the management of the new premises and for informing eventual future corporate projects. This case study also suggests the necessity of complementing real estate and facility management with human resources policies and underlines the importance of devoting proper attention to internal communication. May it be necessary to appoint a new professional who is able to apply an integrative approach as such?

An 'intelligent office building' is one that successfully relates to its occupiers, being able to adapt according to the changing needs of its users. That is the extent to which an 'intelligent building' can support human activity in daily life at work. This can depend, on one hand, on the technological devices installed with advanced control technology and the architectural features characterizing the work setting, as a flexible office space. But, on the other hand, it depends on the organizational structure and managerial intentions. The work conducted demonstrates how not only the result of a post-occupancy evaluation is important, but the process itself is very helpful. Using a user-centred approach, employees feel more engaged, know they are part of the stakeholders and, consequently, become more conscious and responsible for their behaviour. Their contribution can make buildings function better. Only through this kind of attitude, can it be possible that an office building takes the role of enabler for the well-being of workers, the success of companies, and the competitiveness of regions and countries.

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Appendix (Survey questionnaire)

The appendix shows part of the questionnaire that was administered to the participants in the focus groups. The intent was to induce the interviewees to reflect on some key points, on the basis of which the debate was developed. This method was useful also to quantitatively collect some data considering the large number of people involved in the meetings.

1. What of the following aspects correspond to doubts or worries that you had before the move to the new premises?
   Which of them were positively solved and are no problem at present? Which ones, instead, are effectively cause of annoyance to you?
   For instance:

Table 2: Question 1 of the questionnaire

	Pre-transfer doubts/worries	*After-transfer feeling*	
		Positive matching	*Negative matching*
☐	*Efficiency in daily work*	☐	☐
☐	*Time spent looking for a free workstation*	☐	☐
☐	*Working relationships with colleagues*	☐	☐
☐	*Others: ………………………………………*	☐	☐

2. In your ‘typical working week’, what days do you usually work in the office?

Table 3: Question 2 of the questionnaire

	Weekday	*Morning*	*Afternoon*
☐	*Monday*	☐	☐
☐	*Tuesday*	☐	☐
☐	*Wednesday*	☐	☐
☐	*Thursday*	☐	☐
☐	*Friday*	☐	☐
☐	*Saturday*	☐	☐

3. In your ‘typical working day’ in the office, how much time do you usually spend in the following activities?
   Among them, what are the activities that you do individually and what require collaboration with other colleagues?

Table 4: Question 3 of the questionnaire

	Activity	*Individual*	*Collective*	*Percentage of time*	*/100%*
☐	*PC, writing, reading*	☐	☐		*/100%*
☐	*Storing, filing, paper handling*	☐	☐		*/100%*
☐	*Phone*	☐	☐		*/100%*
☐	*Conference call*	☐	☐		*/100%*
☐	*Video conference*	☐	☐		*/100%*
☐	*Presentation*	☐	☐		*/100%*
☐	*Meeting/talking*	☐	☐		*/100%*
☐	*Learning*	☐	☐		*/100%*
				100%	*TOT.*

4. Express the level of importance (from 1 = very low, to 5 = very high) that you attribute to the following factors, reflecting if they can influence or not the quality and effectiveness of your daily work.

Table 5: Question 4 of the questionnaire

	Factors	*Not important*				*Very important*
		1	*2*	*3*	*4*	*5*
1.	*Personal and non-shared work space*	☐	☐	☐	☐	☐
2.	*Impact/quality of the welcome area*	☐	☐	☐	☐	☐
3.	*Being personally able to control the temperature*	☐	☐	☐	☐	☐
4.	*Relaxing and informal atmosphere*	☐	☐	☐	☐	☐
5.	*Privacy*	☐	☐	☐	☐	☐
6.	*Being able to see outside*	☐	☐	☐	☐	☐
7.	*Being disturbed by mobile phones*	☐	☐	☐	☐	☐
8.	*Being disturbed by people moving*	☐	☐	☐	☐	☐
9.	*Feeling of equality*	☐	☐	☐	☐	☐
10.	*Being able to keep personal items*	☐	☐	☐	☐	☐
11.	*Relaxation areas*	☐	☐	☐	☐	☐
12.	*Sense of personal safety*	☐	☐	☐	☐	☐
13.	*Opportunities to relate with colleagues*	☐	☐	☐	☐	☐
14.	*………………………………………………………………*	☐	☐	☐	☐	☐

5. Now, express the level of satisfaction (from 1 = not satisfied, to 5 = very satisfied) that you attribute to the same factors, in respect of the workspace where you work at present.

Table 6: Question 5 of the questionnaire

	Factors	*Very dissatisfied*				*Very satisfied*
		1	*2*	*3*	*4*	*5*
1.	*Personal and non-shared work space*	☐	☐	☐	☐	☐
2.	*Impact/quality of the welcome area*	☐	☐	☐	☐	☐
3.	*Being personally able to control the temperature*	☐	☐	☐	☐	☐
4.	*Relaxing and informal atmosphere*	☐	☐	☐	☐	☐
5.	*Privacy*	☐	☐	☐	☐	☐
6.	*Being able to see outside*	☐	☐	☐	☐	☐
7.	*Being disturbed by mobile phones*	☐	☐	☐	☐	☐
8.	*Being disturbed by people moving*	☐	☐	☐	☐	☐
9.	*Feeling of equality*	☐	☐	☐	☐	☐
10.	*Being able to keep personal items*	☐	☐	☐	☐	☐
11.	*Relaxation areas*	☐	☐	☐	☐	☐
12.	*Sense of personal safety*	☐	☐	☐	☐	☐
13.	*Opportunities to relate with colleagues*	☐	☐	☐	☐	☐
14.	………………………………………………………………	☐	☐	☐	☐	☐

Developing “Owner Project Capabilities” for Public Sector Clients Delivering Infrastructure Projects: A Dynamic Capabilities Approach

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Abstract

Infrastructure lies at the very heart of social and economic development of a country and the world at large. Yet, despite its importance the delivery outcomes of infrastructure projects have been far from satisfactory. Infrastructure projects face issues of cost and schedule overruns as well as failure to realise expected benefits. Research in the field of project management has emphasized the importance of a 'strong owner' to the success of projects. To act as strong owners, public sector clients that deliver infrastructure projects need to have project capabilities to perform various roles. This paper presents an initial framework on how public sector clients can develop ‘owner project capabilities’, so as to improve infrastructure project delivery outcomes. The theoretical perspective of dynamic capabilities is employed to study how these public sector clients can develop the requisite ‘owner project capabilities’. It is suggested that learning is the mechanism by which owner project capabilities are developed, based on the concept of routines development, and argues for the incorporation of the organizational learning theory within the dynamic capabilities framework. Theoretically the paper contributes to the extension of the current application of organizational capabilities into the public sector infrastructure context. Additionally, it also provides initial insights into the relationship between owner project capabilities and (organizational) learning; and the difficulties faced by public sector clients during the process of capability development.

Keywords: infrastructure development, client capabilities, project capabilities, project owner, project learning

1 Introduction

Infrastructure lies at the very heart of social and economic development of a country and the world at large (Stevens *et al*., 2006). It serves as the bedrock of a nation's competitiveness, economic development, and social well-being (World Economic Forum, 2014). Notwithstanding the importance of infrastructure, most countries experience difficulties in providing for their infrastructure needs, in addition to ensuring that delivered infrastructure provides planned benefits. Whilst the advanced or developed countries face the challenge of maintaining extensive transport, energy supply, water, and telecommunications network as well as upgrading and modernizing them, developing countries face the challenge of meeting their basic infrastructure needs such as access to water and sanitation, electricity, roads and health facilities (McKinsey Global Institute, 2013). The result is an increasing infrastructure deficit, or 'gap', estimated at US$ 1 trillion per annum (McKinsey Global Institute, 2013; World Economic Forum, 2014).

This expanding infrastructure gap comes at a time when public sector clients, around the world, are increasingly being questioned regarding their ability to achieve value for money, and face the grinding pressures of improving infrastructure project delivery while cutting administrative costs. In short, they are being asked to do more for less, i.e. produce more public value with fewer resources. Key issues, frequently brought up, include the lack of appropriate levels of procurement skills that will allow them engage with their private sector supply chain partners on equal terms; sub-standard efficiency and productivity in the production phase; and unnecessarily large organizations with high administrative costs. Furthermore, cost and time overruns are increasingly highlighted (Flyvbjerg *et al*., 2003; Miller and Lessard, 2000; National Audit Office, 2009) and subjected to public scrutiny.

This paper sets out to investigate how these public sector clients charged with project delivery could develop capabilities they need to improve on project delivery outcomes. The paper starts by reviewing the outcomes of completed infrastructure projects and draws attention to the role of the project owner to these outcomes. It argues that to improve project outcomes, project owners need to become strong owners by having the capability to perform various roles. We then review the literature on organizational capabilities with particular focus on addressing the capabilities subset of project capabilities. It is suggested that project owners need 'owner project capabilities' made of three distinct subsets to act as strong owners. The rest of the paper is devoted to answering the question of how public sector clients may develop the desired level of owner project capabilities. In answering this question, the theoretical framework of dynamic capabilities, which focuses on how organizations undertake change by creating, extending or modifying its resources is reviewed and suggested as an appropriate lens to study how capabilities are developed by public sector clients. In particular, how routines - the building blocks of capability – develop and evolve is suggested as giving an insight to capability building. We then give an initial insight into how routines could be developed via project learning and some difficulties that are faced by public sector clients during this process. The paper concludes by arguing that there is no 'one-size fits all' capability set for public sector clients, and that it is a matter of knowing the scope of capabilities they need to manage their projects and how to develop it. Additionally it also suggests that there is also the need for further insights into the relationship between capabilities and learning so as to better understand how capabilities are built.

2 Project Outcomes and the Importance of a Strong Owner

As noted above, the delivery outcomes of infrastructure projects worldwide have over an extended period been poor and far from satisfactory. This has led to increasing scrutiny and questioning of the performance of project owners and operators by their stakeholders. Typically, project owners are being questioned on: their commercial capabilities, i.e. their ability to interact on equal and professional terms with the private sector (e.g. National Audit Office, 2009); project assurance capabilities, i.e. their ability to independently and objectively verify whether a project is on schedule, within budget and will meet future performance (e.g. National Audit Office, 2010, 2012); and their project delivery capabilities (e.g. LEGCO, 2014). Such accusations are supported by a plethora of studies conducted on completed infrastructure projects. These studies show that projects are usually subjected to substantial cost and schedule overruns, fail to realise expected benefits and meet projected demands (Flyvbjerg *et al*., 2003; Flyvbjerg, 2014; Merrow, 2011; Morris and Hough, 1987). For example, in a series of studies on transportation projects in different jurisdictions, Flyvbjerg (2014) suggests that nine out of ten projects face cost overruns, while the demand and benefit side of the projects were out of forecast by between 20-70%. Indeed, it seems that issues of cost and schedule overruns and, failure to derive expected benefits are the norm rather than the exception in infrastructure delivery (Flyvbjerg, 2014; Flyvbjerg *et al*., 2009).

Perhaps the most influential work on the poor outcome of infrastructure projects in recent times has been that of Bent Flyvbjerg and colleagues (e.g. Flyvbjerg *et al*., 2003; Flyvbjerg *et al*., 2009; Flyvbjerg, 2011). This work has done much to clarify project escalation, and how optimism bias and strategic misrepresentation contributes to cost and time overruns on many projects. However, these two concepts have a higher degree of explanatory power in economic infrastructure than in social infrastructure, and it remains the case that many projects experience cost and time overruns without optimism bias or strategic misrepresentation being present (Love *et al*, 2012). Other studies have instead identified factors such as the inability of the project owner to: properly control the front end definition; shape project strategy and cope with political, economic and social turbulence and outside institutions; drive the project and deal with partisanship and contractual turbulence, as factors that affect project delivery outcomes (e.g. Merrow, 2011; Miller and Lessard, 2000; Morris and Hough, 1987). Ultimately, what many studies, on this topic have in common is the conclusion that causes of project failures usually lay in areas that are within the remit of project sponsors rather than that of project execution or implementation by the project supplier or contractor (see Flyvbjerg *et al*., 2003; Meier, 2008; Miller and Lessard, 2000; Morris and Hough, 1987).

In consequence, there is now a growing body of work focusing on the owners and sponsors of infrastructure projects. Although it is still the case that majority of the project management literature is supplier focused. A major scholarly contribution in this regard has been the work of Peter Morris (Morris, 1997, 2013; Morris and Hough, 1987). Arising out of his research on major projects he advocated for the concept of a 'strong owner' as a dimension of project success (Morris and Hough, 1987). This perspective of the role of project owners has recently been reinforced by Merrow (2011), who also advocates for a strong, distinct owner team that will be able to interface authoritatively with the supply side. This view is succinctly summarized as: "The contractor's job is to deliver a project as specified, on time and on budget. The owner's job is to specify the right project" (Merrow, 2011, p. 126). This basically means that the contractor cannot do the owners' work, and *vice versa*, as they have different sets of roles, goals and expectations on the project. This conclusion is supported by the findings of Hui, Davis-Blake, and Broschak (2008) who showed that project owners who demonstrated or exhibited high 'owner dominance' tend to achieve better outcomes.

2.1 The role of the infrastructure owner

Infrastructure projects are delivered within a temporary organization domain created by the coalition of two principal types of organizations: the relatively permanent owner and operator that supplies capital resources to the project and the relatively permanent project-based firm (supplier) that provides human and material resources to the project organization (Winch, 2014). In general terms, the difference between these two organizations is that the latter are project based and work predominantly on projects, while the former are not. The relatively permanent owner and operator on infrastructure projects, is usually a public sector organization in the form of Governmental agencies, departments, municipals, counties, bureaus or any such similar designation that owns and operates completed infrastructure. These permanent owners and operators may also be referred to as 'public sector clients'. Generally the core concern of such 'public sector clients' is that of operations and maintenance of completed infrastructure such as the regular supply of power, ensuring roads are in good condition for transportation purposes, etc. (Winch, 2014). As such, they tend to develop competencies or capabilities in areas core to their operations other than that of infrastructure delivery. However, it is the case that these public sector clients engage in the delivery of infrastructure projects on a periodic basis as the need for them to extend their infrastructure base arises. This may be due to ongoing business concern such as the need to grow, perceived inadequacies in existing infrastructure, or policy initiatives (Winch, 2014). To do so, they are required to define the project thereby delineating its scope and specifications. They are also required to procure and manage project suppliers to ensure project is delivered to specifications, set up internal control measures to ensure the project is completed within budget and schedule, and integrate the completed infrastructure into existing operations. Achieving the above objectives for these infrastructure owners is, however, fraught with challenges. A prime challenge is how to make use of their limited existing resources to develop and promote infrastructure projects whilst maintaining core capabilities necessary to operate and maintain delivered infrastructure. In effect, public sector clients face the tension of using limited resources to develop and maintain capabilities for infrastructure delivery while also performing their core duties of operating and maintaining completed infrastructure.

2.2 Owner capabilities

Organizational capabilities are commonly defined as the particular combination of skills, competences, resources, routines, and behaviours, which enable effective performance and generate competitive advantage. The capabilities literature is vast and varied but is usually divided into two main types: 'operational capabilities' which capture the day-to-day, month-by-month ability of the organization to deliver on its mission; and 'dynamic capabilities' which capture the ability of the organization to change and develop in order to meet new challenges. In other words, operational capabilities deal with the ability of the organization to deploy its resources and to efficiently execute its daily activities; whilst dynamic capabilities deal with how the organization could undergo change and in the process extend its resource base (Helfat *et al*., 2007; Winter, 2003). What is either an operational or dynamic capability is an issue of context and very much dependent on the core activities of the organization. Thus, what may be an operational capability for one organization may be a dynamic capability for another.

A sub-set of the capabilities literature is that of 'project capabilities' stemming out of research on innovation in complex product systems and the project-based organization. These project capabilities refer to the specific knowledge and experience required to engage with internal and external customers, develop bids and implement and execute projects, and can be summarised as the appropriate knowledge, experience and skills necessary to perform pre-bid, bid, project and post-project activities (Brady and Davies, 2004; Davies and Hobday, 2005). The conceptualisation of project capabilities and associated empirical studies has mainly been supplier focused. However, as the literature in the previous section shows, the project owner needs to act as a strong owner for successful delivery of projects. To be a strong owner the project owner may have to perform roles such as being able to manage its interface/interaction with the project supplier, defining the project, and setting up internal control measures among others during project delivery. This ability of the owner organization to mount temporary projects may be viewed as its project capabilities - '*owner project capabilities'* (Winch and Leiringer, 2016*)*. Owner project capabilities are made up of three conceptually distinct sets: of capabilities: '*Strategic capabilities*, *Commercial capabilities*, and *Governance capabilities* (Winch and Leiringer, 2016). *Strategic capabilities* are those which the owner needs in order to successfully implement its investment projects and required at the strategy or front end stage of a project. *Commercial capabilities* are the set of capabilities needed to manage the interface between the owner organization and the project based supplier firm. It is mainly outward facing as it focuses on the interaction between the owner organization and project supplier. *Governance capabilities* are those needed to manage the interface between the owner organization and the temporary project organization involved in the project.

A major question that arises, and the one that is of main interest in this paper, is how the desired level of owner project capabilities can be developed. The answer is by no means straightforward. Investment in infrastructure assets is inherently lumpy compared to managing operations, and therefore poses a number of challenges. To further complicate things different sets of capabilities are acquired in different ways, and the process is heavily influenced by historical factors (i.e. path dependent). Some capabilities can be seen as the outcome of learning through repeated interactions and will follow different learning trajectories depending on if, for example, they concern formal or trust based relations. Other capabilities are the result of specific human resource investments. This means that some capabilities can be developed rather quickly whilst others can only feasibly be developed over time. It also follows that where the investment programme is particularly lumpy or where the size of the client organization is restricted, as will be the case if attempts are made to reduce head count and cut overhead costs, there might be a strong temptation to use third party consultants. However, the use of third party consultants entails the risk of failing to develop adequate in-house capability, even if it is viable (Merrow, 2011). Possessing adequate owner capabilities in-house and the process of developing these capabilities is useful for public sector client organizations if they are to act as strong owners and in the process improve project outcomes.

3 Dynamic Capabilities

In answering the question of how the desired level of owner project capabilities could be developed, the theoretical framework of dynamic capabilities, which focuses on how organizations rely on internal resources to undertake change, offers itself as a useful theoretical lens. Infrastructure projects, which are temporary in nature, fundamentally, are about change in the client organization, as they either extend in scope the existing operational capabilities or create new ones to meet new challenges.

As such it is possible to view the view owner project capabilities as the permanent organization's ability to mount temporary projects by making use of internal resources to undertake this change.

Dynamic capabilities, defined as "*the capacity of an organization to purposefully create, extend, or modify its resource base*" (Helfat *et al*., 2007, p. 4), explains how organizations renew competences and undergo change in order to achieve congruence with changing environmental and business conditions (Teece *et al.*, 1997). In general, organizations renew their competencies, develop new capabilities and undergo change by modifying their resource base – the tangible, intangible and human assets the organization owns, controls or has access to on preferential basis and enables it undertake its activities or routines (Helfat *et al*., 2007). This ability to purposefully create, extend, or modify the resource base is very much dependent on the 'managerial' and 'organizational' processes available to the organization as these are the mechanisms by which organizations either develop or put dynamic capabilities to use (*ibid)*. These processes show how things are done, and are used to achieve two main functions: search and selection procedures – decision making; and configuration and deployment of selected decision – implementation. The search and selection procedure is more of a managerial process whilst the configuration and deployment of selected decision combines both the managerial and organizational processes. Managerial processes specifies strategic paths of decision making during search and selection procedures. The combination of managerial and organizational processes specifies which routines will be used to undertake change processes such as creating new routines, extending or modifying existing ones (*ibid)*. Integral to the deployment of organizational processes are strategic routines such as *resource integration routines; resource configuration routines; routines to gain and release resources; and exit routines* which are used in undertaking the change process (Eisenhardt and Martin, 2000).

In addition to the processes available to an organization, the development of dynamic capabilities is very much dependent on its current 'position' and the 'path' it has taken (Helfat *et al*., 2007). Positions form the base of any future capability development as they represent investments made by the organization over the years. This includes current specific endowments of technology, intellectual property, complementary assets, customer base, and its external relations with suppliers and complementors (Teece *et al*., 1997). Renewing the existing capabilities of an organization without regard to the prior investments it has made has significant implications. There are substantial cost elements involved in discarding existing positions in addition to the fact that some positions, which give the organization its current capabilities and performance advantages, are difficult to replace. Furthermore, capabilities are largely cumulative and rely on previous knowledge. As such, the path travelled by an organization determines its existing capabilities, as well as possible future ones. Thus, past investment may either enhance or constraint the future direction of the organization. This has led to the general notion of capabilities being seen as path dependent and subjected to historical factors (Helfat *et al*., 2007; Teece *et al*., 1997). Accordingly, the paths and positions of an organization guide and shape up the processes during capability development.

3.1 Development and Evolution of Capabilities

The actual process of developing capabilities is by no means a trivial affair. This is partly due to the organization specific nature of capabilities where a collection of routines and resources gives an organization its unique capabilities. Also, the unobservable nature of capabilities in addition to embedded tacit knowledge makes it difficult to observe how they develop. A perspective that gives an initial insight into capability development is the process of how routines develop. Routines are argued to be the fundamental unit or building block of organizational capabilities. As such, capabilities are sometimes defined in terms of routines. Winter (2003) for instance describes capabilities as a high-level routine or collection of routines that enables an organization produce an output. Understanding how routines develop within the organization may give an insight into capability development.

Routines encompass the accumulation of knowledge. Organizations accumulate and/or gain knowledge, leading to the development of routines, by engaging in learning to retain practices or activities that improve efficiency and are deemed beneficial to existing operations; or searching for new knowledge that brings in new practices and development of new routines. Various learning mechanisms, or processes, guide the type of knowledge that is accumulated. Notwithstanding the type of learning mechanism(s) engaged in, one of two major outcomes results: a change or modification of existing routines (and capability), or an improvement of existing routines (and capability). To improve existing routines, organizations undertake *exploitative learning* where they learn from practice, trial and error (experiential learning), and selection and retention of behaviours or routines that are beneficial to the activities of the organization (Zollo and Winter, 2002). This leads to the development of routines that are highly patterned, repetitious or quasi repetitious in character (Gavetti and Levinthal, 2000). Developing new routines in contrast represents a change in how the organization operates, and requires the organization to use *exploratory learning* mechanisms to bring in novel knowledge into the organization to enable the generation of new routines (and capabilities). This is achieved through engaging in a purposeful action and learning, so as to gain new knowledge (Pandza and Thorpe, 2009).

Dynamic capabilities is known to cause change or modification to the existing routines or resource base. This suggests that organizations have to rely more on exploratory learning mechanisms during the development of dynamic capabilities as novel knowledge is what is needed to change existing knowledge trajectories and routines (Pandza and Thorpe, 2009). This has, however, not been the general perspective taken in research that has sought to establish linkage between dynamic capabilities and learning. Existing research seeking to link the two concepts has focused mainly on exploitative learning arising out of experiential learning and knowledge transfer mechanisms with less emphasis on how novel knowledge that leads to the development of new routines and knowledge is brought into the organization. For example, Zollo and Winter (2002) suggest that dynamic capabilities evolves via three learning mechanisms: behavioural learning mechanisms of *experience accumulation*; and more deliberate cognitive processes of *knowledge accumulation* and *knowledge codification* derived from reflection on past experience. Similarly Eisenhardt and Martin (2000) identified the experiential learning mechanisms of: *repeated practice, mistakes, and pacing of experience.* This perspective could, however, be questioned, as the change role nature of dynamic capabilities makes it unlikely that experiential learning is solely responsible for dynamic capabilities development (Pandza and Thorpe, 2009). Instead, it could be argued that the focus should be on integrating into the dynamic capabilities framework an organizational learning theory that has both exploratory and exploitative concepts.

4 Learning for Public Sector Clients

It is evident from the discussion above that learning plays an important role in the development of dynamic capabilities. Learning is, however, a broad concept consisting of different types (or subsets) based on the context and organizational type. The type, or subset, of learning used by public sector clients to develop their project capabilities is that of 'project learning' defined as "… that which encompasses the generation, capture and transfer of learning by individuals and groups within project settings" (Scarbrough *et al*., 2004a, p. 492). Project learning thus occurs: from and in between projects; within and between the temporary project organization and the permanent parent organization; and across various levels such as individual, group (project) and the organizational levels (Artto *et al*. 2011; Scarbrough *et al*., 2004a). The different ways by which project learning occurs may usefully be classified into two main categories: intra- project learning and inter-project learning (Swan *et al*., 2010). Intra-project learning occurs during interactions with other actors on a project and may lead to the generation of novel knowledge. Inter- project learning in contrast occurs when the novel knowledge, or efficient ways of undertaking existing activities, is deployed within the wider organization and on various projects sites. This type of learning leads to improvement in existing routines.

It is commonly stated that the multidisciplinary background of the various actors on a project allows for cross disciplinary problem solving which enhances learning. However, despite the assertion that project environments are appropriate for learning the evidence suggests otherwise – it is generally difficult to engage in project learning (Edmondson, 2003). This is due to a multiplicity of factors such as: the one off and non-recurring nature of projects which makes it difficult to apply knowledge gained from one project to another (Hobday, 2000); the lack of formal structures and incentives to enable learning be institutionalized (Ekstedt *et al*. 1999; Scarbrough *et al*., 2004b); and the decentralized nature of organizations engaged in projects where knowledge gained by one unit is not transferred to others (Eriksson 2013). The multi-level layer of project organizations also affects learning as they tend to act as learning boundaries. This arises when learning at one level generates new shared practices that are different from practices elsewhere in the organization (Scarbrough *et al*., 2004b). This may result in a situation where the transfer of learning from one context (level) to another becomes more arduous due to the need to transfer practices which are completely different to the wider organization.

Public sector clients in particular face other challenges that affect their ability to learn and subsequently develop capabilities. They commonly do not possess all the resources needed to undertake the project. Thus, rather than deploy its own resources and in the process engage in learning, they are forced to outsource and use consultants for duties that are not core to their domain. Outsourcing, although having some positive effects especially in the short term, has long term implications as it affects the ability of public sector clients to engage in learning and subsequently develop capabilities. Consultants and suppliers become repositories of knowledge, as well as are the direct recipients of experience on a project, with the client having no technical input to the project. Furthermore, even where public sector clients decide to engage in learning, they may find it challenging to value, assimilate and exploit the new or novel knowledge being brought into the organization due to a lack of prior related knowledge for infrastructure project delivery. Or put somewhat differently, they may not have sufficient absorptive capacity (Cohen and Levinthal, 1990). Additionally, where the public sector client organisation is able to engage in learning, it faces the challenge of maintaining and making use of the knowledge so it does not atrophy due to infrequent use.

5 Concluding remarks

Many countries presently face massive investments in social and economic infrastructure. The economic role of social and economic infrastructure in modern societies is well understood; and the many contemporary pressures put on the scarce resources available, such as citizens' rising expectations, ageing infrastructure, urbanisation, and sustainability are well rehearsed. What has received significantly less systematic research attention is the role of government bodies in the execution of the projects through which they acquire such infrastructure assets. In this paper, we have tried to take a first step in partially rectifying this imbalance by investigating the public sector organizations charged with the definition and delivery of large infrastructure projects, what capabilities they need and how they can develop the capabilities they need to do so.

History has shown that it is neither feasible nor desirable to establish client organizations that are literally one-stop shops. Thus, it is not a matter of adding extra capabilities to the organization just for the sake of it. However, the whole cycle of making a capital investment infrastructure through ensuring that funds and human resources are available; engaging with suppliers of vital inputs to the new infrastructure and stakeholders with interests in that infrastructure; engineering the facility and coordinating the project to deliver it; and sharing the knowledge gained both within the program of projects to deliver the strategic initiative and capturing it for future investment projects, demands that sufficient resources are allocated to do so. There are many willing suppliers of the specialist services required to move through this life-cycle, but they all demand managerial attention. Further, various procurement types and client organization may demand different combinations of capabilities to manage the whole life cycle. Thus, it is not the case that client organizations should possess all owner project capabilities, but rather knowing the scope of capabilities it will need to manage projects, i.e. what capabilities it may need in-house based on its own unique case, in addition to how it can develop such capabilities to properly manage its suppliers and resources.

We have attempted to demonstrate that approaching the evolution, or development, of dynamic capabilities from the perspective of wholly integrating organizational learning theory will ensure that there is a better understanding of how novel knowledge is brought into the client organization as well as the various learning mechanisms needed at the exploratory and exploitative stages of learning. There is, however, the need for further insights into the relationship between owner project capabilities and learning. This means conducting empirical research on how client organizations undertake learning leading to capability development. These findings will help unravel various learning mechanisms that public sector clients can use to develop their project capabilities.

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Volume III

Building up business operations and their logic

Shaping materials and technologies

Edited by
Arto Saari
Pekka Huovinen

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Preface

This volume III of the WBC16 proceedings is focusing on the building-up and shaping of intelligence into our built environment for life. In total, the 61 papers with the 735 pages are advancing such intelligence in diversified contexts across the globe.

In Section I, firms, business operations and knowledge embedded within the building and construction sector are being built up in terms of business development, market creation, strategic differentiation, competitiveness, knowledge, organisational learning and social responsibility.

In Section II, life-cycles and sustainability within the built environment are being built up in terms of building adaptability, life-cycle maintenance, virtuous and economic sustainability, green business modelling, performance based building, manufactured green buildings, concrete facades renovation, construction materials stewardship, live energy and urban water management.

In Section III, building information modelling (BIM) is being shaped in terms of business value delivery, BIM with Lean Construction, BIM with GIS, data-driven projects, perceptions among clients and users, overcoming barriers, meeting challenges, implementation, predictive semantic inferences and knowledge acquisition.

In Section IV, many novel solutions based on information and communication technologies (ICT) are being shaped in terms of Big Data, integrated and quasi-automated procurement, augmented reality onsite, text mining, virtual reality headsets and smart safety vests.

In Section V, contracting forms, risks and legal issues are being shaped in terms of a “Next Step”, highly economic alliancing, organisational economics, PPPs, risk sharing, extra contractual, context-specific concerns, the concurrency and analysis of delays as well as the adjudication of payment claim disputes.

In Section VI, construction project management (CPM) is being shaped in terms of PM design, stakeholder management, safety design and constructability, time management and space charts as well as cost control via Kaizen and contingencies.

Arto Saari

Tampere University of Technology

May 2016

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Tampere University of Technology

May 2016

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SECTION VI: SHAPING CONSTRUCTION PROJECT MANAGEMENT

The Business Development Management Function: Processes at the Front of the Front End of the Management of Projects

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Abstract

The strategic front-end of the management of projects is where the construction is scoped, defined and designed client-side prior to engagement with main contractors on the supply side through procurement. At the front of the front end on the supply side is the business development management (BDM) function, the euphemism for sales. BDM is claimed to be isolated from other processes along the project lifecycle. Applying marketing theorization around securing work and delivering value for the analysis, this paper addresses BDM in ten major contractors to examine the extent of integration. Marketing offers three theoretical lenses: the transactional marketing mix, the more transformational relationship marketing and the current emergence of the service-dominant logic. Each lens facilitates conceptual evaluation of BDM in terms of current practice at the front of the front end, the extent of integration in the project lifecycle from its own theoretical position, and the rigor of value propositions and delivery. This is complemented at a detailed BDM level by an interaction sales approach. The findings show elements of all theories across the main contractors and in BDM processes in each contractor. A lack of integration is evident using all three analytical lenses and value propositions and delivery are constrained as a result. Management awareness of theory and applied configurations in BDM are thin and provide an explanation for the low integration, resulting in firms constraining their ability to effectively articulate and differentiate value propositions, deliver value propositions to clients and constrain growth in a competitive market.

Keywords: Business Development Management, Marketing Mix, Relationship Marketing, Service-Dominant Logic, Value Propositions

1. Introduction

The strategic front-end of projects is where construction is scoped, defined and designed client-side prior to main contractor engagement. At the front of the front end on the contractor side is the business development management (BDM) function, the euphemism for sales. Projects are specific assets, where selling occurs prior to production to contract. A long period of selling is typical whereby BDM is engaged with selling prior to a specific project and then BDM is injected into the project front end once the specific project is identifiable.

The sales function includes securing sales and delivering value. The emphasis between the two varies conceptually according to the underpinning marketing theorization. There is broadly one transactional approach, the *marketing mix*, and two transformational approaches, *relationship marketing* and the *service-dominant logic*. The transformational approaches place more emphasis on value. The sales function has been neglected in the extant management and marketing literature, especially in regard to value (e.g. Jones et al, 2005; Haas et al, 2012). Sales or BDM has received minimal attention in construction (Smyth, 2000). Marketing and BDM are claimed to be isolated in the project domain (Pinto and Covin, 1992; Turner, 1995). This paper tries to address BDM operations. It investigates: (i) range of activities conducted within the function and related to this (ii) the extent of integration with other functions along the project lifecycle. Applying marketing theorization around securing work and delivering value for the analysis. At a detailed level of BDM an *interaction sales approach* is employed (Haas et al, 2012).

Methodology and methods are interpretative and qualitative. The empirical evidence is drawn from 10 main contractors to examine the way selling is conducted and how value is addressed for delivery and realization. The findings show elements of all three theorizations underpinning BDM processes across the contractors, yet selling is largely conducted without strategic and tactical guidance. Integration is minimal, affecting value propositions, relationship management and practices of co-creation of value. Contractors therefore constrain their service provision from the outset of the project lifecycle. The paper concludes that management lack awareness of theory and a systematic approach to BDM. This constrains selling capabilities, configuring valuable propositions and value realization by clients post-completion. Construction firms therefore curtail potential market growth.

Structure of the paper is traditional: a literature review, methodology and methods, findings and analysis followed by the conclusions and recommendations on BDM in construction.

2. Literature Review

2.1 Marketing Theorization and the Strategic Project Front-End

The management literature has emphasized the business model concept in recent years (e.g. Zott and Armit, 2008). Business models embody strategy, structure and processes with an associated earning logic of revenue and profit. The marketing strategy, of which selling forms a part, is part of the model, even though the mainstream management and marketing literature have few overt connections. Marketing and sales has two main components: securing work and delivering value in order to grown and sustain a reputable business. Although the theoretical approach to marketing affects the emphasis between selling and value, both are necessary to secure new and repeat business, especially project markets (Smyth, 2015).

Marketing has developed three main theoretical lenses: the transactional *marketing mix* (MM) (Borden, 1964), the more transformational *relationship marketing* (RM) (Berry, 1983) and the current evolution of the *service-dominant logic* (S-DL) (Vargo and Lusch, 2004). There are other important contributions, for example entrepreneurial marketing (Morris et al, 2002) and the RM variant of project marketing (Hadjikani, 1996). The lens applied will be largely limited to the three mainstream theorizations. Entrepreneurial marketing has hardly been addressed for projects and in construction, while the status of project marketing has been addressed elsewhere, including the extent to which it is a theorization (Smyth, 2015), yet it will be referred to where relevant.

The marketing mix or MM arose from economics around the exchange process and was founded in reference to mass market consumer goods. The emphasis is upon key inputs (McCarthy, 1964) on the assumption suppliers know what they want and choose from predetermined offers on the market. The customer is largely passive until active at the point of exchange. The emphasis is upon selling products and services, value being largely determined from the inputs. In construction, application is conceptually limited because main contractors have few controls over the key inputs apart from price. Additionally, sales occur ahead of production and the exchange occurs over the project lifecycle. However, it was used extensively within the conceptual limits as means to secure work based upon past inputs, that is track record by sector and building type (Smyth, 2000).

Relationship marketing or RM was founded in the market for intangible business-to-business (B2B) services (e.g. Grönroos, 2000). The emphasis is on process. Selling is conducted through organizational and network relationships, supported by systems and procedures to manage the process. The customer or client and other stakeholders are active and relationship management extends into operations in support (e.g. Ford et al, 2003). Relationships are conceived as delivering value and content is negotiated and customized. RM conceptually aligns with construction. Clients are to be managed as much as projects and between projects to manage the sleeping relationship (Hadjikani, 1996), for example through a key account management (KAM) function (Smyth and Fitch, 2007). RM adoption in construction is partial and has lagged many sectors, commitment being incremental (Smyth, 2015).

The service-dominant logic or S-DL emerged a decade ago (Vargo and Lusch, 2004). The emphasis is on value outcomes. Customers are most active, conceived through the axiom of the *co-creation of value* (Vargo and Lusch, 2015). Value is co-created through organizational resources being combined. In projects informs the configuration of value propositions that can optimize value realization in use and in context (Akaka et al, 2013, 2015). Theoretical development has identified co-creation occurring through dialogue (Ballantyne and Varey, 2006) and interaction (Edvardsson et al, 2011). Interaction brings forward some the RM tenets again. In projects, value in context and use echoes the renewed call for a focus upon benefits delivery and impact (Morris, 2013). In construction, the S-DL implies a medium-to-long term view, which is at odds with the short-term incentive structures of management, financial and stock markets (cf. Smyth and Lecoeuvre, 2015). It accords with addressing client organizational problems or servicing the core business for which valuable projects are the solution. It also addresses total asset management, facilities, whole life cost and potentially responding to climate change issues. Marketing theorization can both articulate the current state (Vargo and Lusch, 2004) and carry normative content (cf. Prahalad and Ramaswamy, 2004). The S-DL has yet to be picked up prescriptively in construction practice.

Changing theorization has shifted the approach to value. From the tangible input focus pre-determined by the supplier to a perceptual primary outcome focus realized value in use and context, marketing has increasingly been decoupled from the exchange with price as the measure of value. Yet the emphasis upon price through competitive bidding for construction, the bidding process is also largely decoupled because the bid price typically has little to do with the incurred cost at the time of the final account when the exchange process is complete.

BDM involvement occurs prior to any project. This is part of client management or KAM and operates at a programme management level of the contractor to maintain the relationship, manage service consistency and workload continuity (Smyth, 2000). This is particularly the case where potential and repeat business clients are perceived as valuable to the supplier in terms of growth and profit. The *client lifetime value* derived the project value of work over, say, 7-10 years is significant to project businesses although many contractors retain the transactional focus upon projects as the main unit of financial consideration (Smyth, 2015).

BDM engages with projects at the front-end where the investigation of client needs and configuring solutions is explored in the main contractor. Previous research has pointed out that marketing occupies an isolated position in regard to project management (Pinto and Covin, 1992; Turner, 1995). Yet somewhat paradoxical, there is an argument claiming BDM is a subset of project management, for example applying a funnel approach to link them (Cooper and Budd, 2007). This raises analysis of BDM at a more detailed level.

2.2 *Business Development Management in Construction*

Selling in the extant management and marketing literature has been neglected (Jones et al, 2005; Haas et al, 20102). The sales literature is generally presented as linear, for example: production à sales à marketing à partnering (e.g. Weitz and Bradford, 1999). For projects selling occurs prior to production. While there has been research into the BDM at general level (e.g. Preece et al, 2003), the detailed analysis of the function has been neglected, especially around configuring value propositions in preparation for and in bid management. It requires firm support to align the inputs, develop the relationships and understand the potential value in use. It requires different degrees of organizational and marketing capabilities to conduct this with effect (Möller, 2006).

Selling is a prime emphasis under MM. Selling and delivering value through relationships have similar weighting under RM. S-DL has focused upon conceptual development and refinement with little or no consideration of selling in the role of service provision and value realization. A recent exception is an *interaction sales approach* for the co-creation of value (Haas et al, 2012). The approach develops the line of argument that BDM becomes part of value co-creation through face-to-face interaction. Thus selling and value creation become intertwined. It re-introduces RM tenets through a relational value creating process to the sales function: *the sales function reflects a role of sales as creator of relationship value* (Haas et al, 2012, p. 95), which becomes part of the service value and thus contributes to the ability to sell too. Haas et al (2012) brings forward 4 conceptual categories to understand the sales process:

1. *Jointness value* – resources are combined dyadically and in the network, in the case of projects at the project front-end as well as during construction (cf. Ballantyne et al, 2011). BDM initiates i) identification of the key relations and relational processes, ii) configuration of the value proposition and service delivery, iii) the co-creation of value.
2. *Balanced initiative* – customers are active (e.g. Levitt, 1983), providing preconditions for innovation, collaboration and combining resources to co-create value (e.g. Tuli et al, 2007). In construction, the client is active and the contractor reactive, for example in developing procurement routes and other innovation (Smyth, 2006). This implies support from organizational capabilities and programme management to guide BDM action.
3. *Interacted value* – relationships provide a means to identify and configure value propositions, which hold potential for the client and end-users to optimize value realization in use (Haas et al, 2012). Win strategies emerge from creative dialogue and by committing to reciprocal promises (Ballantyne and Vary, 2006). BDM initiates the process, implying functional integration (Smyth, 2015).
4. *Socio-cognitive construction* – value is phenomenologically and subjectively realized from the functional and symbolic content in use (Vargo and Lusch, 2015). Thus value is

as much behaviourally derived from the specific assets, following the idea that action shapes interpretations (Weick et al, 2005). In construction, BDM has focused upon value as past performance through track record and current execution regarding time, cost, quality and scope, underplaying benefits delivery and impact (cf. Morris, 2013) and educating clients accordingly (Smyth, 2000) – see Figure 1 for further details.

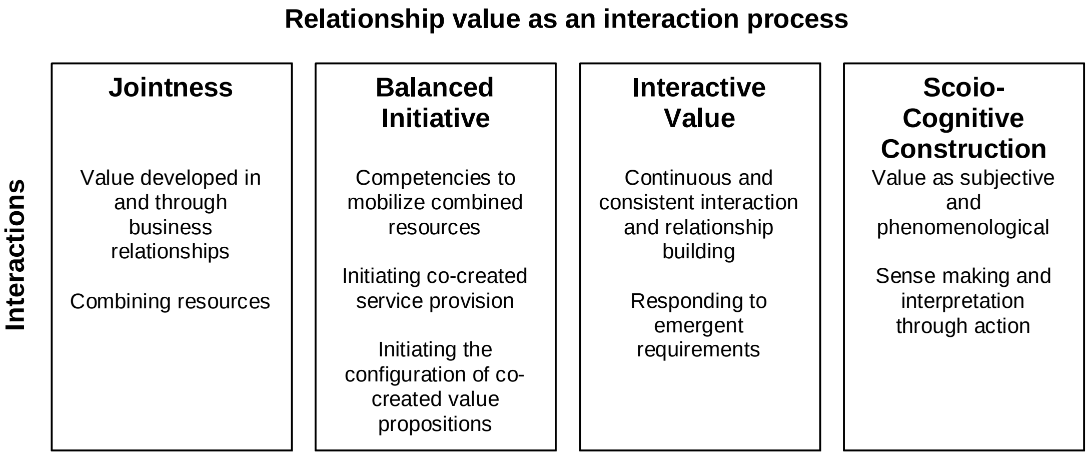

Figure 1: An Interaction-based Framework of Sales' Value Creating Tasks in Projects (developed from Haas et al, 2012)

BDM has a pivotal role at the front of the front-end, connecting the contractor with the client and forming the interface with the project. It has been argued that successful outcomes are dependent upon strategically addressing the front end on the client side (Morris, 1994, 2013) and on the supply side (Smyth, 2015). There are two implications that arise for BDM. First, the interaction sales approach brought forward by Haas et al (2012) has to be conceptually subdivided into the strategic and tactical sales levels of operation to reflect the contractor-project interface and the front end, and the project lifecycle from the front end to the realization of value in use. Second, the long exchange period in construction from post tender negations, through the stage payments to the final account mean that value in use clearly becomes twofold: a) the execution experience as service provision over the entire project lifecycle from the front of the front end to the final account, b) the project content value in use post-completion for the client and end-users. These provide a theoretical contribution to be evaluated through the empirical analysis.

In order to apply the interaction sales approach in detail, the BDM effort to *understand client needs* in order to sell the service and configure value propositions involves a number of potential levels: (i) collecting information on the project and requirements, (ii) knowing the motivations and considerations of the key decision-makers, (iii) understanding client business solutions or organisational purposes the project is addressing, (iv) understanding the client's own core business to get to the bottom of what they perceive as valuable. The MM approach only requires the first level. RM requires the second and third levels. S-DL requires all levels to secure a comprehensive understanding of use value.

3. Methodology and Methods

An interpretative methodology was applied to respect value judgments, subjectivity and information provided in context (Denzin, 2002). Respecting key actors perceptions enriches understanding of attitudes present, the strengths and weaknesses of organizational artifacts, processes and behaviour, yielding meaning to generate patterns of events, draw out experiences, draw attention to outcomes of significance (Smyth and Morris, 2007). The researcher is also interpreting evidence, producing a layered approach (see Table 1). In this research the data comes from 30 semi-structured interviews with those in business development management roles (BDMs) across 10 main contractors. Ownership varied: 4 UK-owned contractors, 4 mainland EU-owned contractors, 1 other European contractor and 1 Antipodean-owned contractor. Sectors of operation included civil engineering and infrastructure, building, refurbishment and fit out, although sector activities did not appear material in how BDM practices were conducted. The period covered is the constrained European market from 2009.

Table 1: Interpretation Levels in Qualitative Research (adapted from Wells and Smyth, 2015)

Levels of Interpretation	Agent	Stage of Interpretation
1.	Interviewee in the main contractor organization	Interviewee interprets events (including processes) as they occur – a sense-making activity
2.	Interviewee in the main contractor organization	Interviewee with other actors moderate their interpretation – an iterative sense-making activity
3.	Interviewee in the main contractor organization	A degree of post-rationalisation as a result of subsequent events, also moderated by social and other contextual factors
4.	Interviewee as informant	Recall moderation in context of interview – interpretative selectivity
5.	Interviewee as informant	Responsiveness to the perceived research agenda and selectivity as to what the actor perceives the researcher wants to hear
6.	Researcher as data collector	Selectivity of information according to values and research context in note-taking and analysis post-interview
7.	Researcher as analyst	Researcher interprets events as perceived in the analysis – a sense-making activity

4. Findings and Analysis

The findings and analysis are presented from the strategy level through the project lifecycle.

4.1 Marketing and Sales Strategy in the Main Contractors

The marketing strategy was variably developed across the firms. It was arguably the most developed in BranCo, applying RM, yet some BDM practices were rooted in MM pipeline selling. Across all the contractrs with marketing plans other functions were largely unaware of the content, for example EuroCo’s procurement department was both unaware of the plan and had no dialogue with BDM to coordinate value propositions in the supply chain. In BritCo marketing was cut post-2008. Marketing” was consigned to a backroom function of processing market information and BDM was absorbed into bid management. UKCo did not have an explicit marketing strategy, seeing BDM as a pipeline of information collection and response – it was reported as *marketing on the run*. EUCo put in place its first marketing plan in 2008 and subsequently developed strategies for key customers, which were presented to board level. Primary content was a strong emphasis on forward work planning. EuroCo customer plans were frequently out of date and not referred to at functional levels (cf. Smyth, 2013). A KAM capability has been introduced for consistent client management. It was poorly resourced and largely operated at project rather than programme management levels.

A strategic intent of jointness to combine resources was absent, despite client demands for collaborative practices in the infrastructure sectors. Contractor perceptions around competitive advantage and intellectual property were constraints to jointness for the co-creation of value through knowledge sharing, innovation and collaborative working. RhoCo and BudCo particularly emphasized these points, but these two organizations were among the most focused on transactional and operational cost. They were defensive rather than transformative to drive dynamic and incremental performance improvement around value.

Procedures to guide BDMs for relationship building and understanding client needs were absent, affecting balanced initiative and interactive value. This represents a lack of strategic support for the tactical BDM operations. BudCo operated a transactional pipeline approach with a strong input-price connection maintained throughout. ElecCo, FinCo and BritCo were also highly transactional and closely adhered to MM practices. Value was perceived as technology and expertise. In EuroCo, management capabilities for innovation and service provision were not recognized. Yet many clients, especially in the public sector were reported to have lost capabilities post-2008 and thus need more strategic support and advice. This was recognized and presented relationship building and co-creation opportunities for FinCo and EuCo, although the latter was better placed and selectively took the opportunity as a type of balanced initiative and interactive value creation.

Overall, strategy development for BDM has improved over the last 15 years (cf. Smyth, 2000), yet remains weak against the theoretical lenses apart from MM.

4.2 BDM at the Strategic Project Front-end

The BDMs sought a mix of high value and high profile clients, with some trade margin offs if the client profile was thought to reinforce sector track record and the ability to secure other new work. This was particularly found in FinCo for public sector and for BranCo for some private sector work. Mid-recession, trade-offs challenged the RM strategy in BranCo. New clients were difficult to secure, especially in new sectors. There was around 10% experimentation in BDM activity for entering new markets and anticipating new markets – an important substitute for market research because contractors reside near the top of the ‘food chain’ (cf. Smyth, 2000). BranCo followed this strategy. One BDM in EuroCo reported that it was difficult to secure resources to prime new sectors even where tasked with the objective. EUCo and BranCo admitted that they were weaker on value than selling. EuCo was the only company that drilled down to all five levels of to *understand client needs*, albeit sporadically and not always succeed in injecting the understanding to value propositions. Initiatives were not always balanced (cf. Haas et al, 2012). BranCo was the only company to employ a *client lifetime value* as a measure, which helped to reinforce interactive value in selling.

Mapping of the key decision-makers helps understand client need as part of RM, namely knowing the motivations and considerations of the key decision-makers.. BranCo was the most effective case company, yet inconsistent practices were also present. Some BDMs conducted formal mapping for their own purposes at organisational, programme and project levels among clients and their representatives, while a few logged their maps on the CRM system, Salesforce®. Engagement with CRM was low across the companies. A number relied on informal processes, mentally mapping people by role and influence. Mapping competencies support interactive value in interaction selling (cf. Haas et al, 2012).

There was a lack of strategic resource commitment and criteria. AntCo tactically committed resources based upon time and effort at project level. Finance management and commercial directors were said to be predominantly transactional. It restricted client engagement and combining resources through jointness.

Customers frequently seek high interaction levels, for example to have a large say in the members of the project teams (Haas et al, 2012; Smyth, 2015). Management awareness of theory and applied configurations are thin with the consequence of low levels of resourced interaction and integration. Practices were uneven and varied. The lack of strategic support was tactically echoed as a lack of guiding procedures.

4.3 BDM Tactics at the Front-end

In the general absence prescribed systems and procedures, routines and action were left to individual responsibility (cf. Smyth, 2015). In FinCo client interaction was cut back following 2008 with reliance upon telephone contact to solicit information to feed the work pipeline, and employing a highly transactional around the bid and contract process: *We tend to be office based. We don't go out and meet the clients*. BudCo are predominantly transactional, claiming to be good at managing high-level relationships yet weak down the hierarchy and into operations. There were similar procedures for internally qualifying project opportunities. These were generally qualified against resource inputs rather than the potential of combined resources to manage risk and create value, that is, through jointness. For example, UKCo classified project opportunities as follows:

1. Platinum – must win;
2. Gold – resources committed to investigation, but the decision to proceed taken;
3. Silver – interesting but no resources committed;
4. Bronze – promising yet too early to know.

In EuroCo opportunities over a threshold cost went to the main board for risk assessment.

Some RM tenets had been absorbed by the BDMs, who were building relationships even if these were left unrecorded CRM IT software. An EUCo BDM summed it up: *its all about people and relationships*; and, *it boils down to some trusted relationships* according to an AntCo BDM. Some BDMs built relationships to improve pipeline information quality and processing. This sales approach overlooked value delivered through relationships or co-creation, including in BranCo. To progress relationships, BranCo made resource commitments against key clients, yet to configure value, non-contractual promises could not be made as the procedures did not exist to deliver against these. Imbalanced initiatives and interactive value were compromised. Cost and risk management mainly drove out value. Even when value was addressed, it was seen in terms of cost, RhoCo pursuing this for efficiency using Six Sigma. Some clients reinforced the transactional approach. However, one client set BDMs "homework" to gauge commitment, offering opportunity to co-created value at the front end. Overall, configuring aligned value propositions proved to be a tactical challenge due to the lack of strategic support.

Some EUCo BDMs perceived value as inputs determined at prequalification. Value was perceived as standard inputs. Prequalification and bidding documents were put together on a cut and paste basis rather than being tailored to context. Many BDMS had no involvement in bid management. FinCo, BritCo and BranCo did, the former two from an MM perspective and the latter from an RM perspective. Yet, BranCo BDMs tended to hand over prospects after pre-qualification. BDM lifecycle involvement, even through a "watching brief" was widely cited as important: *they need a common link* and the *willingness to partake in dialogue*, yet implementation was inconsistent. BranCo was more effective at developing "win strategies" during bid management, influenced by BDM yet not derived from promises due to the lack of integration. BudCo claimed to have an effective link between BDM and bid management, which fed into value propositions. BranCo BDMs were most vocal on this point and it is summed up in EUCo as the challenge of *getting the theme running through*. Bid managers and project managers were largely left unaware of understanding about value or were not required account for this. BDM remains isolated in relation to project management (cf. Turner, 1995).

ElecCo has a different approach, predefining specialist inputs supported by breadth and depth of expertise. This was offered as exchange value in the knowledge of a high degree of client dependency even though there may be customized solutions to context. Realized value in use could be quite high, but it not was not directly co-created. Overall value propositions were high value yet transactional.

Collaboration, early contractor involvement and open dialogue are formal mechanisms for combining resources in joint problem solving that can feed into balanced initiative and interactive value delivery. These measures were mentioned by a number of BDMs across the cases and especially in UKCo. Collaboration was present in infrastructure, driven by clients with service and value in mind.

A lack of integration was evident, despite interactions, and value propositions were suboptimal. Evidential patterns were mostly identified in terms of a lack of systems and procedure for BDM.

4.4 BDM Tactics in Execution and Post-completion

Delivery is constrained by low integration both in service provision for execution and realizing potentially valuable propositions post-completion. Sporadic involvement of BDMs was reported during execution. This was across two types of contact for value delivery: externally the client contact and internally the project team contact. The internal relationship includes key performance indicators and lessons learned fed into configuring future value propositions. BudCo reported limited knowledge feedback to tweak "win themes". EUCo BDMs were charged with making contact twice with site during execution. Where feedback occurred, it was inconsistent and intermittent, and described by one UKCo BDM as being managed "quite randomly". Summing this up, a BDMs reported feedback as important, yet, *in practice it never happens*.

The BDMs were contributing to the function being isolated (cf. Turner, 1995), belying any conceptual argument that BDM is part of project management (cf. Cooper and Budd, 2007).

BDMs, indeed the companies, were disengaged from monitoring value alignment and value realization post-completion, even though the final account is closed long after practical completion on site. Benefits delivery and impact was neglected by BDMs and by the case study firms. Overall, sales interaction falls away and the monitoring of and support for the co-creation of value is low – low jointness, balanced initiative and failure o understand socio-cognitive construction.

5. Conclusions and Recommendations

The sales function has been neglected in the extant management literature, especially in regard to value (e.g. Jones et al, 2005; Haas et al, 2012). BDM has received little attention in projects and construction (Smyth, 2000). The paper set out to review BDM practices on the ground. It investigated the range of activities conducted within the function and related to this the extent of integration with other functions along the project lifecycle. Low integration was prevalent, confirming previous findings (Smyth, 2015). Marketing and BDM have been claimed to be isolated from other processes in the project domain (Pinto and Covin, 1992; Turner, 1995). This is still the case to an extent but there are more touch points and interactions than might be expected from past research, especially at the front end. The notion that marketing is to be subsumed into project management has no current basis, the future aim being to integrate rather than for either function to absorb another.

The informal BDM activities were diverse and inconsistent in supporting a single theoretical lens or the interaction sales approach (cf. Haas et al, 2012). This was the consequence of low strategic investment and commitment for BDM rather than the development and delivery of differentiated value propositions. BDM strategic support in the firm hierarchy was an underdeveloped, including programme management to support BDM prior to any project and at the front end of construction projects. Overall, the transactional *marketing mix* or MM was still prevalent despite the ill-theoretical fit. *Relationship marketing* or RM principles were applied piecemeal, and aspects of the *service-dominant logic* or S-DL were present by implication rather than strategic design. The activity to *understand client needs* only served MM. Selling dominated value within marketing and BDM, and risk and cost dominated value. In summary, selling is largely conducted through BDM without any conceptual underpinning and strategic guidance.

The paper has made a contribution by analyzing BDM using the interaction sales approach conceptually and conceptually added the strategic and tactical analysis. It also investigated BDM at a more detailed level of activity. There is scope to dig down further in future.

The recommendations for practice could be numerous at the level of activity, but the big picture for management at senior level and for marketing and BDM is that there needs to be increased awareness of theory and a systematic approach to BDM. Implementation needs resourcing and commitment with a transformational emphasis upon growth the market.

Research recommendations show clearly that asset specific markets and project businesses in particular require mainstream marketing concepts to be translated into context for these to have use value. Thus care is needed in appropriating and applying marketing theorization in construction.

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New Market Creation in Urban Area Development: An Ecosystemic Business Model Approach

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Abstract

The primary tool to bridge innovations and the market is the business model concept, i.e., the logic of creating and capturing value. Although business model is regarded as a boundary-spanning unit of analysis, most of modern business model frameworks are firm-centric and less suited for analyzing the interdependent nature of organizations residing and evolving in same innovation ecosystems. Through the business model approach, also urban ecosystems are able to build sustainable competitive advantage. However, an ecosystem can cross a variety of industries and encompass a variety of organizations, which makes the identification of its exact boundaries both theoretically and practically difficult. Hence, contributing to ecosystem level business model discussion, this study applies a business model approach to analyze how an ecosystem may innovate and build competitive advantage as a whole.

In particular, this paper focuses on how business model approach can be viewed as the way for leveraging value from innovations in the urban area development context, and explores how urban area development may contribute to new market creation. The Finnish spatial planning system, spanning from strategic spatial planning to physical land-use planning, provides a context for researching innovative opportunity and advantage exploration and exploitation behaviors. Particularly, contributing to the opportunity exploration for new market creation is called for within Finnish urban area development practices. Drawing from Activity Theory and business model literature, in the context of ecosystems, we suggest an ecosystemic business model approach in urban area development. The corresponding analysis of three urban area development cases show how new unofficial spatial planning practices relate to ecosystemic business model approach and new market creation.

Keywords: business model approach, innovation ecosystem, large-scale project, market creation, spatial planning

1. Introduction

Today's business environment incorporates a diversity of innovation stakeholders, ranging from public organizations, research institutes, large and small firms onto individual users and citizens (Lappalainen et al. 2015, Gobble 2014). Hence, the concept of innovation has spread from the internal parameters of corporations to include also the wider ecosystem (Durst & Poutanen 2013, Ahokangas et al. 2015). Relying on open innovation (Chesbrough et al. 2014), also cities have started to utilize e.g., public-private-people partnerships (Lappalainen et al. 2015). Innovation ecosystem thinking is therefore useful in seeking to understand the dynamic relationships between different industries, private and public organizations and governments (Lappalainen et al. 2015, Papaioannou et al. 2009, Durst & Poutanen 2013) when they are building new markets.

The primary tool to bridge innovations and new market creation is the business model concept, i.e., the logic of creating and capturing value (Chesbrough 2010, Teece 2010). The business model is a boundary-spanning unit of analysis (Zott et al. 2011) that connects an organization with its environment, customers, competitors and larger society (Teece 2010). In ecosystemic contexts value creation and capture are embedded within the whole ecosystem of players, meaning that value is co-created and co-captured (Ahokangas et al. 2015, Lehto et al. 2013). The business model concept serves as an open innovation platform, connecting focal organization with other organizations, communities and individuals for joint development of innovations (Saebi & Foss 2015). Through the business model concept, also urban ecosystems can be seen to be able to build sustainable competitive advantage (Lappalainen et al. 2015).

However, most of modern business model frameworks are firm-centric and less suited for analyzing the interdependent nature of organizations residing and evolving in a same innovation ecosystem (Iivari et al. 2015). Therefore, business model research needs to consider also ecosystem level business models (van der Borgh et al. 2012). Contributing to this view, this study regards the business model as a tool to build synergy among the ecosystem members for determining how the ecosystem innovates and builds competitive advantage as a whole (Jansson et al. 2014, Iivari et al. 2015).

Specifically, this paper explores how business model approach can be viewed as the way for leveraging value in the urban area development context. Urban development agencies may provide opportunity exploration scenes (Oosterlynck et al. 2011, Hirvonen-Kantola et al. 2015). Particularly, enhancing the opportunity exploration for new market creation is called for within Finnish urban planning and development practices. Thus, this research enquires *how business model approach can contribute to new market creation in urban area development?*

Now, we will introduce the concepts of innovation ecosystem and ecosystemic business model. Then, we suggest an ecosystemic business model approach to be applied in our analysis on urban area development. We also show how urban planning and development practices relate to the innovation ecosystems' business model approaches and their life cycle, in three urban area development cases.

2. Theoretical framework

2.1 The emergence of innovation ecosystems

The notion of ecosystems has gained increasing attention in academic literature as a concept to understand and explain the complexity and the interconnected nature of modern business environment (Durst & Poutanen 2013). The ecosystemic perspective is considered to reflect a fundamental change in the way we think of business in general, particularly in relation to innovations (Gobble, 2014). The term business ecosystem was first introduced by James Moore (1993) who calls a business ecosystem an economic community supported by a foundation of interacting organizations and individuals—the organisms of the business world (Gobble 2014). Ecosystems are focused on commonly created value, renewal, and constant innovation in order to achieve a sustainable competitive advantage in their business environment (Ahokangas et al. 2015, Lehto et al. 2013).

Ecosystems are partly intentionally formed and partly a result of accidental emergence (Moore 1993). Business ecosystems are hence characterized with high complexity, interdependence, co-operation, competition and coevolution (Iansiti & Levien 2004, Jansson et al. 2015). Moore (1993) states that firms create a new business ecosystem based on four evolutionary stages from birth, expansion, leadership, and self-renewal. At the birth stage, it is essential for the ecosystem members to go beyond just satisfying their immediate customers. At the expansion stage the scale-up potential of the business concept of an ecosystem is tested. At the leadership stage the business ecosystem reaches stability and profitability. The final stage, self-renewal or death, is caused by the threat of rising new ecosystems. Hence, there is a continuous life-cycle process of the ecosystem members taking place within an ecosystem (Hirvonen-Kantola et al. 2015).

The underlying thought behind ecosystemic perspective is to expand the capabilities of one actor beyond its own boundaries and transfer knowledge into innovation through collaborating with others (Adner 2006). The joint utilization of complementary capabilities in pursuit of new innovations is hence highlighted within ecosystems, and in this way, ecosystemic thinking closely relates to open innovation (Chesbrough et al. 2014). Although open innovation originates from corporate R&D, its application has expanded beyond inter-firm collaboration (Chesbrough et al. 2014). Also cities and regions have started to seek the benefits of openness and ecosystemic thinking through public-private-people partnerships based on quadruple helix model (Lappalainen et al. 2015).

The ecosystemic thinking is particularly relevant for the smart city concept, which refers to cities themselves acting as innovation drivers (Schaffers et al. 2012). A city can be considered ‘smart’ when investments in human and social capital and traditional and modern ICT-based infrastructure fuel sustainable economic growth, high quality of life and wise management of natural resources through participatory government (Schaffers et al. 2012). Test-beds, living labs, collaborative platforms and testing environments provide good development opportunities for innovation creators and help them to bring their solutions to the market (Launonen & Viitanen 2011). Launonen and Viitanen (2011) stress that innovations need to be designed for real life situations in order to have commercial value. However, urban area development in this context is still bound to traditional land-use planning based on zoning, which makes fast responding to changes and the free development of new markets challenging.

2.2 The concept of ecosystemic business model

The business model is the primary tool for leveraging value from innovations (Chesbrough 2010). The business model bridges innovations and new market creation, i.e., the logic of creating, capturing, delivering and sharing value (Teece 2010, Amit & Zott 2015). Value creation and capture are based on opportunities that require business models for the successful exploration and exploitation of those opportunities and the subsequent competitive advantage (Ahokangas & Atkova 2015, Teece 2010). In ecosystemic contexts value creation and capture are embedded within the whole ecosystem of players, meaning that value is co-created and co-captured (Ahokangas et al. 2015, Lehto et al. 2013). Collaboration of the focal firm with its ecosystem is one of the defining factors of business model openness (Frankenberger et al. 2014). However, the ecosystemic business model can also be regarded as the business model of an ecosystem with mutually connected opportunities. Thus, in an ecosystemic context, the business model functions as an open innovation platform that connects an organization with other organizations, firms, communities, individuals and larger society for joint development of innovations (Saebi & Foss 2015). Therefore, the business model is a boundary-spanning unit of analysis (Zott et al. 2011).

Casadesus-Masanell and Llanes (2011) discuss open source, open core, open edge and proprietary business models. Within ecosystemic smart city contexts this categorization can be interpreted to concern the roles of the city as the focal player of the ecosystem with the rest of the ecosystem when innovating new offerings and creating new markets. With an open source business model the ecosystem jointly co-creates value for its customers whereas in proprietary mode the focal player tries to control value or market creation activities of the ecosystem. In open core business model the focal player remains open whereas the rest of the ecosystem players run their activities independently. In the open edge mode the city as the focal player defines the rules of collaboration allowing the rest of the ecosystem act within the established rules.

Through the utilization of the business model concept, urban ecosystems are capable of building sustainable competitive advantages (Lappalainen et al. 2015). The business model is a tool to build synergy among the ecosystem stakeholders in order to determine how the ecosystem innovates as a whole (Jansson et al. 2014, Iivari et al. 2015). Most importantly, however, within the ecosystemic business model approach, cities may thrive for new market creation by enabling the innovation ecosystem to shift from an evolutionary stage to another (Moore 1993). In addition, cities may allow for the logic of creating, sharing, delivering, and capturing value to develop freely or in a defined manner. Hence, the ecosystemic business model approach needs to consider also business model's viability, evolution and its place in the product or service lifecycle, which in this research refers to spatial planning practices (see also Demil & Lecocq 2010). With the emergence of the idea that the built environment is a source of competitive advantages for urban regions (Hirvonen-Kantola et al. 2015), the question of how business models may boost new market creation is particularly relevant for innovation ecosystems that are nowadays being catalyzed in different cities in Finland, in the urban area development context.

3. Research strategy and methodology

3.1 The context of urban area development

The urban area development takes place within the Finnish spatial planning system, spanning from strategic spatial planning to physical land-use planning, and provides a context for researching innovative opportunity and advantage exploration and exploitation behaviors (Hirvonen-Kantola et al. 2015). However, our spatial planning system is a normative and multilevel system based on land-use planning. Although, the attention has been paid to the European discussion on urban policy as creating prerequisites for urban development (Jauhiainen & Niemenmaa 2006).

In Finland, local planning authorities have been granted an independent role, and the system has offered opportunities for strategically active municipalities. As the ecosystem's facilitator we may thus identify at least the municipality with active land policy and local planning monopoly, as these are portals to opportunities. Here, the most important mechanism of control is the Land Use and Building Act (LBA, Maankäyttö- ja rakennuslaki 1999/132). The land-use planning system is a functionalist and rationalist hierarchical system in which general planning ideally guides detailed planning, and which aims to produce legally binding plans that enable development and implementation.

Municipalities draft their own master and detailed plans, and the powers of approval and ratification are given to the local municipal councils, which makes the local government central stakeholder in the ecosystem. Detailed plans regulate development by defining building rights, efficiencies, dimensions and functions in detail, attached to land-owning information. Plans can be initiated and paid for by both landowners and municipalities, that is, by diverse ecosystem stakeholders. Indeed, the planning practice seldom conforms to formal planning hierarchy, since landowner rights are well protected in the LBA. In addition, investors and the Ministry of the Environment expect speedy preparation of detailed plans, although business considers urban planning slow.

Diverse Public-Private-People partnerships are applied in urban planning and implementation, and any interested party participation is emphasized. The planning authority must publicize planning information so that interested parties are able to follow and influence the planning process (LBA 62 §). Here, openness is a competitive advantage to the innovation ecosystem reaching for new market creation. When launching the preparation of a new plan a Participation and Assessment Scheme has to be drawn up and publicized. It should cover participation and interaction procedures as well as processes for assessing the plan's impacts (LBA 63 §).

However, the business impact assessment with value propositions and competitive advantage identifications is typically neglected, and the content of ecosystemic business model unformed.

In recent years, planning has advanced from top-down government to negotiations with developer-contractors, setting common goals and tying in the ecosystem stakeholders at the beginning of planning projects. The implementation of plans has been integrated with planning, and the detailed plan has become a type of project plan. In order to plan in neo-liberal conditions some cities have developed unofficial practices, which are central instruments in spatial planning. In fact, the three urban area development cases that we will study next, point out the role of unofficial urban planning and development practices, in approaching new market creation as the business opportunity for the ecosystem with mutually connected opportunities arising from the urban area development context.

3.2 Ecosystemic business model approach

Building on the literature review, we will apply a business model approach in exploring how urban area development may contribute to new market creation. Drawing from Activity Theory (Engeström 1987, 2001) and business model literature, in the context of ecosystems, we first suggest a new ecosystemic business model approach in urban area development (Figure 1), to be applied in our analysis.

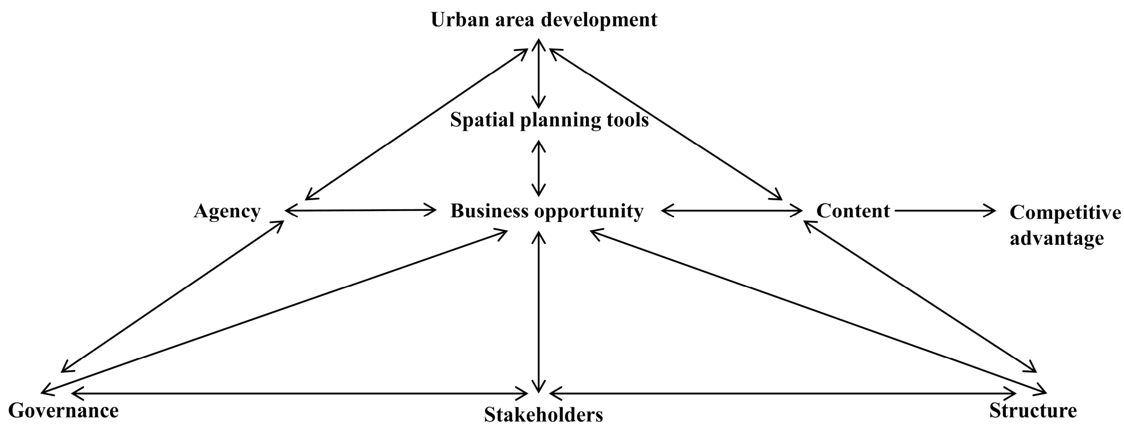

Figure 1: Ecosystemic business model approach in urban development.

In our model, a business opportunity is set as the focal sense—meaning—which affects directly all the other key factors. These are the subject, object, outcome, rules, community, division of labor, and tools included in the human activity system (Engeström 1987). Hereby the structure is transformed into a business model framework. As opposed to the human activity system just mentioned, we consider the urban area development as context to define business opportunities, and thus we add context on top of the model. We also regard spatial planning tools as mediating artefacts.

The model covers the opportunity, stakeholders, content, context, structure and governance of the ecosystem. Starting with agency, it can be seen as the subject of the ecosystem, holding a portal to opportunities, or being responsible for facilitating the activities and interaction within the urban ecosystem. The other side of the coin, the stakeholders including government, industrial/business, academia and citizens form together with the city the community of the ecosystem. Second, the context of the ecosystem can be viewed from innovation perspective as renewal and new market creation can be seen as the key co-creation activities of the ecosystem players. The structure, i.e., the configuration of the ecosystem then defines and delimits the scale and scope, plus division of labour of the units involved. Third, the governance and mechanisms of control as rules relate to the openness of the ecosystem business model, varying from open source to proprietary. This can also be seen in the content of the ecosystem activities that form the basis for the value proposition as the object of the ecosystem as well as its competitive advantages as outcome.

In this paper, three urban area development cases in progress are noted as the hot spots (Gratton 2007) applying the ecosystemic business model approach for new market creation. These cases utilize different types of urban planning and development practices, and they are regarded as one of the most important strategic urban development projects (Salet & Gualini 2006, Oosterlynck et al. 2011) in their cities as they are set to integrate the aims of the local land-use planning, and business and industrial policy. The data concerning the cases was gathered through various forms of primary, participatory (Wallerstein & Duran 2003) data collection methods, e.g. following up the urban area development processes, participating in quadruple collaboration, workshops and meetings, as well as follow-up interviews with focal actors.

All the elements included in the ecosystemic business model framework were identified in the three urban area development cases, and depicted in Figures 2–4. Then, it was analyzed if any of the elements had risked the innovation ecosystems' openness and evolution, in search for new market creation.

4. Analysis

4.1 New market creation in urban area development

Cities may strive for new market creation by enabling the innovation ecosystem's evolution. Moore (1993) states that firms create a new business ecosystem based on four evolutionary stages: birth, expansion, leadership, and self-renewal. At birth, the ecosystem members go beyond just satisfying their immediate customers. At expansion, the scaling up potential of the business concept of an ecosystem is tested. At leadership, the business ecosystem reaches stability and profitability. Finally, rising new ecosystems results in self-renewal or death.

The following analysis on three urban area development cases in progress—the development of the Hiukkavaara Arctic smart city, urban regeneration of the Karjasilta school area in Oulu, and the future Vehkala business and enterprise area in Vantaa—show how urban planning and development practices relate to the innovation ecosystems' business model approach and the ecosystems' life cycle. To start with, INURDECO-SWC quadruple collaboration project aimed at creating the Hiukkavaara Arctic smart city innovation ecosystem (Figure 2), and a detailed plan for Hiukkavaara center, energy efficient block concepts, plus an operational model for Hiukkavaara living laboratory including innovative real property conveyance for threshold projects testing energy-efficient solutions.

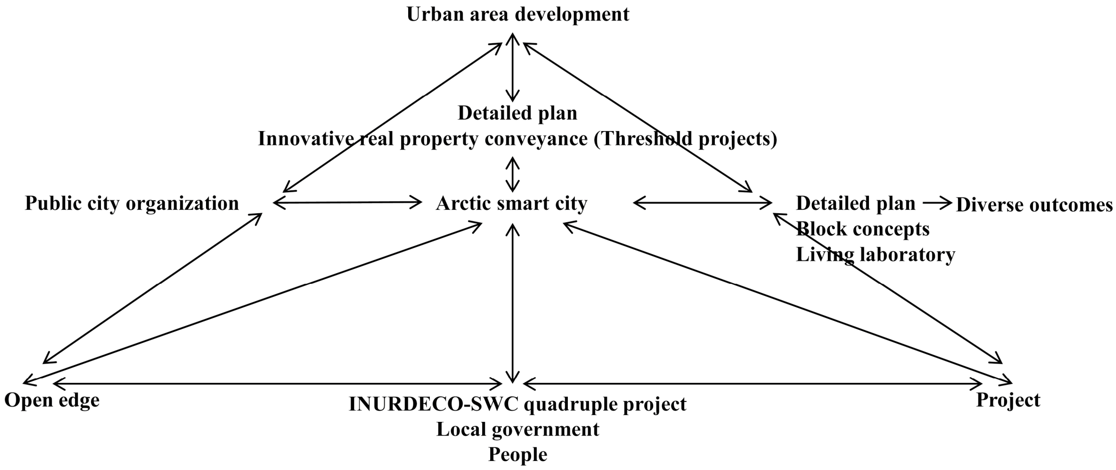

Figure 2: Ecosystemic business model approach in the Hiukkavaara Arctic smart city.

Ideally the ecosystem would have had a business model approach with an open source, in which the ecosystem jointly co-creates value for its customers (Casadesus-Masanell & Llanes 2011). In practice, it had open edge governance with detailed planning channeling the ecosystem's interaction process. However, with multiple content and diverse scales and scopes, the innovation ecosystem lost synergy, which derives from insufficiently identified business opportunities. In the end, the Arctic smart city living laboratory sustains a test-bed by a continuous innovative real property conveyance process, with motive for knowledge. For the capability for self-renewal of the ecosystem's remaining part, the ability to update the threshold project parameters is vital. As such, the life cycle of the innovation ecosystem in the Hiukkavaara Arctic smart city ceased along with the finalized detailed planning project.

Whereas in the Karjasilta school area regeneration related innovation ecosystem, the sight for the expansion stage was built-in the innovative real property conveyance practice. Here, the city sought for unforeseeable prospects including a business lab. In the lab, smart city modules meant for mass customization have been developed, which indicates a will for scaling up. However, in this business model approach (Figure 3) the innovation ecosystem risks sustainable competitive advantage with structure tailored for the current development and construction project, which forms the core for the developer-led ecosystem's governance.

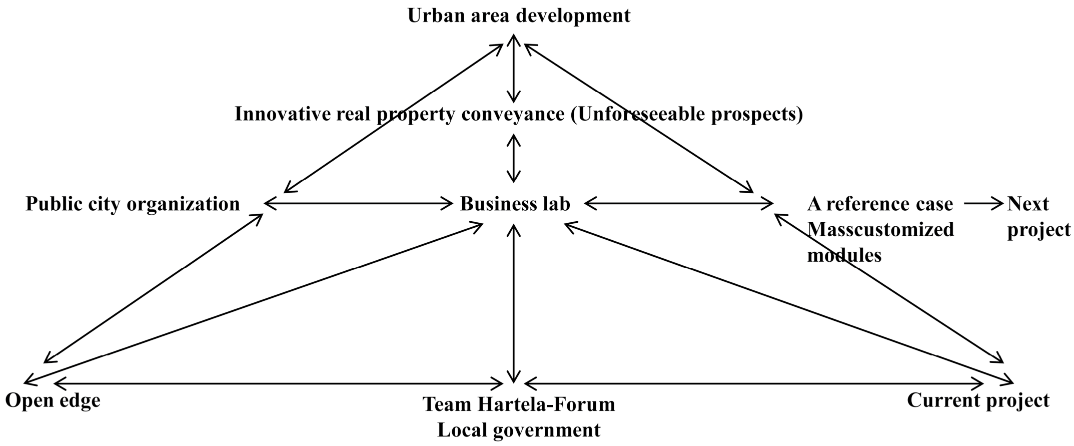

Figure 3: Ecosystemic business model approach in the Karjasilta school area regeneration.

The most future-oriented ecosystemic business model approach (Figure 4) can be found from the Vehkala business and enterprise area. Even though this is an ecosystemic business model approach with open edge, urban area profiling as the core—and mediating artefact—aims at creating a specialized, co-creating ecosystem permanently located in the Vehkala business and enterprise area. There will be a district with diverse stakeholders supporting the selected profile of the area. For its regional scale and scope, the ecosystemic business model approach will possibly be able to scale up to modify the local market. This ecosystemic business model approach will be challenged at the leadership stage, whether it can reach stability and profitability, and finally self-renewal.

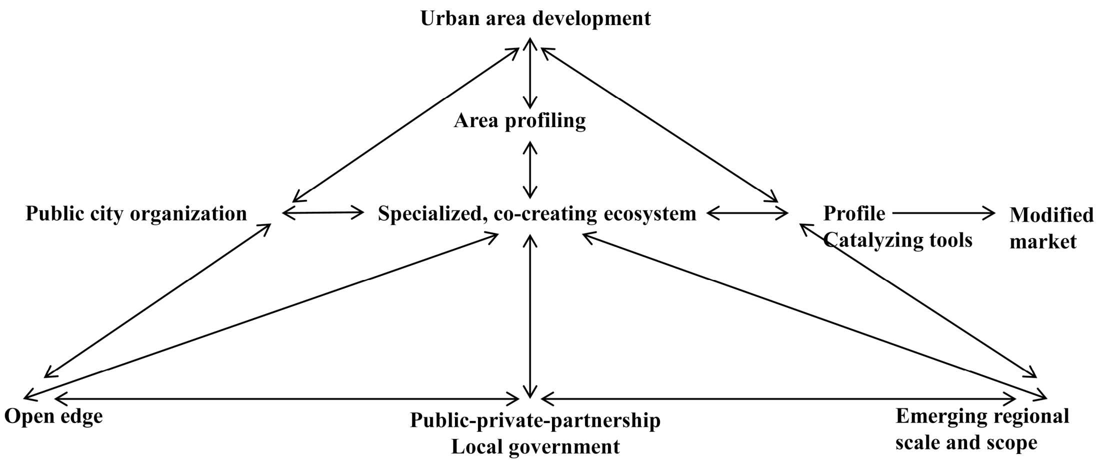

Figure 4: Ecosystemic business model approach in the Vehkala business and enterprise area.

5. Conclusions

We have studied in this article, how business model approach can be applied to analyze new market creation in urban area development. Our contribution is the suggested ecosystemic business model approach, and the analysis on how urban planning and development practices have embraced the ecosystemic business model approach and contributed to new market creation. Hence, this study contributes to business model literature from ecosystem perspective, as well as to the procedural theory of spatial planning utilizing large-scale urban projects as open innovation platforms. We illustrated the applicability of the ecosystemic business model approach through three urban area development cases.

In the ecosystemic business model approach, the city may strive for new market creation by catalyzing ecosystems by offering them an urban area development platform, enabling the innovation ecosystem shift from an evolutionary stage to another, and allowing openness—the ecosystem's natural logic of creating, sharing, delivering, and capturing value. Even though the analyzed ecosystemic business model approaches were with open edge, they had a core facilitated by the city organization. However, our analysis revealed that the nature of this core—a mediating artifact—is decisive in targeting the ecosystems' expansion, leadership, and self-renewal. Here, for instance innovative real property conveyance and area profiling, with more open cores, serve emerging ecosystems better than detailed planning, a normative project.

The ecosystem also needs a clear focus on the opportunities at its birth stage. Possibilities for scaling up need to be similarly considered at the start for the pursuit of new opportunities. We argue that the key for successful exploration and exploitation of opportunities is to have a future-oriented perspective on the ecosystem's life-cycle with a long-term aim. Our analysis shows that all the elements of the business model approach; agency, stakeholders, context, content, structure and governance, need to be continuously reflected during the ecosystem's evolution in order to secure synergy. As the first two cases reveal, the lack of such perspective may result in the cease of the ecosystem's sustainability and risk of its full potential in new market creation. We conclude that the ecosystemic business model approach in urban area development can contribute to new market creation, when there is a clearly defined opportunity and content. This secures the ecosystem's evolutionary path and enables full potential for new market creation.

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A Technique for Developing Strategic Differentiation for Small Architectural Firms

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Abstract

Since the crash in 2007, the number of small architectural firms has risen dramatically as both recently graduated and recently laid off architects decide to go out on their own. In such a crowded market firms will need to find some way to distinguish themselves from their many competitors. Arguing from the Resource Based Strategy theory the authors assert that to be successful architectural firms must build and promote competences which are both scarce and in demand in order to compete successfully. This should especially be the case in a 'buyers' market'. Architect starting their own firms must provide something more than standard package of architectural services will not be enough to permit new firms to gain clients. A series of case studies was used to compare this theoretical proposition with the experience of recently established architectural firms (+-5 years). The case studies gathered firm histories including the original goals of the principle architect(s), their entrance strategies and marketing approaches, their client list and portfolios of acquired and completed projects. This permitted a comparison to be made between the firm profile the architects originally desired to establish, and the profiles eventually realized. In particular, the perceived selling points which the principle architects believed would provide them with the ability to acquire projects with the services they eventually were able to sell. The case studies supported the assertion that a clear differentiation strategy is one means of successfully launching a firm and gaining a client base.

Keywords: Architectural Firm, Strategy, Differentiation, Competences

1. Introduction

This paper described the results of a preliminary study of the use of the Personal Construct Theory (PCT) and the Repertory Grid Technique (RGT) (Kelly, 1955) to elicit values which characterise a small architectural firm and can be used to guide a strategy of differentiation. The tool has two uses: as a research tool the Repertory Grid is intended as a standardised means of eliciting differentiating values from small firms and establishing a field of values within which small firms typically position themselves. Establishing this field of values would be helpful to principals of small firms in determining their own position, and to researchers in achieving a better understanding of the strategic context in which small architectural firms operate. The second use for the tool is as a consulting or diagnostic tool for individual small firms. The tool is intended not only to elicit characteristic values, but also to contrast the firm with its nearest competitors in terms of these values and thus enable a clearer differentiation of the firm.

2. Small fish in a big market

2.1 The problem facing the many small firms in a very competitive market

The architectural field is characterized by a very large number of very small firms chasing relatively few commissions. Ironically, the crash in 2007 has led to a significant increase in the number of these very small firms. Massive layoffs amounting to as much as 40% of the architectural workforce in countries such as the UK, and the Netherlands, although the impact of the global financial crises (GFC) was to a lesser impact in Australia the number of staff turnover increased considerably moving across practices or contractual amendments – ie. work-week of four days instead of five. In the Netherlands, for example, between layoffs and a pattern of continued newly minted architectural graduates has meant that for many architects the only way to practice has been to freelance or attempt to set up their own firm. This has resulted in a 9% increase in the number of boutique firms and a 47% increase in the number of freelancers between 2007 and 2014 (Consultancy.nl, 2014). All of these new firms fiercely compete with existing and well-established architectural firms for what until very recently has been in most countries a declining amount of architectural work on offer. To be successful in such a hostile market environment one might expect that a firm would need a carefully considered strategy – one in which the firm is carefully positioned in the market between potential clients and their competitors.

2.1.1 The Coxe strategy

What might be considered the standard approach to strategy for architectural firms was developed by the Coxe Group in the 1980s and focuses on conformance to six viable architectural firm types (Coxe, 1987). However, we would like to argue that this approach is no longer adequate to the needs of architectural firms (Heintz, 2012). While the Coxe Groups' fundamental point of knowing who and what a firm is, helps firms to structure themselves well and remains valid, the current situation calls for more. Specifically, the current situation calls for a method for architectural firms to differentiate themselves from their nearest competitor firms, normally firms of the same Coxe type.

The architectural market, especially at the small end, is an unusual market in the sense that there are comparatively many sellers and comparatively few buyers. Clients enjoy a relatively strong position in the architectural market; there are always many architectural firms ready to compete for any commission offered. In terms of the types developed by the Coxe Group, the majority of an architectural firm's competition will be firms of the same type. The vast majority of small firms still offer a "wide range" of design services, claiming competence in all types of building and for all types of clients. These will most commonly be type C Strong Service business-centred-practices (Coxe, 1987). Hence, while the Coxe type strategy may be very helpful in ensuring that a firm is well structured, it is of little use in differentiating a firm from its nearest competitors. For that a firm needs to discover how it can stand out from those most similar to it.

Heintz & Aranda-Mena (2012) concluded in a previous paper (Montreal paper) that more appropriate methods should be used to investigate the topic of business strategies for architectural firms, especially those start-ups or in transition from small to medium or medium to large. Many of the practices would begin with a design agenda or design-oriented, growth and transition would require a business mind-set. Moments of crises emerge when the core value systems might seem compromised by the principals. In other words, to trade the design or artistic values for commercial values, pride in architecture often emerges when a project is 'not compromised' when moving into the Resource Based View (RBV) or similar model. At the conclusion of their earlier paper the authors identified a lack of real-world and empirical evidence on the models of Business for architectural firms and concluding with their paper suggested a more psychological approach to the research in other to better understand the views and values held by a ray of practices suggesting then reading on Personal Construct Psychology and the Repertory Grid Technique (Kelly, 1955).

2.1.2 The need for differentiation

The *Resource Based View* [RBV] of firm strategy may offer us a helpful lens though which to understand strategy in this more competitive environment. The principle conclusion of the RBV was that to be successful a firm had to find a unique resource or competence to which their competitors did not have access (Penrose, 1959; Barney, 2001). This unique potential was then the source of a competitive advantage.

Seen from this point of view, the general problem solving and design competences that form the core of architectural training and of traditional architectural practice are anything but scarce. Signature styles, or at least the ambition to display a signature style, are also relatively common. And to portray a specific 'signature' as a scarce resource seems a bit sycophantic.

2.2 What counts as a unique resource?

If RBV strategy relies on unique resources, what count as a resource for a small architectural firm? And are any of them unique? As architecture does not require a heavy investment in plant or costly materials, the resources in question are the firm's competences to deliver specific services to their clients. However, it is difficult to imagine a truly unique architectural competence, aside, that is from the architect's signature style, which is not relevant to the majority of clients. We therefore argue that strategy for small firms will be a matter of a scarce combination of scarce competences, rather than of truly unique competences. Architectural firms, small or large, must strive to identify one or more scarce competences to which they have access and build their firms around them.

Competition in architecture takes place on a project-by-project basis – in the selection processes of clients. While clients for large projects will often have relatively robust, transparent selection processes based on pre-established criteria, clients for smaller projects, and therefore smaller firms will have more improvised selection processes. For these clients the two most important selection factors will be price and 'click' – the feeling that they can work with this particular architect. Click is a mixt of personality, values and interaction style. This will typically be assessed on the basis of a presentation based on the firm's portfolio and how it proposes to carry out the design of the project. We therefore propose that the relevant competences are:

- Values
- Competencies required to realize values
- Portfolio as evidence of realized values.

The method we propose here will elicit the value system of the principals of firms interviewed. It is at the level of values that a firm can best determine its potential to differentiate itself form its competitors. Once the value system is determined, the firm can then perform an assessment of its competencies and determine which ones to foreground or to invest in developing further. Finally, the firm can determine how to present its portfolio to best exemplify its chosen values.

3. Personal Construct Psychology (PCP)

The overarching theoretical foundation of this paper and approach is that of Personal Construct Psychology (PCP) also known as Personal Construct Theory (PCT) first published by George Kelly in 1955. The theory has a strong psychological foundation but has also been applied in more pragmatic domains. The over all contribution of the paper is to validate RGT as a briefing method for unearthing of tacit knowledge by firm principals. Results overtime are to inform the authors on emerging business strategies applied by architectural firms, clients and designers. For this, the authors are into determining how well RPT - in conjunction with cluster analysis – is able to reveal:

(1) Architects' visions on attributes of practice differentiation and business development strategies.

Psychology aims to predict behaviour. Similar to other psychological theories PCP is funded on a set of assumptions about man and his relation to the world (Kelly 1955). In this way, through the PCP lens the authors draw on respondents experience to plan for their future. PCP only help to expose those plans or predictions and thus the researchers would have a possibility to provide guidance - and the respondent to see and compare their own practice over time.

This study embraces a pragmatic approach towards its validity in which at this point it only seeks to *make-sense* from the respondent view point, thus internally valid. That is, if the grids make sense to those involved in the study the model is internally valid. This is supported by the epistemological framework of Personal Construct Psychology (PCP) (Kelly, 1955). Kelly suggests, that the sorting scenarios proposed to the client are representative of those with which he must deal in structuring his life role. No such thing as general representativeness can be achieved in the same way that there is no general validity of a test. The problems of representativeness in constructs and element where measured in relation to each hypotheses or client under test (Kelly 1955).

PCP offers a framework for understanding human behaviour and decision-making. PCP works on the premise that people spend a lifetime testing personal predictions or hypotheses. In other words, every person is viewed as a scientist who seeks to apply definitions, concepts and constructs (constructs as attributes attached to concepts) to each of his or her actions. By adopting such a view, PCP provides a framework where subjects think and reflect on their decision-making, attitudes, knowledge and as well as actions taken by individuals and collective groups. One of the research techniques to elicit such knowledge and information is the repertory grid technique RGT (Gaines, 1999).

3.1 The Repertory Grid Technique [RGT]

The repertory grid technique falls under the principles of Personal Construct Psychology. The technique has been applied on a wide range of fields spanning from psychology to management. To begin an RGT session on a particular topic the client (or interviewee) and the researcher (in this case software designer) begins with discussions around given scenarios known as *'elements'*. Such elements could also be situations, people, objects or any chosen scenario under investigation and in the case of this paper they may refer to different software applications that planners are asked to consider. As part of such discussions, the technique requires the client to compare elements thus generating a list of *bi-polar* attributes or *constructs.*

RGT requires respondents to compare and contrast a number of elements, objects or scenarios. For instance, the focus of a grid session could be on the assessment of the interface of a number of planning software applications. This will require comparing and contrasting across all ten elements such as software tools - organised in pairs or triads - thus generating *distinctions* also known as *bi-polar constructs*. When the approach is by triads, this comparison takes place by randomly bringing up three scenarios at a time. Then each respondent needs to identify an aspect that is similar to two scenarios and which makes a difference to a third thus generating grids with elements and bi-polar constructs. Grids are generated implying conscious reflections. Grid validation takes place by individual respondents who follow up discussions, thus respondents have the choice to change the grid. A more detailed account of how constructs are elicited will be presented in the next section of this paper.

3.2 Applying RGT to differentiation of architectural firms

In the context of business strategies for design firms, the application of RGT would involve subjects considering subsets of *competing design firms* as *elements* with the purpose of generating a number of constructs and rating them. The first step is to select a number of architectural firms from the environment of the interviewee. Each participant was asked identify 9 architectural firms which exemplified a set of roles and which served in some way as an example to them. Originally, the authors chose a series of roles which were defined in terms of the characteristics of the firms to be named, however during the interviews it emerged that the interviewees were more able to think of relevant firms when triggered to think of firms in terms of their meaning to the interviewee. In all cases the final two firms were the interviewees own practice as it was then, and as the interviewee would ideally see it develop.

Table 1: Original and Emergent Reference Firm Roles

	Original		*Emergent*

1	*Traditional architecture practice*	*1*	*Former Employer*
2	*Alternative architecture practice*	*2*	*Mentor*
3	*Avant-gard practice*	*3*	*Ideal Model (Firms which the subject would like to imitate)*
4	*Small start-up*	*4*	*Negative Model (Firms which the subject would definitely not like to imitate)*
5	*Small established*	*5*	*Competitor*
6	*Design driven practice*	*6*	*Ally*
7	*Process driven practice*	*7*	
8	*My own practice*	*8*	*Subject's own practice*
9	*My ideal practice*	*9*	*Subject's ideal practice*

The way the interviews were structured was by organizing triads, consisting of three of the element architectural firms, and asking the respondent to identify a commonality amongst two practices which makes a difference to the third. For instance, if the triad consisted of elements 1, 4, & 6 (traditional, small start-up, design driven firms). The respondents might then group 1 and 6 together and differentiates them to 4 yielding the construct *Experience*, and the contrast *Lack of negotiation skills*. This means that for the respondents a traditional practice and even a design driven practice are better fit to negotiate with clients. This implies that a small start-up is less prepare with such an important business skill.

The process is repeated with as many practice combinations as felt exhaustive to cover the topic and subtopics of the paper. This could be developed over on-off session or over a number of sessions.

4. Interviews

The study consists of a series of 5 interviews (4 in the Netherlands, and 1 in Switzerland) of principals of small architectural firms using the PCT/RGT technique. The Interviews were conducted according to the protocol described below. Each interview resulted in a completed Repertory Grid comprising of between 7 and 10 constructs consisting of values and their contrasting 'opposite'. These in turn provide a characterisation of each firm individually, and of the strategic context collectively which will be presented in a follow up paper to this one.

4.1 Firms Interviewed

This section reports on emerging constructs on five interviews as a scoping qualitative study.

4.1.1 Frim PN1 A&R10

In going so far as to include the word 'renovation' in the name of the firm the owner-architect signals to potential clients that their problem is not a second choice selection for the firm – not a poor substitute for a new building. By focusing the practice on renovation, the firm has been able to assemble experience in the problems specific to the renovation and repurposing (transformation) of older buildings. The firm supplies advice during the initiative phase, including assistance in obtaining renovation subsidies for listed buildings. The owner-architect started the firm on a part time bases, and have been working fulltime for 3 years by the time of the interview. The firm had 3 contract workers in addition to the principal.

4.1.2 Firm PN2 (Urbmath)

The sole owner-architect started Firm N1 immediately upon graduation from architectural school. Indeed the firm's approach is directly taken from the architect's graduation project – a center for Rotterdam Contemporary Youth Culture. What sets Firm N1 apart from other young architectural firms is the architect's personal interest and facility in what he calls Youth Culture. In essence the architect is hip. He is a figure in the Rotterdam hip-hop scene, and is accepted as a credible speaker for youth culture by the municipality and by private clients. The firm was 3 years old at the time of the interview, and had grown to 5 contract workers.

4.1.3 Firm PN3 (ORGA Architect)

PN3 is specialized in sustainability, specifically "Bio-based Building", and is active in research into bio-based architectural materials as well as design of sustainable buildings. In addition the firm has a strategic partnership with a small contracting firm, also specialised in bio-based building. The firm has received media attention, and the principal has received an award for entrepreneurship and achievement. The firm was 6 years old, and had 4 fulltime employees in addition to the principal.

4.1.4 Firm PN4 (SJO Architecten)

The 2 principals of SJO Architecten took over the firm on the retirement of their previous employers. The succession had been carefully structured by the previous employers, who hoped to leave a legacy and an imprint on the firm. The firm had changed its name less than a year before the interview. The firm had been healthy up to the crisis in 2008, and had continued with reduced staff since then.

4.1.5 Firm PS1 (OOS Architektur)

Firm motto/slogan: **Design is our passion**

PS1 is an architectural firm based in Zurich which was founded in Zurich in 2000 by the four architect-principals. In recent years it has grown into a larger commercial firm with corporate clients operating in Zurich and neighbouring areas. Besides office facilities, other projects also include housing projects and converting old factories into social-housing systems in the townships of Aathal, Flums and Schönau near Zurich. The factory conversions has become one of their trademarks their own office being in an old factory in Zurich's industrial suburb Haltestelle.

"We create space in all scales, and design it comprehensively. Our team is made up of specialists in architecture, interior design, urban planning, spatial development, scenography and branding. They transform the requirements, subjects and values of users and clients into a customized spatial environment. In addition to our wide experience, we continually observe new trends and developments and ensure that the knowledge gained flows into the projects. A trans-disciplinary approach and holistic methods characterize the development process and the results of our work.”

The practice was 13 years old at time of interview and had approximately 20 employees and two principals, both interviewed.

4.2 Interview Results

The method generated both a wide spectrum of constructs, and therefore of values, reflecting the variety of firms interviewed. Yet it was also possible to group the constructs in clear clusters around three themes: Design & Ideology, Process, and Business. The Design cluster was the least surprising. Architects traditionally attempt to distinguish themselves through their portfolio and signature or style. However, we saw some constructs, such as the Flexible-Specific construct that contrasted sharply with the traditional architectural interest in specificity and idiosyncrasy. The Process cluster contained constructs that were both internally focussed and externally focussed.

Table 2: Clustering of constructs, clusters, subclusters and example constructs

Cluster	*Subcluster*	*Construct*	*Contrast*
Design & Ideology	*Design*	*Elegant Design*	*Mediocre Design*
		Flexible, Impersonal	*Specific, Personal*
	Ideology	*Official Culture*	*Subculture*
		Design Driven	*Social Impact Driven*
Process	*Process*	*Joy/Fun*	*Professional/Corporate*
		Openness to share knowledge	*Won’t share knowledge*
Business	*Internationalisation*	*Swiss Market*	*International market*
	Specialisation	*(Social) Housing*	*Divers portfolio*
		Sustainability	*General Services*
	Services	*Architect*	*Architect Developer*
	Size	*Big projects*	*Only small projects*
	Marketing	*Waits for work to come in*	*Creates work*
	Business	*Business as ususal*	*Business innovation*
		Want to make money	*Careless of money*

The process cluster is a combination of current and desirable attributes to the practice - inwards to the firm. Theses align with the practice culture and also technical skills such as ability to share knowledge and problem solving.

The business cluster is outwards to the firm - with constructs such as business growth, national or international expansion, business size, client base and marketing strategies just to mention some.

The overall appraisal is been a positive one in the sense that grid process and results gives instant feedback articulated by the interviewer. In this way, participant and researcher can discuss results and modify them if necessarily. Amongst the graphics for date analyses are: structured repertory grids, cluster analysis, dendograms, principal component analysis and socio maps which are beyond the scope of this paper but previously studied in depth by one of the authors over a PhD investigation (Aranda-Mena, 2003). Grid analytical work will follow up to this paper.

4.3 Feedback on the tool

The authors have asked two of the respondents to provide some comments or feedback on actual Repertory Grid Technique. Here below some of the feedback. In general the interviewees responded positively, e.g. “Extremely Interesting” -- PN4.

4.3.1 Feedback from PN4

“Extremely interesting.”

Thinking about help to the specifics of the firm.

“This is very nice because then you start to think of how you want to position yourself.”

Forced choice is what makes you start thinking.

Each different set requires that you make a switch, either positive or negative.

4.3.2 Feedback from OOS

The Repertory Grid Technique was perceived as good and effective method but it was pointed out that in order to drilldown into more understanding of differentiation across the element organisations more information from the competitors would be required other than the more superficial perception. Follow up *zoom-in* sessions would be required.

Perhaps a follow up session purely focused on internal resources including human resources, skills and assets. It will be then easier to also compare with competitors. This was referred as a *360° degree pan-view.*

Other topics such as organizational maturity were discusses. Especially in relation to architecture which tends to be a “highly-controlled” culture where principal architects tend to keep the knowledge to themselves and run their studios on a top-down approach. Swiss example of Peter Zumthor, Mario Bota came to the discussion as highly personalized practices which must likely will die when their funding members are gone.

A world-view that still prevails in architecture culture is that of the architect at the top of the pyramid above investors and above society. In the view of the interviewees ***design*** is a core business attribute which has to be a must but from there a number of skills and competencies have to be develop.

The triad technique works well however, the perception is that the discussion is too superficial as the tendency is to generate and *outside-view* instead of “drilling-into”.

A recommendation (for the follow up interview) is to have/provide more information (or allow time to research) the particular elements (architecture practices) in order to have a more informed/factual discussion.

The two respondents much liked the triad interviewing technique and are looking forward to follow up discussions and engagement with our research paper/topic of much value to them!

5. Discussion

Past present and future.

Many of the constructs generated are similar to the questions the Coxe group used in their typological approach. On the one hand this suggests that few new values were disclosed. On the other hand it does make it possible to cycle between discussions of typological consistency and points of differentiation within the type.

However, the results do suggest that where the Coxe typologies suggest that few Strong Idea firms would have an interest in profitability, this may no longer be true. Indeed, the firms interviewed, although generally successful, did not fit easily into the Coxe typologies, particularly the distinction between practice-centred-business and business-centred-practice.

Developing tactics, bottom up.

During the interviews a more interviewee centred approach, e.g. the emergent elements, was found to elicit more productive conversation around the constructs. This sets the goals of research and consulting against each other, as mapping the range of strategic values would require using a consistent set of elements and constructs in order to build up a body of data that could be analysed with the statistical tools from the RGT.

The brevity of interviews, and the dependency on perceptions of the element firms, means that the interviews are limited to an exploration of values. The element firms serve as devices with which to prod the interviewees to reveal their values. The results, therefore, are not a complete analysis of capabilities of the interviewee’s and element firms, but rather an analysis of the values by which the interviewee would like to differentiate their firm from the element firms. Further work would be required to determine the degree to which the interviewee’s firm possessed the desired capabilities or needed to invest in developing them.

All of the firms interviewed expressed a clear desire to distinguish themselves from what they saw as the way the previous generation did business. Whether it was in terms of authenticity, design innovation and research, corporatism or business innovation. Interestingly, while there was a clear interest expressed by all the firms interviewed in profitability, most also wanted to contrast themselves from what they perceived as the conservative ‘corporate’ firms which are normally associated with profitability.

Customer orientation. [Actually, the strategy of differentiation of firms implies a similar differentiation of clients. The scarce competences will not be of interest to every client; otherwise they would not be scarce.]

6. Conclusions

On the validity of the current data collected the authors maintain that the paper is of qualitative nature and no further validation other than that of the respondents is required. In other words, internal and not external validity is expected at this point. However, it is envisioned that over a series of interviews eliciting constructs and elements will sum up of statistical analysis with external validity (Wright, 2006). At this point the authors are expecting to provide generic templates to assist industry with various entry points into PCT based mentorship sessions.

Results at this stage indicate wide range of emerging constructs, which have been categorised into a more specific number of clusters. A hierarchy of clusters are discussed such as (1) Design Oriented, (2) Ideology, (3) Process and (4) Business are amongst the most crucial discussion themes.

To conclude, this paper is argumentative in nature and as the abstract and introduction states, it aims to position the Repertory Grid Technique as a method to assist architectural firms with their growth. The RGT has proven to be a flexible, engaging methods that begins from the view-point of the respondents and not from a more traditional prescriptive approach such as the earlier investigated and tested techniques such as the RBV.

One aspect of RGT which could be better addressed in future sessions include ***timing*** control as it is easy to branch into a number of internal and external issues to the practice with some of the interviews taking 90 minutes or in the Zurich case over several sessions. It would be interesting to limit the agenda to more specific topics for discussion with the view to revisit the interviewee and expand from particular points. The other side to timing is that of discussing experiences or aspects to the practice in past, present or even future. The timing in this sense provides a way to compare a point of reference within the same practice as it grows, shrinks or experiences transitions points from stability to crisis and bouncing back (or not) to stability. This aspect of timing can be better managed during the interviews in order to encourage “reflections” and provide a retrospective history to particular clients or firms.

The final argument is that of the utilised terminology via the RGT for eliciting the constructs and thus developing the grids. RGT would provide a number of predefined elements, however the authors found that different respondents react differently to the same set of elements and is some cases better words would suit those same elements – ie. same meaning under different words and in other cases even cultural or language adaptation. This is an interesting development as the interviews took place across three different countries and although in English, the connotations of the elements and in some cases the actual literal translation into Dutch or German would provide a different meaning, in such cases, the element name would be refined to suit the client or respondent and not the interviewer. In this case the authors expect to see overtime a number of similar elements or constructs under different names or labels and possibly moving across different languages too.

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Enhancing Competitiveness of Construction Project Risk Management through Benchmarking of the IT Industry: Organizational Attitudes, Barriers and Solutions

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Abstract

Projects in the construction industry are accompanied by unique unforeseen threats to overall project goals and risk management (RM) reduces the detrimental effects to the project. However, risk provides a platform for opportunities if properly managed. Contrary to the slow pace of adoption in the construction sector of Singapore, the IT industry possesses a long history of properly managing risk. RM measure are redefined and improved by the IT industry from past projects failures. The demand for productivity gains, skill upgrade and sustainability drives a consistent investment of above S$250 million by the Singapore government in the construction sector. It is therefore imperative to tackle the challenges facing the industry to enhance its long-term competitive edge and business sustainability. Hence, this paper seeks to: (1) to explore and understand the construction and IT industries' acceptance of RM and; (2) to recommend practices that could be adopted by the construction industry from the IT industry in order to increase implementation levels of RM. Attitudinal inclination towards RM was collected via questionnaire from IT and construction companies. The data was analysed using mean score ranking and examined with T-test for statistical significance differences among the different sectors. The results revealed that the barriers reported by the construction industry were significantly different from those experienced by the IT industry. Furthermore, the results established that IT industry practitioners tend to be risk takers who desire training in RM skills while construction industry practitioners tended to be risk avoiders who resisted the changes required to implement RM. Similarly, when compared to the IT industry, the construction industry respondents lack adequate understanding of RM benefits. The study concludes with recommendations for the construction industry to increase its awareness of the benefits of RM and provides recommendations to increase its implementation.

Keywords: Construction Industry, Information Technology, Risk Management, Singapore.

1. Introduction

In the construction industry, identification and analysis choice of risk is opined to improve business risk (Rostami et al., 2015). Failure to adequately envisage unforeseen risk is detrimental to any project. Where RM failure occurs, key stakeholders lay the root causes on implementation rather than on RM core principles (Gendron et al., 2015). The ability to assess and overcome risk provides fertile grounds for project investment growth (Yafai, et al., 2014). Singapore development ideals towards an advanced economy targets superior skills with the construction industry as a key sector. The sustainable growth to provide housing and infrastructure for the growing population requires a long-term strategic outlook. RM is a critical tool for managing projects and failure to manage risks leads to project failure. Construction project involves a large number of players. The Information Technology (IT) and the construction industries came into prominence under the initiatives of the Singapore Government to automate many work functions. IT industry records a long standing history in implementing project management (PM) (Larssen, 2006). Implementation of project and RM arose as a result of the industry's reputation for its many earlier failures. Because so many IT projects have failed, substantial research were conducted to improve their likelihood of success through the implementation of RM. Due to early developments and awareness, the industry has since enjoyed a higher success rate, decreasing overruns on budget and schedules (The Standish Group 1995). RM standards are devoid of basic principles in applying RM in Small and Medium Scale Enterprises (Rostami et al., 2015). Similarly, the anathematised state of RM use in small projects presents a negative trend to the ideals of total RM (Hwang et al., 2014). Oman construction industry places majority risk factors in government category (Yafai, et al., 2014). Companies that hire construction services on a recurring tenure systematically avoid applying RM procedures in projects (Serpella et al., 2014). The construction industry has a very poor reputation for managing risks with projects failure deadlines and cost (Mills, 2001). The construction industry is devoid of a good track record of coping with risks with poor reputations for dealing with risks that produce cost and schedule overruns (Smith et al., 2006; Azhar et al., 2008). In order to distinguish existing deficiencies in the implementation of RM in the construction industry, it would be prudent to perform comparative case studies with the IT industry. This process should stimulate the construction industry to recognize the importance of RM and to improve their capabilities to manage risks, ultimately helping to deliver more successful projects. Therefore, this study seeks to: (1) to identify organizational attitudes towards RM; (2) to recommend RM best practices in the construction industry.

2. Risk Management, Information Technology and Construction Review

2.1 Risk Management

Uncertainties provide a bedrock for discomfort to stakeholders in any project (Olsson, 2007; Serpell et al., 2014). Although inherent in this discomfort lies significant opportunities worth embarking on (Hillson, 2011; Serpell et al., 2014). Risk is defined as the possible occurrence of a detrimental event to a project (Hillson, 2011; Serpell et al., 2014). International Organization for Standardization (2009) defines risk as a combination of the probability of the occurrence of a defined hazard and magnitude of consequences of the occurrence. Project Management Institute (2004) defines risk as an uncertain event or condition that, if it occurs, has a positive or a negative effect on project objective. Most concentration of project managers are directed towards the negative side (Hillson, 2011; Serpell et al., 2014). Hence, identifying, adequate examination and methodological application to risk reduction is key to any project (Tohidi, 2011; Serpell et al., 2014). RM process involves risk planning, identification, assessment, analysis, response, monitoring and recording and management process (ISO, 2009; Serpell et al., 2014). Risk identification and analysis are the most crucial elements in the process of RM (Mills, 2001; Hwang, Chua, 2011; Hwang et al. 2012). Ebrahimnejad et al. (2009) importance of risk identification are: (1) to avert possible events; and (2) relative importance on risks. Lyons and Skitmore (2004) and Hlaing et al. (2008) identified common risk identification techniques. The essence of risk analysis is to quantify the effects of major risks that are identified (Mills 2001). Hayes et al. (1986) stated that project risk analysis is often subjective affecting prospective benefits of RM from being realized. Effective risk analyses require a neutral and unbiased approach, though that is understandably difficult due to the potential for conflicts of interest. Techniques for risk analysis includes direct judgement, expert systems, code optimization, sensitivity analysis, probabilistic analysis, Monte Carlo simulation, kinetic tree analysis, expected monetary value, risk adjusted discount rate, and risk premium (Ahmed and Azhar, 2004; Lyons and Skitmore, 2004; Mills, 2001). RM is viewed from a negative domain rather than a neutral domain from the construction professionals' perspective in Indonesia (Hartono et al., 2014). Mills (2001) summarized that: (1) a cost-benefit assessment; (2) the removal of unnecessary contingency; (3) the clear recognition and acceptance of risk and; (4) realistic cost estimating.

2.2 Information Technology (IT) Industry and Risk Management

The evolving IT spheres provides several platforms for risk assessment. IT businesses provide project solutions that deliver new functionality for existing systems as well as create new systems for processing, storing and manipulating confidential data. To deliver products on time and at minimal cost, players in the industry have to be concerned with systematic invention, production and maintenance. Controlling and managing risks in this industry does not end with the completion of projects. RM to the IT environment is an essential management responsibility rather than a technical function carried out by the IT experts who create, operate and manage the IT system (IT Governance Institute, 2005). The Standish Group (1995) stated that formal managerial processes should be applied to the IT industry because when IT projects fail, it is usually due to the lack of management rather than technical mistakes. This aspect has triggered debates over the importance of RM in the IT industry (Mcmanus 2004). Taylor (2004) and Schwalbe (2009) stated that IT projects are usually linked to business processes and organizational systems that often involve a complex hierarchy of a large number of stakeholders. IT project managers tend to address RM as a standalone process and feed the results into their company integrated project management system (Marks, 2011). Many IT firms use integrated systems in order to balance the operational and economic cost of protective measures. IT professionals are trained and educated in terms of skills, tools, software, and technical and managerial techniques that can be used for RM.

2.3 Construction Industry and Risk Management

The construction industry is characterised by large-scale, complex assembly of components on-site, often requiring significant coordination of project team members (Geddes 1996). Construction firms make business decisions relying more on intuition, personal judgment, and experience than from formal and systematic processes. The deficiency of RM implementation in Singapore construction industry is due to the lack of familiarity with techniques, concepts and methods of RM (Taroun & Yang, 2011). Construction professionals' possess natural inertia to adopt new systems of procedures which are not familiar to them (Enegbuma et al., 2014). Taylor (2004) and Han et al. (2006) proposed the use of intelligent RM system in the industry. Akintoye and MacLeod (1997) regarded cultural issues as one of the major barriers to RM adoption with negative attitudes and mistrust towards risk analysis. Akintoye and MacLeod (1997) summarized the causes as: (1) lack of expertise in the techniques; (2) lack of information and knowledge; (3) time constraints; (4) doubts on applicability; (5) reliance on experience; (6) doubts of its benefits; and (7) lack of client commitment. In risk mapping for cost estimation, ontology approach examines potential risk paths to project perceived future cost overruns for international projects (Yildiz et al., 2014). Knowledge based approach by learning from previous risk experienced from successive projects have been identified as a means to counter future risk (Serpell et al., 2014). Risk sharing between owners and contractors can be modelled by integration of fuzzy logic into systems dynamic modelling structure (Nasirzadeh et al., 2014). RM can be monitored and analysed using a risk evaluation system built on the maturity levels (Serpell et al., 2015). RM technique are not applicable for use in all project situations (Forbes et al., 2008; Serpell et al., 2014). RM and risk identification is better handled through continuous learning process by contractual parties to a project (Perera et al., 2009; Serpell et al., 2014). RM improvements to meet client quality, cost and time needs for small sized projects in Singapore are prominently affected by lack of time, budget and profit margins (Hwang et al., 2014). Lack of managerial skill and underlying knowledge in choice of RM tool presents a challenging factors for SMEs (Rostami et al., 2015). Low level of enterprise RM (ERM) maturity exists among firms in Singapore (Zhao et al., 2014a). Insufficient resources characterised by lack of time, money and people were most critical (Zhao et al., 2014b).

3. Research Methodology

To accomplish the research aim of exploring and understanding the construction and IT industries' acceptance of RM and recommending practices that could be adopted by the construction industry, an extensive literature review was carried out to gain insight into the existing research on RM in both IT and construction sectors. The research instrument for comparison of both the IT and construction sector was developed via a questionnaire (Creswell, 2014). The questionnaires consisted of three sections namely: profile of respondents, RM implementation and suggestions to improve risk implementation. The sampling were randomly carried out for both IT and construction sectors derived from two sources. IT sample respondents were derived from the database of National Computer System (NCS) and Inland Revenue Authority of Singapore (IRAS) while construction was derived from the Contractor registry of Building Construction Authority (BCA). Each respondent was required to be assigned based on adequate knowledge and experience in the RM implementation processes in the firms. The responses were ranked using a five-point Likert scale from 1-Strongly Disagree to 5-Strongly Agree and analysed using mean score approach (Zhao et al., 2014a). The means score results was compared using a two-sample t-test to examine the statistical difference among the two sample respondents.

4. Data Analysis and Discussions

4.1 Information Technology and Construction Industry Demographics

The IT industry responses were 43 completed questionnaires. The work type in Table 1 revealed that PM and project managers made up for 72%. This points to the ability of the IT firms to competently carry out PM which forms the basis for this comparison. The number of employees showed that 93% of the sampled firms possessed over 500 staff strength. The larger the staff strength denotes adequacy in manpower and training in RM within the IT firms. The skill set and manpower is further enhanced by the interaction of the personnel with 70% clientele from both domestic and international. The years of experience in redefining and improving RM techniques is reflected by majority of 28% possessing 5-10 years. The high number of PM certification suggests that continuous professional development is encouraged within this sector.

Table1: Demographics of Respondents

		IT			***Construction***		
			N	***%***		***N***	***%***
Characteristics Company	*Work Type*	*PM*	*31*	*72%*	*PM*	*13*	*40%*
		Development	*5*	*12%*	*Development*	*9*	*28%*
		Design	*7*	*16%*	*Contractor*	*6*	*19%*
					Sub-contractor	*4*	*13%*
	Number of Employees	*350 - 500*	*3*	*7%*	*< 50*	*9*	*28%*
		> 500	*40*	*93%*	*50 - 150*	*19*	*59%*
					151 - 250	*4*	*13%*
	Client Type	*Domestic*	*13*	*30%*	*Domestic*	*29*	*91%*
		International	*0*	*0%*	*International*	*0*	*0%*
		Both	*30*	*70%*	*Both*	*3*	*9%*
Respondent	*Job Title*	*Project Manager*	*31*	*72%*	*Consultant*	*3*	*9%*
		Developer	*5*	*12%*	*Risk Manager*	*4*	*13%*
		Designer	*7*	*16%*	*Project Manager*	*11*	*34%*
					Quantity Surveyor	*7*	*22%*
					Architect	*7*	*22%*
	Years of Experience	*< 5*	*10*	*23%*	*< 5*	*3*	*9%*
		5 - 10	*12*	*28%*	*5 - 10*	*15*	*47%*
		11 - 15	*10*	*23%*	*11 - 15*	*9*	*28%*
		> 15	*11*	*26%*	*> 15*	*5*	*16%*
	PM Certification	*PMI*	*27*	*62%*	*PMI*	*0*	*0%*
		Others	*8*	*19%*	*Others*	*2*	*6%*
		No	*8*	*19%*	*No*	*30*	*94%*

On the contrast, the respondents from the construction industry revealed a 40% involvement in PM. This forms a wide difference of 32% when compared to the IT industry. Other work types were developers, contractors and subcontractors. 60% of the firms were relatively small with staff strength of 50-150. Small companies might be limited in their ability to implement comprehensive RM systems due to the lack of financial capabilities and expertise. A total of 75% of the respondents have experience of between 5-15 years while 10% of them had less than 5 years of experience in the industry. In contrast to the IT industry, 94% of the construction respondents declared that they did not possess any PM-related certification whereas only 19% from IT had no such certification. This may imply that the respondents from the construction industry have not received formal training in management, possibly in preference to enhancing technical skills and knowledge.

4.2 Organizational Attitudes towards Risk Management

Subsequently, the respondents were asked about their companies towards risks that they faced in their business operations, processes and activities. An attempt was then made to assess their firm's attitude towards risks by asking if management could be regarded as risk takers, risk avoiders, or neutral to risk. Table 2 revealed that 67% respondents considered their firms to be risk takers. Those who identified their firms as risk takers were asked about the reason for their selection, most reported that because their organization had established organizational RM policies and processes, their firms were not afraid to take on risky projects. Majority of the IT firms reported that they had been implementing RM for a relatively long span of time (72% for greater than 5 years). Because the practice is well-established, it is likely one of the reasons that the firms were proactive on taking risks.

Table 2: Risk Management in Organisations

Organizational Attitudes Towards Risk Management (RM)		***IT***		***Construction***	
		N	***%***	***N***	***%***
Risk Attitude	*Risk Taker*	*29*	*67%*	*9*	*28%*
	Risk Avoider	*8*	*19%*	*14*	*44%*
	Neutral	*6*	*14%*	*9*	*28%*
Years of RM	*< 1*	*0*	*0%*	*6*	*19%*
	1 - 2	*0*	*0%*	*24*	*75%*
	3 - 5	*12*	*28%*	*1*	*3%*
	> 5	*31*	*72%*	*0*	*0%*
RM Implementation	*Not at all*	*2*	*5%*	*21*	*66%*
	All Projects	*27*	*63%*	*1*	*3%*
	Some Projects	*14*	*33%*	*10*	*31%*
RM Beneficial?	*1 (Strongly Disagree)*	*0*	*0%*	*0*	*0%*
	2 (Disagree)	*6*	*14%*	*1*	*3%*
	3 (Neutral)	*5*	*12%*	*28*	*88%*
	4 (Agree)	*16*	*37%*	*3*	*9%*
	5 (Strongly Agree)	*16*	*37%*	*0*	*0%*
Benefits of RM	*Time Saving*	*10*	*23%*	*14*	*44%*
	Cost Control	*10*	*23%*	*14*	*44%*
	Strategic Planning	*3*	*7%*	*0*	*0%*
	Increase of Stakeholders' Value	*0*	*0%*	*1*	*3%*
	Increase of Understanding of Risk	*7*	*16%*	*0*	*0%*
	Achievement of Project Goals	*0*	*0%*	*1*	*3%*
	Minimal Disruptions	*5*	*12%*	*1*	*3%*
	Utilization of Resources	*8*	*19%*	*1*	*3%*

Furthermore, as shown in Table 2, 63% of the IT firms stated that they implemented RM on all of their projects. Of course, for a firm that considers itself a risk taker, implementation of RM would be a logical “must” on most of their projects. 74% of the respondents choose high ranks, indicating that the implementation of RM was perceived as beneficial to their firms. The survey questionnaire listed possible benefits that can be gained through RM implementation. Most respondents reported that time saving (23%) were the main benefits yielded by RM. Efficient RM allows organizations to develop contingency and mitigation plans that help them to manage potential risks and activate plans to address risks quickly when they occur. The regular review of contingency plans to monitor and control risks allows project managers to better predict cash flow and available budget for work to be completed. RM implementation prevents cost and time overruns and support more efficient utilization of available resources. Implementation of RM can be challenging due to various reasons. On the contract, Table 2 also shows that 28% of the respondents regarded their firms as neutral to risk and 44% reported being risk avoiders. It is noteworthy that respondents from development and contractor firms who encounter uncertainties in projects conform to a passive attitude of risk. However, this result may correspond with the research conducted by Smith et al. (2006), indicating that the lack of RM has persisted in the construction industry even though this industry is bound by a high degree of risk from complicated activities. In fact, 94% of the construction industry respondents reported that they had less than 3 years of experience implementing RM. The degree of implementation of RM is relatively low when compared to the IT industry with a total of 66% reporting that their firms did not implement RM at all on their projects. Although 31% of the firms indicated that they practiced RM on some of their projects, and 3% did so on all their projects, the benefits from RM implementation are apparently not well recognized. The majority, 88% were neutral about its benefits and 3% disagreed that there were benefits. Nonetheless, the survey respondents did indicate that proper implementation of RM may produce better identification and management of risks that affect cost and schedule performance (time saving–44%; better cost control–44%). The inference thus presents a scenario where firms from the construction industry are doubtful about the benefits of RM which invariably hinders implementation.

4.3 Barriers of Risk Management Implementation

Table 3 interestingly shows that more than 90% of the respondents believed that the benefits of RM were neither properly captured nor recognized by their companies (Lack of Belief in Benefits: *M*=4.09; one sample T-test P-value=0.00). On the other hand, none of the other barriers generated were identified as significant obstacles in their firms. The findings suggest that if an IT firm does not implement RM, it is more likely due to the lack of recognition of the benefits of RM rather than limitations of time and budget or resources such as tools and trained project managers and employees. This result may imply that most IT firms have policies, systems, and processes for RM, and their employees have been educated and trained in the area of RM. On the contrast, construction industry respondents believed that insufficient budget was one of the major obstacles hindering implementation of RM in their organizations (*M*=3.94; *P*=0.00). This may not be a surprise as the respondents originated from relatively small to medium-sized companies with limited financial capabilities for investment, development and implementation of RM. Furthermore, 78% of the respondents agreed that untrained staff (*M*=3.63; *P*=0.00) and project managers (*M*=3.56; *P*=0.00), as well as the lack of tools and systems (*M*=3.56; *P*=0.00) were barriers in their companies.

Table 3: Risk Management Barriers

Barriers	***SD***		***D***		***N***		***A***		***SA***		***M***		****One sample T-test***		*****Two sample T-test***
	IT	***C***	***IT***	***C***	***IT***	***C***	***IT***	***C***	***IT***	***C***	***IT***	***C***	***IT***	***C***	
	%	***%***	***%***	***%***	***%***	***%***	***%***	***%***	***%***	***%***					
Lack of Belief in Benefits	*0%*	*0%*	*2%*	*56%*	*5%*	*13%*	*74%*	*31%*	*19%*	*0%*	*4.09*	*2.75*	***0.00***	*0.13*	***0.00***
Operations Comfort	*14%*	*0%*	*79%*	*28%*	*7%*	*13%*	*0%*	*59%*	*0%*	*0%*	*1.93*	*3.31*	***0.00***	*0.06*	***0.00***
Not Requested by the Client	*0%*	*0%*	*93%*	*28%*	*5%*	*6%*	*2%*	*66%*	*0%*	*0%*	*2.10*	*3.38*	***0.00***	***0.03***	***0.00***
Not Approved by the Client	*0%*	*0%*	*74%*	*31%*	*7%*	*19%*	*19%*	*50%*	*0%*	*0%*	*2.44*	*3.19*	***0.00***	*0.25*	***0.00***
Insufficient Budget	*0%*	*0%*	*86%*	*0%*	*0%*	*6%*	*14%*	*94%*	*0%*	*0%*	*2.28*	*3.94*	***0.00***	***0.00***	***0.00***
Time Constraint	*0%*	*0%*	*93%*	*22%*	*7%*	*6%*	*0%*	*72%*	*0%*	*0%*	*2.07*	*3.50*	***0.00***	***0.00***	***0.00***
Lack of Tools and Systems	*0%*	*0%*	*100%*	*22%*	*0%*	*0%*	*0%*	*78%*	*0%*	*0%*	*2.00*	*3.56*	***0.00***	***0.00***	***0.00***
PMs Not Trained	*0%*	*0%*	*100%*	*22%*	*0%*	*0%*	*0%*	*78%*	*0%*	*0%*	*2.00*	*3.56*	***0.00***	***0.00***	***0.00***
Staff Not Trained	*0%*	*0%*	*100%*	*16%*	*0%*	*6%*	*0%*	*78%*	*0%*	*0%*	*2.00*	*3.63*	***0.00***	***0.00***	***0.00***
No Culture in the Company	*0%*	*0%*	*100%*	*34%*	*0%*	*25%*	*0%*	*41%*	*0%*	*0%*	*2.00*	*3.06*	***0.00***	*0.69*	***0.00***
Not Much Risk Managed	*3%*	*0%*	*95%*	*13%*	*3%*	*13%*	*0%*	*75%*	*0%*	*0%*	*2.00*	*3.63*	***0.00***	***0.00***	***0.00***

This may imply that RM in Singapore construction industry remains in its infancy and the adaptation of key players to appropriate RM tools and systems is not yet common. It is also possible that insufficient financial support for RM discourages development and implementation of tools and systems, further contributing to the lack of opportunities for training project managers and other project players. This may also explain why the potential benefits from RM are not fully recognized. Considering that the mean scores of the listed barriers are statistically different between the IT and construction industries, it can be concluded that the firms from the construction industry face more barriers to RM than the IT industry. In other words, due to active implementation of RM, IT firms have likely overcome most of the listed obstacles while the firms from the construction industry have not. These results suggest that different strategies for increasing implementation in the two industries are required.

4.4 Improvement of Risk Management Implementation

Organisational culture and applicability of RM techniques are vital towards effective implementation and project success (Akintoye and MacLeod, 1997; Forbes et al., 2008; Serpell et al., 2014). As a result, the respondents were asked to select methods that could improve their current organizational environment towards adapting better RM. As summarized in Table 4, about 90% of the respondents agreed that RM implementation in IT firms can be improved by: (1) educating staff on the importance of RM (M=4.12; P=0.00) (2) conducting training sessions covering the knowledge, skills and tools of RM (M=4.14; P=0.00); and (3) enforcing the use of RM through appropriate measures (M=4.02; P=0.00). This may infer that IT firms have already established processes and systems for RM but they recognize that continuing opportunities for education and training should be given to their employees in order to maximize the positive impact of RM at their firms. As shown in Table 4, the results from the methods for improvement cited by the construction industry were significantly different from IT. These differences are discussed later in more detail. On the contrast, 72% of the respondents in the construction industry agreed that their firms should develop internal systems to improve the degree of RM implementation (M=3.66; P=0.00). This strategy was not recommended by the IT firms. M=2.00; P=0.00 suggests that such systems might already be in place. The mean difference of the responses between the IT and construction industries was found to be statistically significant (two sample T-test P-value=0.000).

Table 4: Risk Management Improvements

Methods for Improvement	***SD***		***D***		***N***		***A***		***SA***		***M***		****One sample T-test***		****Two sample T-test***
	IT	***C***	***IT***	***C***	***IT***	***C***	***IT***	***C***	***IT***	***C***	***IT***	*C*			
	%	***%***	***%***	***%***	***%***	***%***	***%***	***%***	***%***	***%***					
Develop Internal System	*0%*	*0%*	*100%*	*6%*	*0%*	*22%*	*0%*	*72%*	*0%*	*0%*	*2.00*	*3.66*	***0.00***	***0.00***	***0.00***
Educate Staff on the Importance	*0%*	*0%*	*0%*	*31%*	*2%*	*13%*	*84%*	*56%*	*14%*	*0%*	*4.12*	*3.25*	***0.00***	*0.13*	***0.00***
Conduct Training on Knowledge and Skill	*0%*	*0%*	*0%*	*44%*	*0%*	*6%*	*86%*	*50%*	*14%*	*0%*	*4.14*	*3.06*	***0.00***	*0.72*	***0.00***
Invite Relevant Experts	*0%*	*0%*	*98%*	*25%*	*2%*	*0%*	*0%*	*75%*	*0%*	*0%*	*2.02*	*3.50*	***0.00***	***0.00***	***0.00***
Enforce Use of RM	*0%*	*0%*	*0%*	*34%*	*2%*	*28%*	*93%*	*38%*	*5%*	*0%*	*4.02*	*3.03*	***0.00***	*0.84*	***0.00***

Construction firms felt that bringing in relevant experts would be important to encouraging more implementation of RM (*M*=3.50; *P*=0.00) while this method was not one of the top priorities of the IT industry (*M*=2.02; *P*=0.00; two sample T-test *P*=0.00). The results imply that to increase implementation levels in the construction industry, proper internal tools and systems should first be deployed. Experts should be engaged with sufficient financial investment to support the effort. With a proper infrastructure, better implementation of RM can be established and intensive and training can be held to train employees.

5. Conclusions and Recommendations

RM continually plays a pivotal role for effective project delivery. This study examined and compared the status of RM performed by the IT and construction industries. The study observed contrasting differences in the educational level of the respondents where, IT possessed higher levels of training when compared to respondents from construction industry. However, educational training alone does not translate to high level of expertise in RM but relies on the respondents’ ability to apply management skills effectively in any risk assessment situation. This buttresses the need for constant improvement in the practical knowledge on RM by construction sector. The findings also revealed that IT industry respondents took an affirmative stand on the values of their industry in propensity to take more risk and ensure adequate techniques are put in place to mitigate any unforeseen risk that may arise. This ensures higher competitive, productive and financial gains in the long run. This may reflect the flip positive opportunities inherent in risk. In retrospect, IT firms exhibiting the characteristics of risk takers may benefit from more opportunities to generate higher payoff. Caution is warranted here because the assertion is true only when highly productive and effective RM measures are in place such that risks are successfully mitigated or eliminated. IT industry has been implementing RM more and longer than the construction industry. Construction industry respondents took a more conservative standpoint as cautious risk takers. IT and construction firms surveyed for this study agreed that RM is beneficial and may produce better schedule and cost performances, more barriers were reported by the firms from the construction industry. Plausible methods recommended for the construction industry to improve RM implementation were different from the IT industry. The firms from the IT industry reported that they have established systems and tools for RM and thus need to focus more on education and training. The construction firm indicated that proper systems needed to be deployed and used with the engagement of RM experts. It is imperative to educate and train staff on the importance and processes of RM, eventually enhancing the company's capability to mitigate risks and exploit opportunities. Construction firms can achieve long-term success via RM through more investment on a competent RM structure with proper IT solutions and training programs. Governmental and statutory requirements could also increase RM levels. It may be practical to develop a series of certifications focusing on RM and to devise a scheme for giving benefits to companies achieving such certifications. Due to the relatively small sample size, it may not be appropriate for the results of this study to be generalized for broader interpretation of the entire construction and IT industries. Another limitation is that the lack of RM implementation observed in the construction industry might be due partly to the small size of the firms that participated in the survey. It might be especially challenging for small firms to allocate sufficient resources to the development and implementation of rigorous RM.

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Changing Construction: Perspectives on Knowledge and Learning

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Abstract

The problem of knowledge in construction is not 'just' about knowledge, but about learning and about putting knowledge into action in order to change practices. This paper will use the Danish knowledge system as a case study in order to analyse where and why problems with regard to knowledge occur in construction. This analysis is based on a literature review of seminal studies on knowledge in general and a comprehensive documentary analysis of policy studies on the Danish knowledge system combined with qualitative research interviews of key persons. This paper starts out with a brief exploration of Danish policy studies and initiatives on knowledge and learning in construction. The paper then moves on to outline an analytical framework to understand knowledge and learning within construction. This paper suggests that an analytical framework should: 1) adopt a systemic perspective on construction and refurbishment, 2) highlight the absorptive capacity of firms as a crucial concept for adopting new knowledge, 3) be sensitive to the historicity and path-dependency of the individual construction project, 4) embrace communities of practice as the key framework for learning; and 5) manage the recurrent changes in knowledge types during construction projects, notably from tacit to explicit knowledge and vice versa. Based on this analytical framework, this paper has in broad terms analysed how the various Danish policy studies of the knowledge system have articulated the problem of knowledge in construction, identified how these articulations become controlling of the corresponding solutions, and pointed out some of the shortcomings as a result. With these insights in mind, it is the hope that future studies and public policies will adopt a more reflexive and reflective approach to the problem of knowledge in construction.

Keywords: Knowledge flows, bounded rationality, governance, social shaping, communities of practice

1. Introduction: A sticky problem

Knowledge or rather the lack of knowledge-sharing has frequently been evoked as a core problem with regard to improving the sustainability, performance and productivity of construction. Hence, a range of policy analyses along with development initiatives and research studies have been conducted over the years in Denmark. The policy analyses include for example the use of technological services in construction (Bang, 1997), a survey on learning and knowledge (Alsted Research, 2003), the characteristics of the communication landscape in construction as formulated by the development programme Project House (Christoffersen, 2000) and the repeated call for improved dissemination of building knowledge (see e.g. Carlsen et al., 2005). A number of other policy studies have focused on activities related to research and development in construction. These include among others an analysis by the Danish Building Development Council (abbreviated BUR) on production, use and dissemination of technical building knowledge (Dræbye, 1997) and several mappings of construction-related research and development activities (see e.g. Christoffersen and Bertelsen, 1990; Boligministeriet, 1993; Det Offentlige Forskningsudvalg for Byer og Byggeri (translation: The Public Research Committee on Cities and Construction), 2000; Haugbølle and Clausen, 2002). These have been followed by a number of public action plans like the programme ‘The Future of Construction: From tradition to innovation’ (By- og Boligministeriet & Erhvervsministeriet, 2000), the action plan on research and development activities (Udvalget vedrørende byggeforskning i Danmark (translation: Committee on Construction Research in Denmark), 2002), and a proposal for strengthening research and learning in construction issued jointly by the industry, government and knowledge institutions (Koordinations- og initiativgruppen for viden i byggeriet, 2009).

Along with the long line of policy studies a number of experiments and development activities have been carried out, which have pointed at possible ways to improve the dissemination and sharing of knowledge in particular with regard to the use of new information and communication technologies (ICT). These experiments and development activities include among others the Tele-byg project on the use of virtual communication in long-distance consultancy (Hansen et al., 2002) as well as the MELFO and Melfa projects on the use of handheld devices (PDA or smart phones) to support mobile e-learning for dyslexics. A number of initiatives like the BygSol programme (Christensen, 2008) and Bricklayers in Motion (see e.g. Bertelsen, 2011) have also been targeted at developing vocational training and improving the competences of craftsmen and unskilled labour. The construction-related research on knowledge include among others studies of morality and knowledge production among consulting engineers (Munch, 2005), the cultural organisation in construction and its role in knowledge application (Thuesen, 2006) and the constitution of partnering (Gottlieb, 2010). In recent years, extensive efforts have also been put into developing and applying Building Information Modelling (BIM) among Danish consultants in particular and more lately Virtual Design and Construction (VDC) among some of the major Danish contractors.

Despite all of these efforts, the “problem of knowledge” seems not only to be sticking around, but also to be accentuated by a general shift in most industrialised countries from new construction towards refurbishment activities. Refurbishment entails a different set of challenges compared to new construction, which calls for new strategies, knowledge and development of practices among construction professionals, policy makers and knowledge institutions. Hence, a range of new initiatives are being launched to address these challenges in many countries like the UK Green Deal programme, the Belgian BrusselsRetrofitXL programme and the European roadmap for moving to a low-carbon economy by 2050 (European Commission, 2011).

Denmark is no exception to this general line of development. Thus, two large private foundations recently initiated and funded a think tank to develop a new comprehensive refurbishment strategy for the built environment. The think tank was composed of some 30 members representing all major parties of the built environment. Over the course of a year the think tank held a number of consultations with experts, professionals and policy makers to identify relevant challenges and formulate corresponding initiatives to address these. At the end of 2012, the think tank published its strategy with seven initiatives related among others to improving statistics on refurbishment, accelerating innovation, strengthening education and improving dissemination of knowledge (Tænketank for bygningsrenovering, 2013).

One of the ensuing initiatives encompassed a more substantial analysis of ‘the problem of knowledge’. This chapter will report on the results of this analysis and take a closer look at where and why problems occur with regard to knowledge within construction. It will take as its starting point that the problem of knowledge is not ‘just’ about knowledge, but about learning and about putting knowledge into action in order to transform practices. The chapter will identify different perspectives on knowledge and discuss how these understandings and metaphors of knowledge articulate knowledge differently as a problem and thus becomes controlling of the corresponding solutions.

2. Methodology

2.1 Ontological position

The analytical framework of this paper is developed on the basis of a number of seminal studies on knowledge in general. The ontological position is based on the following assumptions about knowledge in construction and refurbishment, more specifically:

- An analytical framework needs to address five levels to give a comprehensive understanding of the problem of knowledge in construction. These five levels are: 1) construction as a system, 2) firms as key players, 3) projects as the focal point, 4) communities of practice in groups and professions, and 5) individuals as bearers of skills.
- An analytical framework of knowledge in construction needs to be able to include both explicit and tacit knowledge as both forms are strongly prevalent among the different actors of construction.

- An analytical framework needs to acknowledge that knowledge-sharing among project participants and dissemination of knowledge from e.g. development projects takes place through many different means depending on the type of knowledge etc.
- An analytical framework needs to consider knowledge as functional rather than actor-centred, i.e. production, distribution and use of knowledge is not exclusively linked to the different type of actor, but all actors may to a varying degree over time and space act as producers, intermediaries and users of knowledge.
- An analytical framework needs to recognise that the formulation of knowledge problems and possible solutions to these problems of knowledge is largely dictated by how knowledge in construction is perceived and conceptualised.

2.2 Research design

The research design follows a case study design. Flyvbjerg (2006: 230) states that paradigmatic cases *'develop a metaphor or establish a school for the domain that the case concerns.'* Identifying a case as paradigmatic is particular challenging as noted by Flyvbjerg (2006: 232) as paradigmatic cases by their very nature transcends any sort of rule-based criteria. The analysis of the Danish knowledge system on construction and refurbishment may be considered paradigmatic in the sense that it shares a number of characteristics and similarities with other industrialised countries e.g. with regard to the distribution of construction output as new built versus refurbishment, the application of the same European rules of procurement, and the use of a range of similar construction products as in many other countries due to the European internal market. However, there are a number of differences in national building codes, industrial structure etc. that makes it less likely to use the Danish knowledge system as an exemplar for construction knowledge systems in general.

The case also have elements of being a critical case, which makes it possible to draw conclusions or generalisations of the kind that *'if it is valid for this case, it is valid for all (or many) cases'* (Flyvbjerg, 2006: 230). These arguments relate to characteristics of the Danish construction industry like Danish construction professionals being generally considered as highly skilled and knowledgeable, a well-paid workforce with social status, high degree of digital literacy and extensive access to ICT solutions. Hence, if problems of knowledge exist in the Danish construction industry, the same kind of problems – and maybe even in an accentuated form – are likely to be found in other national construction industries.

2.3 Methods and data

The study is based on a documentary analysis combined with qualitative research interviews. The longitudinal documentary analysis is based on a comprehensive selection of written Danish sources covering the most prominent policy studies etc. over a period of over more than two decades. This longitudinal study has been combined with a cross-sectional study of the present situation and challenges through qualitative research interviews with seven key persons representing major actors of the construction industry. These include a representative from educational institutions, information offices, research institutions, contractors, trade unions, wholesalers, and R&D funding offices.

3. The problem of knowledge in construction

3.1 A systemic perspective

Gann and Salter (2000) adopt a systemic perspective on construction, where innovation must be understood in the context of both the technological support infrastructure for producing knowledge and the regulatory and institutional environment. The individual elements of the system are connected to each other through flows of knowledge. Haugbølle et al. (2012) has developed Gann and Salter (2000) systemic perspective to also explicitly include the building users and suggest that links between the individual element can predominantly be understood as business processes between actors in three different types of markets, learning processes and policy processes (see Figure 1).

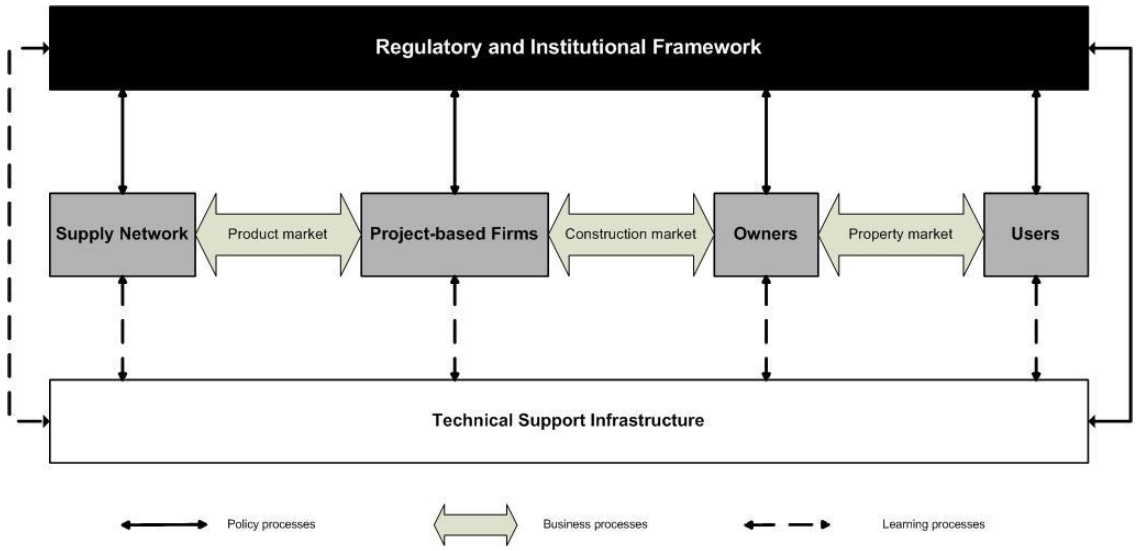

Figure 1: Systemic perspective on construction (Haugbølle et al., 2012: 452)

The majority of policy studies on the problem of knowledge in Danish construction have focused on how new research-based knowledge can be made available for use in the project-based companies of construction. Most of these policy studies criticise in particular the universities and other knowledge institutions for not disseminating new knowledge appropriately to the project-based firms of construction, in particular contractors and consultants. Thus, the preferred solution to the knowledge problem is to improve dissemination from the universities and the like through e.g. mandatory dissemination plans for R&D projects, joint information services e.g. as a sort of digital one-stop-shopping solutions etc.

However, a systemic perspective on the problem of knowledge as mentioned above indicates that it is far too narrow to focus on the dissemination from knowledge institutions. A systemic perspective would rather suggest that the problem of knowledge can be found in four different locations:

- The interaction between the political-institutional apparatus on one side and business as well as users on the other side.
- The interaction between the individual companies and its customers throughout the entire supply chain spanning three separate markets of products, construction and property.
- The interaction between knowledge institutions and each of the business actors – supply network, project-based firms, owner and users of buildings.
- The capabilities and interaction within each of the individual units.

3.2 Firm versus project: Absorptive capacity

Especially the capabilities and interaction within each organisation has often been neglected in Danish policy studies, even though this is central to a firm's ability to adopt new knowledge. A central key concept in this context is 'absorptive capacity'. Cohen & Levinthal (1990: 128) defines this ability to absorb knowledge in the following way:

> *'…the ability of a firm to recognize the value of new, external information, assimilate it, and apply it to commercial ends is critical to its innovative capabilities. We label this capability a firm's absorptive capacity and suggest that it is largely a function of the firm's level of prior related knowledge.'*

The development of a firm's absorptive capacity depends on both the individual's and the organisation's ability to adopt knowledge, which is both history-dependent and path-dependent. Cohen & Levinthal (1990: 132) further point out that the firm's ability to adopt new knowledge depends on the communicative structures inside and outside the firm, including the nature and distribution of expertise within the organisation:

> *'Absorptive capacity refers not only to the acquisition or assimilation of information by an organization but also to the organization's ability to exploit it. Therefore, an organization's absorptive capacity does not simply depend on the organization's direct interface with the external environment. It also depends on transfers of knowledge across and within subunits that may be quite removed from the original point of entry. Thus, to understand the sources of a firm's absorptive capacity, we focus on the structure of communication between the external environment and the organization, as well as among the subunits of the organization, and also on the character and distribution of expertise within the organization.'*

In project-based industries like construction, the absorptive capacity is not solely linked to the firm as such, but as well to the often many projects being managed by the firm simultaneously and over time. Hence, the interplay between the firm as the basis and the individual projects as well as across projects is crucial for understanding and dealing with the problem of knowledge in construction. In his earlier work with innovation in the project-based organisations of construction, Winch (1998) has suggested the following model for different types of knowledge flows between the project, the firm and the surroundings of both (see Figure 2).

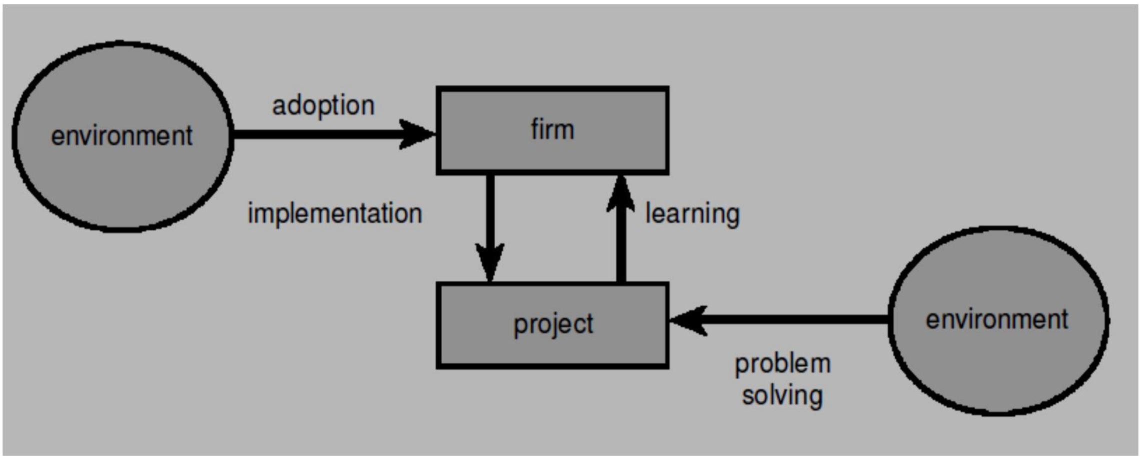

Figure 2: Knowledge flows between project and firm (Winch, 1998: 273)

The model is a reminder that the problem of knowledge must be addressed along at least three dimensions:

- External to the firm – either horizontally in networks with like-minded people for example within the same profession or vertically in networks across disciplines.
- In-between the individual projects and the firm.
- Within the project between the respective project participants, but external to the firms involved in a project.

What the model however fails to acknowledge is the need to address the knowledge flows taking place between different projects either simultaneously in time or consecutively over time.

3.3 No project is an island: Historicity and path dependency

Projects are not only vital for both new construction and refurbishment but the very organising principle of construction firms. The uniqueness of projects is often used as an explanation for why it is difficult to share knowledge and create change in construction. Despite the widely held assumption of projects being both unique and isolated events, projects are not isolated islands as Engwall (2003) points out. Instead projects are embedded in an organisational context and with a historicity marked by previous projects, parallel courses of events and ideas about the post-project future.

Following Engwall (2003), knowledge in projects is not isolated or necessarily unique, but is tied up on experience from previous projects as well as project-independent factors such as general business policies that go beyond the individual project. In this way, previous experience and general policies creates a path dependency that sets the scene for future projects (Figure 3).

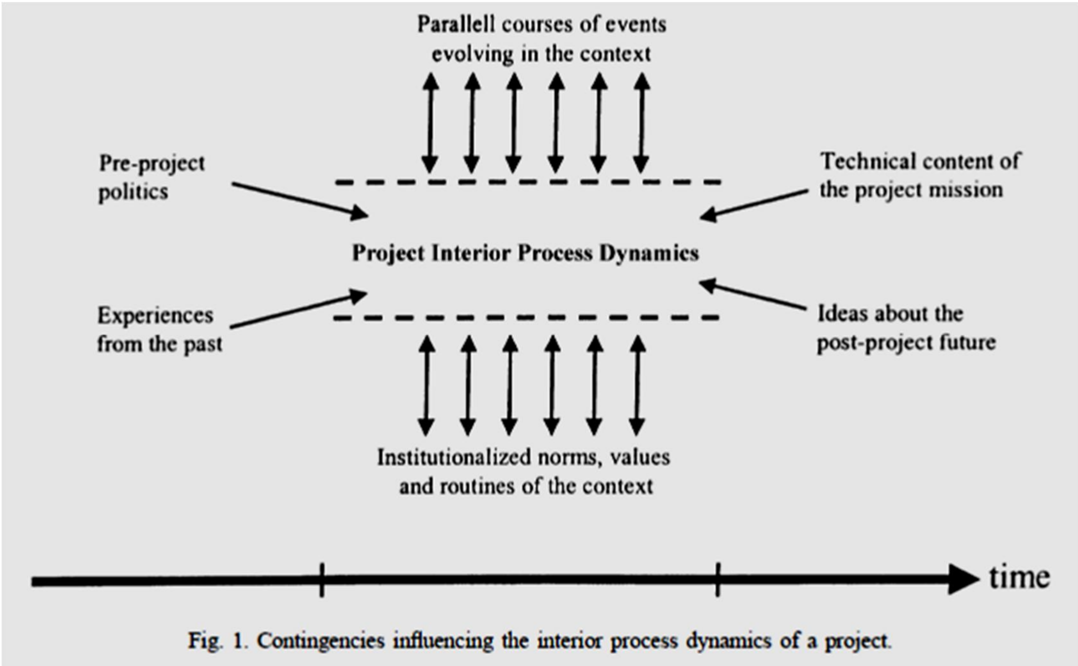

Figure 3: Factors affecting the project's dynamics (Engwall, 2003: 805)

In most Danish policy studies there is a strong rhetoric on the project-based nature of construction and the barriers to knowledge and change created by this very nature. However, a range of possible interventions related to the contingencies influencing the interior process dynamics of a project tend to be ignored. While these contingencies may be overlooked in policy studies, some of the major Danish consulting firms and contractors now attempt to address these in their internal training and course activities on management. But management and learning within and across projects is only side of the knowledge problem in construction. Another side of the problem is related to how trades and professions operate and are organised.

3.4 Learning: Communities of practice

Collaboration, knowledge-sharing and learning across the many trades and professions within construction is notoriously challenging as have been recognised by several (see e.g. Christensen, 2008 and Thuesen, 2007). But these shared communities of practice within trades and professions also hold strong a potential for being a part of the solution to (part of) the problem of knowledge in construction.

Communities of practice have in recent years received considerable attention in the context of organisational development and efforts to understand and improve knowledge and improve learning in organisations. Wenger (1998: 4-5) defines learning as an active participation in the practices of a community and forming of identity in relation to these communities:

'A social theory of learning must therefore integrate the components necessary to characterize social participation as a process of learning and of knowing. These components (…) include the following:

1) Meaning: *a way of talking about our (changing) ability – individually and collectively – to experience our life and the world as meaningful.*

2) Practice: *a way of talking about the shared historical and social resources, frameworks, and perspectives that can sustain mutual engagement in action.*

3) Community: *a way of talking about the social configurations in which our enterprises are defined as worth pursuing and our participation is recognizable as competence.*

4) Identity: *a way of talking about how learning changes who we are and creates personal histories of becoming in the context of our communities.'*

With regard to innovation and change management, the problem of knowledge in Danish construction projects is not only a matter of learning new things, but also to 'unlearn'. The ability to discard knowledge – where appropriate – is also an important aspect of communities of practice, although this is often overlooked.

Knowledge and learning across communities of practice like trades and professions within construction presents challenges because of the very characteristics that are also their strengths, i.e. the internal autonomy of the communities, their informal nature, and not least their differences in prevalence of knowledge types.

3.5 Tacit versus explicit knowledge: Repeated shifts

Knowledge management deals with collecting, developing, distributing and applying knowledge in organisations. One of the most important and seminal work was done by Nonaka and Takeuchi (1995), who studied knowledge and innovation in Japanese companies and developed the so-called SECI model. The SECI model analyses the interaction and transformations between tacit and explicit knowledge. The SECI model points out that both forms of knowledge are important and that the conversion between them is important (see Figure 4).

		TO	
		Tacit knowledge	Explicit knowledge
FROM	Tacit knowledge	Socialization	Externalization
	Explicit knowledge	Internalization	Combination

Figure 4: The SECI model – four types of conversion of knowledge (Adapted after Nonaka & Takeuchi, 1995: 62)

The construction process is typically characterised by the involvement of several firms and trades, which implies numerous and repeated shifts between tacit knowledge and explicit knowledge. The ability to handle these shifts in order to accumulate, disseminate and apply knowledge in practice is probably one of the construction industry's main challenges with regard to knowledge. As pointed out bluntly by Danish practitioners: First, the client must articulate his tacit and more or less explicit knowledge about his needs for a new building. The consultant then turns these into to explicit knowledge in the shape of formal documents such as drawings and specifications. This explicit knowledge is then being adopted and adapted to tacit knowledge, which is the primary knowledge base among the craftsmen in construction companies. Finally, the actual building will be managed by building caretakers based on their mix of explicit and tacit knowledge on caretaking of that particular building, and it will be measured against the more or less tacit knowledge of the end-users of how appropriate the services delivered by the building suits their needs.

4. Conclusions

This paper has provided a brief exploration of an extensive number of Danish policy studies and initiatives on knowledge and learning in construction over the past two decades.

The paper then moved on to outline an analytical framework to understand knowledge and learning within construction. This paper suggests an analytical framework that: 1) adopt a systemic perspective on construction, 2) highlight the absorptive capacity of firms as a crucial concept for adopting new knowledge, 3) is sensitive to the historicity and path-dependency of the individual construction project, 4) embrace communities of practice as the key framework for learning; and 5) manage the recurrent changes in knowledge types, notably from tacit to explicit knowledge and vice versa.

Based on this analytical framework, this paper has in broad terms analysed how the various Danish policy studies of the knowledge system have articulated the problem of knowledge in construction, identified how these articulations become controlling of the corresponding solutions, and pointed out some of the shortcomings as a result. With these insights in mind, it is the hope that future studies and public policies will adopt a more reflexive and reflective approach to the problem of knowledge in construction.

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Hindrances to Enterprise Risk Management in Construction Firms: An Organizational Learning Perspective

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Abstract

In recent years, holding a holistic view of risk management has become the trend in various industries. In this trend, enterprise risk management (ERM) has been viewed as the fundamental paradigm and has attracted the attention from the academics and practitioners worldwide. Implementing ERM in construction firms is inevitably associated with organizational learning. The objectives of this study are to (1) identify the critical hindrances to ERM in Chinese construction firms (CCFs) and (2) analyze them in tandem with theories of organizational learning. To achieve these objectives, a total of 36 hindrances to ERM and 12 hindrances to organizational learning were identified through a literature review, and a questionnaire survey was performed with 119 respondents from 119 CCFs in the global construction market. The results indicated that 20 hindrances were deemed critical, among which "insufficient resources (e.g. time, money, people, etc.)", "lack of a formalized ERM process", and "lack of internal knowledge, skills and expertise" were the top three hindrances. In addition, the critical hindrances to ERM were interpreted from the perspective of organizational learning, and the 12 hindrances to organizational learning were linked to the critical hindrances to ERM. This study presents the theoretical rationale behind the critical hindrances to ERM implementation and contributes to the literature through interpreting ERM implementation from an organizational learning perspective.

Keywords: Risk management, organizational learning, construction firm, hindrances.

1. Introduction

In recent years, enterprise risk management (ERM), as a holistic view of risk management, has attracted the attention from the academics and practitioners worldwide (McGeorge and Zou, 2013). The Committee of Sponsoring Organizations of the Treadway Commission (COSO, 2004, p.2) defines ERM as “a process, effected by an entity’s board of directors, management and other personnel, applied in strategy setting and across the enterprise, designed to identify potential events that may affect the entity, and manage risk to be within its risk appetite, to provide reasonable assurance regarding the achievement of entity objectives.” Because construction businesses are inevitably afflicted with various and complex risks, construction firms have been considered as prime candidates for ERM implementation (Zhao et al., 2013a). Implementing ERM in construction firms can be seen as a gradual organizational change, and Zhao et al. (2014a) interpreted ERM implementation in construction firms from the perspective of organizational change. In addition to organizational change, organizational learning is also necessary for ERM implementation. This is because learning is a medium for change (Alas and Sharifi, 2002), and improves the ability to adapt to change, at both individual and organizational levels (Garvin, 1993, Senge, 1990). Learning and change were not only parallel and simultaneous, but are also interactive processes, as learning has a mediating role in the change process (Lähteenmäki et al., 2001). In the tumultuous environment, learning also helps to reduce uncertainty and thus inevitably reduce resistance to change (Lähteenmäki et al., 2001). Hence, change and learning should not be isolated from each other and ERM implementation cannot be isolated from organizational learning.

In project-based construction firms, most management staff has been familiar with and adopted project risk management (PRM). Thus, it is necessary for the individuals who are accustomed to PRM to learn ERM fundamentals and how to further PRM contributions to ERM. Without this individual learning process, ERM cannot be implemented at all levels across the firm, because individual learning is the basis of organizational learning (Senge, 1990). In addition, the existing learning processes that support PRM can also contribute to ERM implementation, because PRM is an integral part of ERM. The focus on learning from risks is likely to institutionalize risk information and change PRM practices to a corporate-level approach (Dikmen et al., 2008). Furthermore, Smallman (1996) argued that organizational learning, together with data collection and collation as well as forecasting, comprised holistic risk management.

Implementing ERM in construction firms is not easy. Zhao et al. (2014b) reported that most of the Chinese construction firms (CCFs) based in Singapore had low-level ERM implementation. The low-level ERM implementation could be attributed to the influence of various hindrances (Zhao et al., 2015). The objectives of this study are to (1) identify the critical hindrances to ERM in CCFs in the global market; and (2) analyse these hindrances in tandem with theories of organizational learning.

2. Background

2.1 Hindrances to ERM implementation

Previous studies have reported that a number of factors hindered ERM implementation in various industries. Confronted with these hindrances, firms in various industries tend to find it difficult to fully implement ERM and the percentage of firms adopting or implementing ERM was not high. In the construction industry, Zhao et al. (2014b) found that none Singapore-based CCFs had high-level ERM implementation, whilst Liu et al. (2011) indicated that only 14.7% of the leading CCFs in the global market had fully implemented ERM. In this study, hindrances are barriers to initiating ERM and carrying out ERM along the maturity continuum, in all the phases of ERM implementation. In the earlier phase of the larger research project, Zhao et al. (2014a) identified a total of 36 hindrances from previous studies, as shown in Table 1.

Table 1: Hindrances to ERM implementation [Adapted from Zhao et al. (2014a)]

Code	*Hindrances to ERM implementation*	*Code*	*Hindrances to ERM implementation*
H01	*Low data quality*	*H19*	*Perception that ERM interferes with business activities*
H02	*Lack of data*	*H20*	*Inadequate training on ERM*
H03	*Insufficient resources (e.g. time, money, people, etc.)*	*H21*	*Lack of an ERM business case*
H04	*Lack of a formalized ERM process*	*H22*	*Lack of perceived value or benefits of ERM*
H05	*Lack of risk management techniques and tools*	*H23*	*Lack of commitment of the board and senior management*
H06	*Lack of internal knowledge, skills and expertise*	*H24*	*Not perceived as a priority by senior management*
H07	*Lack of qualified personnel to implement ERM*	*H25*	*Lack of board or senior management leadership*
H08	*Lack of a risk management information system (RMIS)*	*H26*	*The movement of the ERM champion from senior management into other areas without a successor*
H09	*Unsupportive organizational structure*	*H27*	*Lack of consensus on benefits of ERM among board members and senior management*
H10	*Unsupportive organizational culture*	*H28*	*Other management priorities*
H11	*Lack of a common risk language*	*H29*	*Lack of a clear ERM implementation plan*
H12	*Lack of risk awareness within the organization*	*H30*	*Inability to coordinate with other departments*
H13	*Confidence in the existing risk management practices*	*H31*	*Lack of a set of metrics for measuring performance of ERM*
H14	*Existence or re-emergence of the silo mentality*	*H32*	*Unclear ownership and responsibility for ERM implementation*

H15	*Lack of shared understanding and approach to risk management across departments*	*H33*	*Organizational turf*
H16	*Lack of understanding relating to effective ERM process*	*H34*	*Employees' reluctance to give up power*
H17	*Perception that ERM adds to bureaucracy*	*H35*	*People' reluctance to share risk information*
H18	*Perception that ERM increases costs and administration*	*H36*	*Recession and business downturn*

2.2 Organizational learning

Organizational learning can be defined as "a continuous testing of experience and its transformation into knowledge available to whole organization and relevant to their mission" (Senge, 1990, p.6). Organizational learning stems from the knowledge acquisition of the individuals within the organization, and progresses with the exchange and integration of this knowledge until collective knowledge is created (Hedberg, 1981, Jerez-Gómez et al., 2005). Although organizational learning has its roots in individual learning (Senge, 1990), it is distinct from adding together the individual learning of the organization's different members (Alas and Sharifi, 2002, Hedberg, 1981).

Sfard (1998) proposed two metaphors of learning: the acquisition and participation metaphors, which are also known as the cognitive-behavioral approach and the sociocultural (or situated) approach, respectively (Ellström, 2010). From the perspective of the acquisition metaphor, the mind is a container of knowledge, and learning is a process of filling the container and implanting knowledge there. Knowledge is viewed as a property or capacity of an individual mind (Paavola et al., 2004). By contrast, the participation metaphor regards learning as a process of participation in cultural practices and shared learning activities. From this perspective, learning cannot be separated from working and other social practices where it is used (Brown and Duguid, 1991). In this view, learning is "situated" in these relations and networks of activities of participation (Paavola et al., 2004). Sfard (1998) argued that both approaches were needed. They are not simply rivals but complement each other. There is also a third approach to organizational learning: the knowledge-creation approach. It is based on the view that the production, transformation, and utilization of knowledge are fundamental for understanding organizational learning (Ellström, 2010).

Table 2: Hindrances to organizational learning

Code	*Hindrances to organizational learning*	*Code*	*Hindrances to organizational learning*
L01	*Lack of leadership commitment and support*	*L07*	*Reluctance to accept knowledge*
L02	*Lack of internal knowledge*	*L08*	*Lack of knowledge absorptive or retentive capacity*
L03	*Lack of organizational commitment*	*L09*	*Lack of channels for dialogue and sharing meaning*
L04	*Lack of psychological safety*	*L10*	*Arduous relationships*
L05	*Lack of motivation*	*L11*	*Downsizing or layoff strategies*

L06	*Reluctance to share knowledge*	*L12*	*Unsupportive organizational culture*

Previous studies have identified several hindrances to organizational learning because individuals have been trained to think and act in conflicting ways (DiBella and Nevis, 1998). As indicated in Table 2, 12 hindrances to organizational learning are identified from previous studies (Argyris, 1995, Atak and Erturgut, 2010, Cohen and Levinthal, 1990, Ellström, 2010, Fisher and White, 2000, García-Morales et al., 2006, Hayes, 2007, Husted and Michailova, 2002, Lipshitz et al., 2002, Pfeffer, 1998, Popper and Lipshitz, 2000, Senge, 1990, Shrivastava, 1983, Szulanski, 1996).

3. Method and Data Presentation

As a systematic method of collecting data based on a sample, the questionnaire survey technique has been widely used to collect professional views in risk management research (Deng et al., 2014, Hwang et al., 2014, Mu et al., 2014, Zhao et al., 2014c). In this study, a questionnaire survey was performed to investigate the hindrances to ERM implementation. The comprehensive literature review supported the development of the questionnaire. In the survey, the respondents were asked to rate the influence of the 36 hindrances on ERM implementation using a five-point scale (1=very insignificant, 2=insignificant, 3=neutral, 4=significant, and 5=very significant).

Table 3: Profile of respondents

Work experience	*N*	*%*	*Designation*	*N*	*%*	*Location*	*N*	*%*
5-10 years	*54*	*45%*	*Senior management*	*35*	*29%*	*China*	*35*	*29%*
11-15 years	*25*	*21%*	*Department management*	*26*	*22%*	*Asia (w/o China)*	*46*	*39%*
16-20 years	*17*	*14%*	*Project management*	*58*	*49%*	*Africa*	*28*	*24%*
21-25 years	*11*	*9%*				*Europe*	*4*	*3%*
Over 25 years	*12*	*10%*				*Latin America*	*6*	*5%*

The population consisted of all the industry practitioners with extensive experience in risk management of CCFs in the global market. As there was no sampling frame in this survey, the sample was a non-probability sample. The non-probability sampling plan can be used to obtain a representative sample (Patton, 2001), and has been recognized as appropriate when the respondents were not randomly selected from the entire population, but were rather selected based on whether they were willing to participate in the study (Liu et al., 2016, Wilkins, 2011). A list of senior and middle management staff of CCFs were obtained and 500 questionnaires were sent out. A total of 119 completed questionnaires were received, representing a response rate of 24%, which was acceptable compared with the norm of 20-30% with most questionnaire surveys in the construction industry (Akintoye, 2000, Hwang et al., 2015). The profile of the respondents is shown in Table 3.

4. Results and Discussion

4.1 Ranking of hindrances to ERM implementation

In this study, the 36 hindrances were ranked based on their influence mean scores, which ranged from 2.82 to 4.29 (see Table 4). The normalized values of the mean scores were calculated to select the critical hindrances. This method was adopted by Xu et al. (2010), who identified the factors with normalized values equal to or greater than 0.50 as critical factors. Thus, the hindrances, which received the mean scores closer to the maximum mean scores, are deemed as critical hindrances. The analysis results indicated that 20 out of the 36 hindrances obtained normalized values above 0.50, implying that these 20 factors were critical hindrances to ERM implementation in CCFs.

"Insufficient resources (e.g. time, money, people, etc.)" (H03) was ranked top, suggesting that ERM implementation in CCFs was not assigned with sufficient time, money and manpower. The majority of time, money and people were invested into project construction, and insufficient resources were allocated for ERM programs, signalling that these firms did not attach adequate importance to ERM.

Table 2: Ranking of hindrances to ERM implementation

Code	*Mean*	*Rank*	*Normalization*	*Code*	*Mean*	*Rank*	*Normalization*	*Code*	*Mean*	*Rank*	*Normalization*
H01	*3.73*	*11*	*0.62*	*H13*	*3.42*	*25*	*0.41*	*H25*	*3.73*	*11*	*0.62*
H02	*3.78*	*9*	*0.65*	*H14*	*3.24*	*28*	*0.29*	*H26*	*3.18*	*30*	*0.25*
H03	*4.29*	*1*	*1.00*	*H15*	*3.54*	*21*	*0.49*	*H27*	*3.33*	*27*	*0.35*
H04	*3.91*	*2*	*0.74*	*H16*	*3.5*	*23*	*0.47*	*H28*	*3.46*	*24*	*0.44*
H05	*3.82*	*8*	*0.68*	*H17*	*2.82*	*36*	*0.00*	*H29*	*3.83*	*7*	*0.69*
H06	*3.9*	*3*	*0.73*	*H18*	*3.61*	*20*	*0.54*	*H30*	*3.23*	*29*	*0.28*
H07	*3.87*	*4*	*0.71*	*H19*	*3.14*	*31*	*0.22*	*H31*	*3.66*	*16*	*0.57*
H08	*3.66*	*15*	*0.57*	*H20*	*3.86*	*5*	*0.71*	*H32*	*3.64*	*18*	*0.56*
H09	*3.64*	*18*	*0.56*	*H21*	*3.51*	*22*	*0.47*	*H33*	*3.01*	*32*	*0.13*
H10	*3.67*	*14*	*0.58*	*H22*	*3.85*	*6*	*0.70*	*H34*	*2.97*	*34*	*0.11*
H11	*3.34*	*26*	*0.36*	*H23*	*3.64*	*18*	*0.56*	*H35*	*2.9*	*35*	*0.05*
H12	*3.67*	*14*	*0.58*	*H24*	*3.71*	*12*	*0.60*	*H36*	*2.98*	*33*	*0.11*
Normalized value = (Mean - Minimum Mean)/(Maximum Mean - Minimum Mean)											

"Lack of a formalized ERM process" (H04) received the second position. This result implied that if there was not a formalized ERM process in a firm, the ERM implementation in this firm would be significantly hindered because such a formalized process can serve as a guide for the staff involved in ERM implementation. The lack of such a formalized process can make staff misunderstand how to implementation ERM.

"Lack of internal knowledge, skills and expertise" (H06) was ranked third. This result suggested that CCFs lacked internal knowledge, skills and expertise relating to ERM, which significantly hindered ERM implementation in these firms. Although ERM was advocated in Chinese firms after the State-owned Assets Supervision and Administration Commission of the State Council of China issued the Guidance to ERM for Central Enterprises in 2006, the CCFs still lacked internal knowledge, skills and expertise relevant to ERM and most of the overseas subsidiaries obtained these resources from their parent companies.

4.2 Interpretation from the organizational learning perspective

Some of the 12 hindrances to organizational learning can be used to interpret the critical hindrances to ERM implementation. Without the senior-level commitment and support, the learning culture would not be created; resources would not be invested into the learning and training programs; the staff would not perceive the learning as being emphasized; and finally, organizational learning mechanisms would not be set up and institutionalized. Thus, the critical hindrances relating to the top management (H23-H25), the organizational culture and structure (H09 and H10), the resource investments (H01-H08, and H31), as well as the training and understanding of ERM (H18, H20 and H22) can be linked to “lack of leadership commitment and support” (L01) in the hindrances to organizational learning.

According to the literature, organizational learning is associated with knowledge acquisition (Huber, 1991, Shrivastava, 1983), participation in the learning process (i.e. situated learning) (Brown and Duguid, 1991), and knowledge creation (Bereiter, 2002, Engeström, 1999, Nonaka, 1991). In the CCFs, ERM implementation involves knowledge acquisition from inside and outside the firm, the participation of the relevant staff in the training programs and risk communication, as well as the creation of knowledge from the ERM practices. Six factors (H01, H02, and H04-H07) significantly hindered ERM implementation because they contributed to the “lack of internal knowledge” (L02) relating to ERM. Specifically, as the data are the predecessor of information and knowledge, the lack of high-quality data can result in the lack of internal knowledge. Also, the lack of a formalized ERM process, relevant techniques and tools represents a low level of knowledge relating to ERM. In addition, the staff qualified to implement ERM are likely to have the relevant knowledge, skills and expertise, and the lack of such staff can therefore led to the lack of internal knowledge.

There should be a channel through which people share their ideas and knowledge. A risk management information system (RMIS) can serve as a platform where the relevant staff can communicate the risk information as well as the lessons learned in ERM implementation (Zhao et al., 2013b), while training programs allow external and internal trainers to share their experience and knowledge relating to ERM with others. Thus, “lack of a RMIS” (H08) and “inadequate training on ERM” (H20) hindered ERM implementation because they represented the lack of channels for sharing knowledge. As setting up such channels needs resource investments and senior-level support, the negative influence of the four hindrances (H03 and H23-H25) can also be interpreted using this hindrance to organizational learning.

Even though there are channels for dialogue and sharing knowledge, the effectiveness of knowledge acquisition depends on the individuals’ ability to absorb and retain the knowledge (Cohen and Levinthal, 1990, Szulanski, 1996). The personnel unqualified to implement ERM may also lack the capacity for absorbing and retaining the knowledge relating to ERM, thus contributing to the lack of internal knowledge, skills and expertise. Therefore, the two hindrances (H06 and H07) can be linked to “lack of knowledge absorptive or retentive capacity” (L08) in the hindrances to organizational learning. In addition, downsizing or layoff strategies are often used when a firm faces a recession or business downturn. These strategies involve the departure or turnover of the staff, who may be experienced and knowledgeable, and would lead to the loss of the experience and knowledge (Fisher and White, 2000, Pfeffer, 1998). Thus, the two hindrances (H06 and H07) can also be linked to “downsizing or layoff strategies” (L11) in the hindrances to learning.

In some cases, the staff would fear that their self-interest would be threatened due to organizational learning, thus leading to the lack of psychological safety. “Perception that ERM increases costs and administration” (H18) is representative of “lack of psychological safety” (L04) because some staff may believe that the additional costs and administration threaten the firm performance, which is associated with the bonus or interest of them. Such a misunderstanding derives from the “lack of perceived value or benefits of ERM” (H22). Thus, the two critical hindrances (H18 and H22) can be linked to “lack of psychological safety” (L04).

Motivation measures are necessary for organizational learning (Szulanski, 1996). As the relevant employees need to spend time, energy and knowledge in ERM implementation, they should be convinced that these resources can pay off. Thus, the metrics to measure ERM performance should be developed and used. The tangible increase in firm performance can motivate the relevant staff to actively participate in the ERM implementation. In turn, the lack of such metrics and perceived benefits of ERM would discourage the staff from contributing to the learning process relating to ERM, thus hindering ERM implementation.

Organizational learning can be hindered by the unsupportive organizational culture, such as the blame culture (Hayes, 2007) and defensive routines (Argyris, 1995). Two critical hindrances (H10 and H12) can be linked to “unsupportive organizational culture” (L12) in the hindrances to organizational learning. As ERM implementation includes learning from the past mistakes, errors, failures and disasters, the unsupportive culture would render these negative issues as taboos and discourage the staff from investigating the root causes of them. Consequently, the employees would remain confident in the existing risk management practices and not believe that it is necessary to implement ERM, which is likely to lead to the underlying assumption that the risks can be dealt with by the current risk management practices. Thus, the staff would not attach adequate importance to the potential risks and lack risk awareness.

5. Conclusions

ERM implementation has been advocated in the construction industry and requires organizational learning in firms. This study attempts to identify the critical hindrances to ERM in CCFs and analyse these hindrances in tandem with theories of organizational learning. To achieve these objectives, a total of 36 hindrances to ERM and 12 hindrances to organizational learning were identified through a literature review, and a questionnaire survey was performed with 119 respondents from 119 CCFs in the global construction market. The results indicated that 20 hindrances were deemed critical, among which “insufficient resources (e.g. time, money, people, etc.)”, “lack of a formalized ERM process”, and “lack of internal knowledge, skills and expertise” were the top three hindrances. In addition, the critical hindrances to ERM were interpreted from the perspective of organizational learning, and the 12 hindrances to organizational learning were linked to the critical hindrances to ERM.

Despite the achievement of the objectives, there are limitations to the conclusions. Firstly, the identification of the hindrances to ERM may not be exhaustive. Additionally, as the survey was performed with the CCFs, one should be cautions when the results are interpreted and generalized in other firms. Nonetheless, the implication of this study is not limited to the CCFs because the theoretical rational behind the critical hindrances can be used to interpret the hindrances in other construction firms. In addition, this study contributes to the literature through interpreting ERM implementation from an organizational learning perspective.

Future studies would investigate the interaction mechanisms among the hindrances to ERM implementation, and identify the influence paths comprised by some of these factors. The theoretical rational behind these mechanisms and paths would be found in organizational learning theories, and a set of best practices, which help the management to handle the influence of these factors and pursue the benefits of ERM, would be proposed based on the interaction mechanisms and influence paths.

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Implementing Social Responsibility in Construction Project: An Empirical Investigation on Stakeholders' Interest and Power

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Abstract

Given the enormous social and environmental impacts of construction lifecycle, organizations in the construction supply chain realise the need to implement social responsibility (SR) in their construction projects. Different project stakeholders have different understandings towards SR and they display different capabilities of setting forth initiatives, of calling for supports, and of achieving outcomes. This research aims to investigate the stakeholders' interests and power on SR implementation in construction projects and thus discover the invisible gaps between the stakeholders' concerns and influences. A total of 35 SR Issues (SRIs) categorized into seven themes were identified from construction lifecycles perspective. A questionnaire survey was subsequently conducted among the construction practitioners in Hong Kong to investigate the stakeholders' interest and power on these 35 SRIs. Paired t-test and descriptive statistical analysis were adopted to reveal the gaps between stakeholders' interest and power. This study could provide enlightenments to project stakeholders for them to identify the SRIs that they have power on; however, with inadequate commitment to implement. Suggestions can also be made for construction organizations, including main contractor, developer, government, and consultants, to distribute their finite resources optimally to implement SR in construction projects.

Keywords: Social Responsibility, Project stakeholder, Construction project management, Project social performance, Sustainability

1. Introduction

Construction organizations are facing unprecedented pressures and challenges in performing their social responsibility (SR) because of the social and environmental impacts caused by their construction activities (Othman, 2009). According to the report of UNEP-SBCI (2014), the entire lifecycle of buildings consume one-third of the worlds' energy, accounting for 30%–40% of the worlds' greenhouse gas emissions, 40% of the world's resources, and 12% of global water use. Construction in general also has a poor reputation in terms of ethical issues (Ho 2010, Ho 2011, Oladinrin and Ho 2014), being widely regarded as a sector rife with corruption and bribery (Moodley, Smith et al. 2008). In order to improve the notorious reputation of the industry, there is a need for attentions on the implementation of SR practices in construction projects.

SR Issues (SRIs) in construction projects focus on diverse aspects, such as health and safe working conditions, sustainability, environment, community development, and philanthropy. Given the uneven allocation of social resources and public attention, SRIs are attended to in different degrees. Organizations tend to engage in the high-profile SR programs to reinforce their reputational competitiveness on the market (Broomhill 2007). Owing to the Matthew effect, these issues would temporarily become the flavour of the mouth, whereas some important issues may be ignored or may receive inadequate attention. Investigating on the emphasized and the neglected SRIs are highly important in making appropriate SR strategies in the future.

With regard to the various SRIs, different project stakeholders focus on different priorities (Jonker and Nijhof 2006). Stakeholders from public and private sectors should take accountability for the overall project social performance (Shen, Hao et al. 2010). They engage in different ways to initiate, support, enforce, and supervise the implementation of SRIs. Given their different standings and available resources, project stakeholders tend to have their own understanding towards SR and display different abilities to accomplish their initiatives. However, what stakeholders are interested in may not always be what they are most capable of. In addition, SRIs would only be successful if powerful stakeholders utilize their power and exert their influences strategically (Prado-Lorenzo, Gallego-Alvarez et al. 2009). Stakeholders thus need to realize where their power lies so that they can distribute their resources optimally to maximize their overall social performance.

Although SR has been extensively studied, limited attentions have been devoted on the implementation of SR in the context of construction projects (Zeng, Ma et al. 2015). In addition, the stakeholders' interest and power on SRIs has never been compared. In this paper, we tried to answer the following questions. What are the most pressing SRIs in construction industry at present? What SRIs should be prioritized in the future SR policy? Does any gap between stakeholders' interest and power exist? How could stakeholders strategically engage in different SRIs? This study intends to find the answers to these questions through an empirical research conducted among Hong Kong construction practitioners to investigate the current situations of project stakeholders' interest and power.

2. Literature Review

2.1 SR in construction projects

SR was introduced as self-regulatory initiatives for businesses for the benefit of the wider society (Sheehy, 2014), and SR has recently received extensive attention from the academic and industrial communities (Schultz et al., 2013). Whether SR is profit-oriented or society- oriented or whether SR is voluntary or compulsory in nature are not the most crucial problem to be solved; SR could be a continuum between two extremes and consistently shifting along with the changing social requirements (Bhimani and Soonawalla 2005, Pirsch, Gupta et al. 2007). Taking SR as a contemporary moral standard for the proper conduct of business, responding to social problems should also be embedded as one of the purposes in the pluralistic organizational objectives (Enderle 2006).

Construction activities are associated with vast social and environmental problems, including construction wastes, noise pollution, eco-disturbance, severe working conditions, resources exploitation, and corruption and bribe (Moodley, Smith et al. 2008, Barthorpe 2010). Construction projects provide opportunities and potentials to different stakeholders. Many stakeholders (e.g. the companies along the construction supply chain, construction practitioners, end users, and societies, etc.) benefit from construction development while the construction activities exploited substantial natural resources and bring harms to environment and communities. There is a voice that stakeholders alongside enjoy their benefits but also owe similar amount of responsibility. Although SR has become popular among scholars and industrial leaders, few studies have investigated SR in the context of construction industry and is particularly rare in construction project environment (Zeng, Ma et al. 2015). Several studies through archival analysis and interviews that were conducted in some developed countries have shown that some large construction companies have realized the significance of SR and have agreed with the necessity of embracing moral commitments to the society (Petrovic Lazarevic 2008). However, the implementation of SR practices and programs are ineffective and inefficient because of the diverse and fragmented nature of the construction industry (Jones, Comfort et al. 2006). Looking from the perspective of the stakeholders, this research assesses the different concerns and powers stakeholders have on SRIs; thus, this study would facilitate SR implementation in construction projects.

2.2 Stakeholders' interest and power

Construction projects usually involve numerous stakeholders and even hundreds of organizations and individuals that can affect or be affected by these projects, and the stakeholders have different interest and demands throughout the whole project lifecycle (Packendorff 1995, Aaltonen and Kujala 2010). An investigation on the stakeholder' interest on infrastructure projects shows that conflicts and contradictions are inevitable among different stakeholders (Li, et al. 2012). This conclusion also applies on stakeholders' preferences on SR. Lindgreen, et al. (2009) investigated the American organizations and found that these organization place varying emphasis on SR. Likewise, Zeng, et al. (2015) proposed a project SR framework for major infrastructures, demonstrating that project stakeholders should display different spectra of SR in different phases of their projects.

Obviously, not every stakeholder exhibits the same capabilities to attend to SRIs in construction projects. The stakeholders' power has been discussed for decades as an important dimension of stakeholder salience in the three-attribute model of Mitchell, et al. (1997). Some stakeholders with claims or interest may not possess the corresponding power to influence (Mitchell, et al. 1997). By contrast, some powerful stakeholders who exhibit superior ability to initiate some SRIs may not be enthusiastic in delivering these capabilities. Regardless of their intentions and preferences, powerful social actors are supposed to bear the corresponding responsibilities according to the fundamental principle; otherwise, they shall lose their power in return (Davis 1967, Enderle 2006). Therefore, the stakeholders being aware of their power and responsibility is crucial so that they can use these capabilities to influence the implementation of SR agenda in construction projects.

Analysis of the stakeholders' interest and power is an important task in stakeholder management (Polonsky 1996, Polonsky and Scott 2005). However, the analysis was made from the perspective of the focal company, and the result serves as the basis in devising the corresponding stakeholder strategies (Friedman and Mason 2004, Eesley and Lenox 2006). The mechanism by which the stakeholders' interest and power are distributed on different SRIs and whether there are any gaps between stakeholders' interest and power on SRIs exist remain to be elucidated.

3. Methods

To ensure the content validity of the survey, we identified the SRIs through archival analysis and expert screening. First, a pool of 80 SRIs specifically related to construction lifecycle practices were extracted through archival analysis. The sources included academic literature (journal articles published from 1970 to 2015 and were searched in Google scholar using the keywords CSR, sustainability, business ethics, construction, building sector), corporate reports (annual CSR/ sustainability report for the last five years of top construction companies, including Bechtel, The Turner Corp, AECOM, Kiewit Corp, Gammon, and Leighton), CSR standards, guidelines, and initiatives of international organizations (publications from GRI, ISO, Oxfam, UNEP, and WBCSD). Second, we invited 20 experts of project management experts to eliminate the SRIs that they consider unimportant or reduplicative, in order to come up with a shorter list of SRIs to be used in designing a questionnaire. This process was conducted using the Delphi method; after three rounds of anonymous questionnaire, a list containing 35 SRIs was finalized with the under 20% contradiction. The list covered the whole project lifecycle, including the three construction phases, namely, pre-construction, construction, and post-construction stages. In each stage, the SRIs were classified under seven CSR subjects in accordance with the ISO 26000 (SR Guidance). These subjects were 1) organizational government (OG); 2) human rights (HR); 3) labor protection (LP); 4) environment (En); 5) fair operation (FO); 6) customer issues (CI); and 7) community involvement and development (Co). During the screening, the major related stakeholders were also required to be nominated by the experts. A total of seven major contractors were identified, namely, main contractor (MC), developer (DV), end user (EU), government (GV), consultants (CS), NGOs, and district councils. Using these 35 SRIs and 7 related stakeholders, the questionnaire for this study was built in the form of a matrix, with the 35 SRIs as the row titles and the 7 stakeholders as the column titles. In the matrix blanks, the respondents would be asked to evaluate their interest and perceptions of the 7 stakeholders' influence on each SRI using a 5-point scale. The word "influence" was used instead of "power" because of their similarity in daily usage and the negative connotation of the word "power" (Brass and Burkhardt 1993). The questionnaire aims to determine the respondent organizations' subjective interest and to objectively evaluate the 7 main stakeholders' power on the 35 SRIs.

For the pilot study, three versions of the questionnaire (English, Traditional Chinese, and Simplified Chinese) were delivered to small groups of people who use the corresponding language. A formal survey was subsequently conducted on 120 practitioners invited from different stakeholders from the construction industry in HK. Considering the complexity of the questionnaire, the survey was conducted in a paper-based method. Assistance was provided in case the respondents have any queries or confusions. Finally, 89 valid questionnaires were collected (valid response rate 74%). The respondents are categorized mainly into four groups of stakeholder: MC companies (n = 35), DV companies (n = 11), GV departments (n = 6), CS companies (n = 20), and the rest are categorized as others, which include EU, investors, NGOs, sub-contractors (n = 17).

The data on all 35 SRIs were first analyzed as a whole. Considering the disproportion of the sample in this survey, the data was required to be reweighted to reduce the over- or under - representation of the stakeholder groups before calculating the average for the holistic analysis. The average stakeholders' interest and power on the 35 SRIs were compared based on the reweighted data. Second, the entire sample was divided into four subgroups according to stakeholder grouping (MC, DV, GV, and CS). In each subgroup, paired t-test was adopted to test the differences between the stakeholders' interest and power. Paired t-test is frequently used to test the significant difference between two observations in a group of subjects (Hsu and Lachenbruch 2007). Furthermore, to illustrate the details of the interest-power gaps for each stakeholder group, the interest-power profile in seven subjects and the interest-power fluctuations throughout the project lifecycle stages were shown for detailed comparative analysis.

4. Results and Discussion

4.1 Overall gaps between interest and power in all stakeholders

In Figure 1, the stakeholders' average interest is generally higher than the average power, indicating the stakeholders' positive commitments to SR, although the lack of adequate power to launch their initiatives is one of their obstructions. The stakeholders' interest on 35 SRIs reveals that much attention has obviously been devoted on LP issues and some of En issues and CI, whereas limited attention was devoted on OG and Co issues. This result corroborate with that of an investigation on UK construction companies, where health/safety and environmental issues are currently the hotspot SRIs, whereas less concern are devoted on community and governance (Jones, Comfort et al. 2006). The disparities between interest and power vary significantly among the seven subjects of SR. The SRIs on LP, FO, and CI have the significant gaps between higher interest and lower power. The result is reasonable because HK government

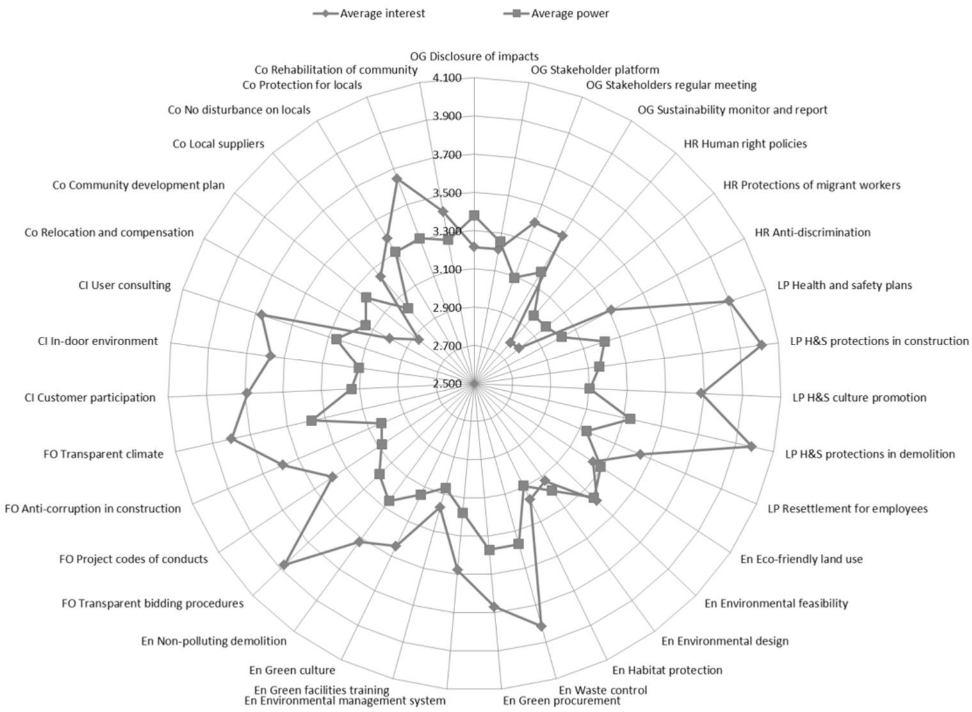

Figure 1: Overall gaps between stakeholders' interest and power

put construction health and safety as the top focus of industrial legislation. Moreover, HK is one of the leading transparent markets in the world (ranked 17th out of 175 countries in corruption perception index in 2014). This finding show that the legislation of local government highly influence the businesses' emphasis on SR. The SRIs that stakeholders' interest is higher than their power (LP, FO, CI, and part of En) are beyond the ability of any single stakeholders and require the communications and collaborations among multiple project parties from public and private sectors (Bendell, Collins et al. 2010, Savage, Bunn et al. 2010). By contrast, stakeholders have more power compared with their interest on HR, and part of OG and Co. More concerns and resources should be invested on these issues because these are within their current capabilities; however, these issues are neglected by stakeholders due to some reasons, such as disclosure of project impacts on the environment or society (OG), HR and protections of migrant workers (HR), and relocations and preparing community development plans (Co).

4.2 Main contractors (MCs)' interest and power on SRIs

The MCs are one of the core project team members, and they take charge of the most essential processes in the project lifecycle. Most SRIs in construction projects will not be successful without the effective engagement of the MCs. The result of the paired t-test on the MC subgroup (Table 1) shows that the mean of MCs' interest is not significantly different from the mean of their power (t = −1.409, p = 0.159). This finding indicates that the MCs' preferences on SRIs and self-perceptions of power are approximately consistent. MCs' power is slightly higher (mean = −0.05934) but not statistically significant. Figure 2 shows that the MCs' power is superior over their concern levels mainly in the dimensions of CI and FO issues. In the project lifecycle, the MCs' interest-power difference is largest in the construction phase than in the undifferentiated beginning and end phases. Moreover, MCs show superior power on LP issues and in the project construction phase. Thus, the occupational health and safety protections issues, especially the on-site protection and safety measures, should be mainly dominated by the MCs. In addition, the SR initiatives of the MCs are more effectively implemented during the construction phase, that is, when they are more powerful to coordinate resources and obtain support from other stakeholders.

Table 1: Paired t-test result of MCs' sub-group

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
MCinterest - MCpower	-.05934	1.27029	.04211	-.14198	.02330	-1.409	909	.159

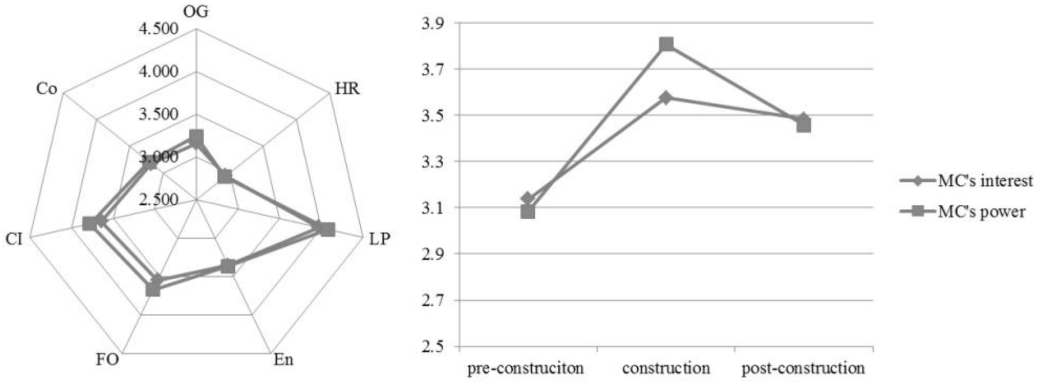

Figure 2: MCs' interest-power in the seven subjects and in the three project lifecycle stages

4.3 Developers (DVs)' interest and power on SRIs

The DVs generally play a powerful role in construction projects because they can directly raise their demands in bidding documents or contracts, as well as the social requirements of the construction outcomes. The paired t-test shows that the DVs' interest and power are significantly different (t = −2.709, p = 0.007) (Table 2), indicating that the mean of DVs' power is significantly higher by 0.14063 than the mean of the DVs' interest. This difference shows that the DVs still exhibit the potential of fulfilling their responsibilities on some issues where they may not be recognized as important. Further comparison of the seven subjects were made and the result (Fig. 3) reveals that the DVs possess more power but devoted less interest in the SRIs on Co. Moreover, Co issues have attracted vast attentions in the SR agenda, especially in mining industry (Jenkins and Yakovleva 2006). The major DV in mining industry have exerted much effort to obtain social license to operate in local communities. However, data has revealed that community issues apparently difficultly attract DVs' attention in the construction industry. On this point, construction DVs should recognize their capabilities in community issues, devote themselves in developing local facilities, care for local residents, and contribute to local employments. In terms of the project lifecycle, DVs' power is highest in the pre-construction stage, exceeding the interest in the same period. By contrast, DVs' power drops to the lowest point in the construction stage and power is considerably lower than the interest. Considering that the DVs' interest continuously rises but the power dramatically decreases after the construction began, DVs should make comprehensive SR plans in project inception and design stage and presents all the plans before construction starts.

Table 2: Paired t-test result of DVs' sub-group

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
DVinterest - DVpower	-.14063	1.01735	.05192	-.24270	-.03855	-2.709	383	.007

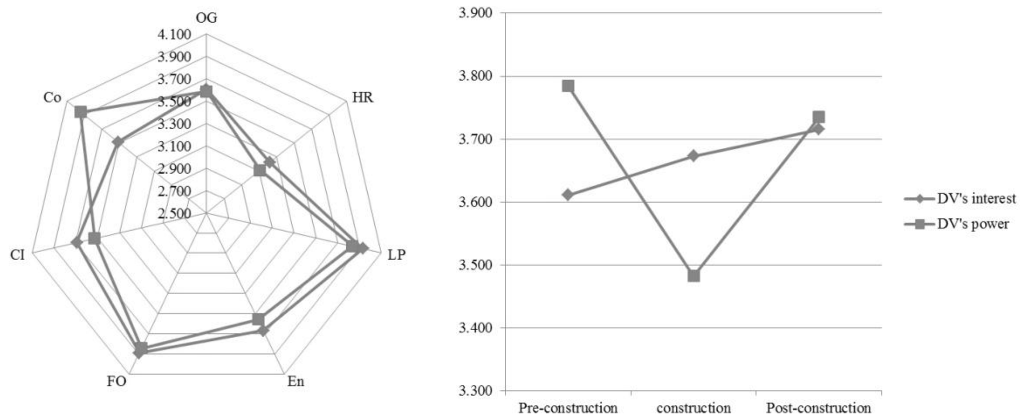

Figure 3: DVs' interest-power in the seven subjects and in the three project lifecycle stages

4.4 Governments (GVs)' interest and power on SRIs

The GV departments set the baseline for the SR of projects; therefore, their power is undoubtedly high. However, whether GVs' interest to set forth to higher level of SR legislation, or encourage SR implementation, is in the same level with their power is questionable. Table 3 demonstrates that there exists a significant difference between the GVs' interest and power ($t = -5.224$, $p = 0.000$). The mean of GVs' power is higher by 0.33333 than the GVs' interest, indicating that in HK, GVs' attentions on SR in construction projects are not considerably sufficient. This phenomenon is possibly caused by the uneven distribution of funds among the different departments, as well as the current strategies of the construction authorities. This lack of attention on SR legislation possibly results in the lagging development of construction market in HK. Among the seven subjects (Fig. 4), the GVs' power-interest gap is most distinctive in the HR dimension, suggesting that the attention the HK GVs' is paying on HR issues are inadequate in view of its social development level. In addition, the government should further endeavor to devise HR policies that are beneficial to the minorities and that eliminate discrimination in construction projects. Similar to DVs, the GVs exhibit the highest power in pre-construction stage, and this power remains considerably high in the whole lifecycle. However, the GVs' interest on SRIs is relatively low and reaches its lowest level in the construction stage.

Table 3 Paired t-test result of GVs' sub-group

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
GVinterest - GVpower	-.33333	.92459	.06380	-.45911	-.20755	-5.224	209	.000

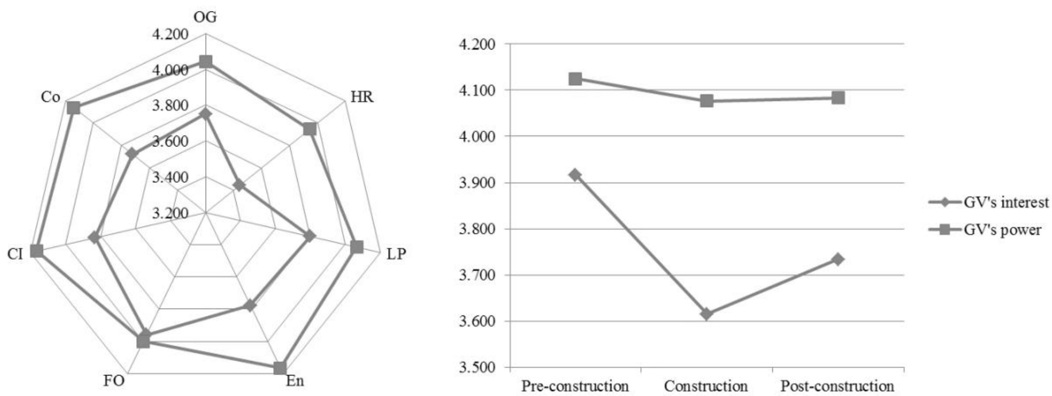

Figure 4: GVs' interest- power in the seven subjects and in the three project lifecycle stages

4.5 Consultants (CSs)' interest and power on SRIs

Significant gap is also detected (Table 4) between the CSs' interest and power (t = 5.044, p = 0.000). However, the opposite pattern of difference is observed; the interest is greater by an average of 0.25215 than the power, implying that the CSs are more proactive and aggressive on SRIs in the construction industry. CSs possess the most advanced knowledge or techniques in improving project social performance and their attitude toward SRIs are relatively positive. However, given that CSs are normally under the command of their clients, implementing their SR plans without the DVs' supports is difficult, although CSs could provide socially responsible alternatives for DVs to decide, such as greener or more resource efficient design, stakeholder communication scheme, and community development plans. This interest over power is observed in all of the seven subjects, especially in the CI and FO dimensions (Fig.5). To effectively achieve the SR goals, CSs must actively align with more powerful stakeholders, such as DVs and MCs, to initiate and implement the SRIs. Figure 5 also shows that the gaps between CSs' interest and power increases along with the progress of the project. This finding implies that it becomes more difficult for CSs to implement their SRIs if they did not bring them up before the construction began.

Table 4 Paired t-test result of CSs' sub-group

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
CSinterest - CSpower	.25215	1.32064	.04999	.15401	.35029	5.044	697	.000

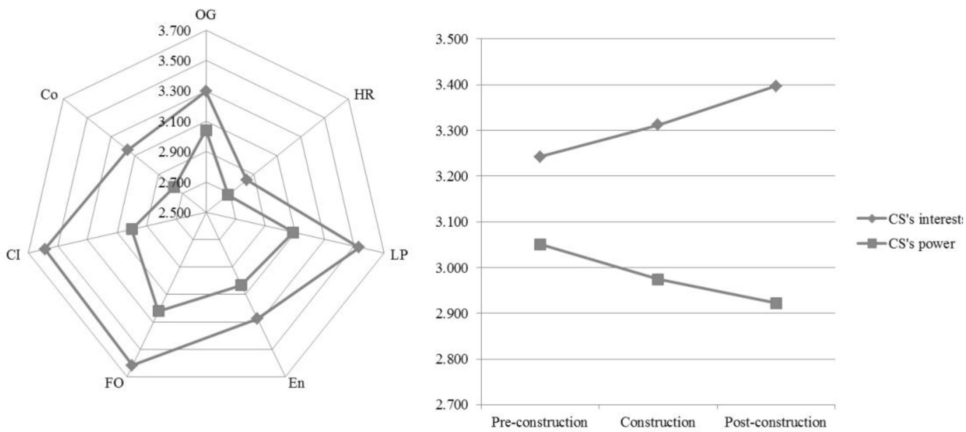

Figure 5: CSs' interest- power in the seven subjects and in the three project lifecycle stages

5. Conclusions

The comparison between stakeholders' interest and power revealed that some SRIs (labor protection, fair operation, customer issues, and environmental issues) are in greatest need of stakeholders' collaborations and joint efforts for their successful implementation. Some issues, including re-allocation and compensation of local residents, development plan for community, and disclosure of the social and environmental impacts of projects, call for more attention from project stakeholders. Main contractors, as key members of project teams, know the SRIs that they have power on. They have power to implement labor protection issues, including employees' health and safety in different project stages. In addition, main contractors should take advantage of their prevalent status in the construction stage to implement their SR initiatives at the right time. Compared with the exclusive power that developers have in presenting SR demands in project scope, developers showed inadequate interests on implementing SRIs. And this lack of interest phenomenon implies that the construction developers have the ability to set forth community development plans and community protection issues but do not have enough motivations to implement them. Moreover, although developers are influential, their status is only superior before construction begins. Government departments should lead the implementation of SRIs in construction projects; however, they have insufficient interest on most SRIs, particularly during construction stage. By contrast, consultants are more disposed on performing SR, even though they lack in power. It suggests that consultants should begin reinforcing their controls on SRIs by aligning with the powerful stakeholders (e.g. governments or developers).

Understanding the stakeholders' interest and power can reveal the implications of the distribution of responsibilities of SRIs in construction projects. Interest implies the stakeholders' intentions and goals on SR, whereas power is the responsibility that they are expected to assume. The result of this study will not only serve as guidance to project managers in engaging powerful stakeholders on SRIs implementation, but also as decision supports for construction organizations to strategically allocate their finite resources on the SRIs that they have superior power on. This investigation has also shed light on the SRIs that are currently neglected by powerful stakeholders; these SRIs call for future concerns and investments. However, the sample size should be increased and balanced among the stakeholder groups to make the result more representative. Considering that this questionnaire survey is devised in the context of HK construction industry only, the results can be hardly utilized in other regions because the results may vary under different social background.

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The Virtue of Sustainability

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Abstract

The ambition of this conceptual paper is to better understand the fundaments upon which sustainability can be achieved within the context of the construction sector today. The most common methodological approaches to achieving sustainability seem to be based on the presumption that an ever increased refinement of assessment tools of different sorts, – such as LCA, LCC, C/B-analysis, etc. – will eventually provide sufficient for assuring the sustainability of project based ventures. In this paper we argue that the implementation and refinement of such tools cannot be said to secure sustainability of projects given their inherent limitations.

The base premise of the research is that control systems typically function well for promoting organizational or individual behaviour to attain project objectives. They are equally essential in most forecasting and anticipation of events that can lead to undesirable consequences in a project. No control system, however, how detailed and effectively implemented it might be, can foresee every eventuality or unanticipated circumstances. Literature shows that assuring sustainability is highly dependent on proper risk control, predictability, framework conditions, and long term assessments. These are all factors that not easily fall in line with the above mentioned systems. Thus, if sustainability is to be achieved through projects, control systems etc. will not suffice to assure sustainability.

The big question is then what is to replace such control systems. The idea of this paper is to explore the insights from classical virtue ethics – in the tradition from Aristotle – to articulate an alternative path to achieving sustainability than through ever more rigorous control systems. The central notion here is the one of character, most notably the character of the project manager. Projects are realised by project teams under the leadership of a project manager. Enabling the project manager to cope with the eventualities threatening the sustainability of the project thus becomes essential. There is a crucial need for enabling future sustainable project managers to handle this kind of tasks.

Keywords: ethics, sustainability, virtue, education

1. Introduction

This paper outlines an understanding of what the contemporary understanding of sustainability can gain from insights from so-called virtue ethics in the tradition from Aristotle (2009). This is carried out as part of a more general enquiry within the field of the ethics of the Norwegian AEC (Architecture, Engineering and Construction) industry. The ambition is seeing the concept of sustainability as lying in so to say the keel water of that of ethics, the first being a translation of terms to make practical morality operational within the engineering disciplines.

The importance of increasing the awareness among engineering practitioners concerning themes covered both by sustainability and ethics seems crucial to attaining what Mirsky and Schaufelberger (2014) maintain as the most important topic to the future of the AEC industry, notably “honourable, professional practice” (Mirsky and Schaufelberger, 2014). More recently, different industries and trades have witnessed an increasing interest in the field of applied ethics in general and in professional ethics in particular (Christoffersen, 2011). Different professions establish rules and regulations, such as medical doctors, teachers, social workers etc., and the number of publications is ever increasing. The authors of this paper have so far not seen this trend reflected strongly in publications concerning the AEC industry in general, or in actual industry agreements in Norway. Notable exceptions from this general statement include the writings of Bown et al. (2007), Bröchner (2009), Corvellec and Macheridis (2010), Fellows et al. (2004), Hill et al. (2013), Ray et al. (1999)).

Considering that the AEC industry in general and in Norway in particular typically receives attention as an industry of doubtful virtue, 1) where neither the police, the tax authorities nor the professional organisations fully master the challenges posed by professional practice (Andersen et al., 2014); 2) where the inherent complexity in itself opens the opportunity for suspicious dealings (Gunduz and Önder, 2012); 3) where fraudulent business practices undermine the reputation of the industry (Slettebøe et al., 2003); and 4) that lacks a clear vision based on a fortified ethical foundation (Wolstenholme et al., 2009), we find this strange. As Hill et al. (2013) comments, there is probably no simple solution, no “quick fix”, to the challenges of ethical nature that the industry faces. Tackling such challenges necessitates, it seems, both insight and endeavour. The notion of sustainability seems to be one key to addressing such problems within the AEC-industry at large.

The concept of sustainability, however, is multifaceted, and is used in different manners within different contexts. As Gomis et al. (2011, 174) point out, ‘sustainable business’, ‘sustainable technology’, ‘sustainable agriculture’, ‘sustainable economics’, etc. are all buzzwords of the literature today. According to Adams (2006), ‘[a]nalysts agree that one reason for the widespread acceptance of the idea of sustainable development is precisely [its] looseness. It can be used to cover very divergent ideas [...]. The concept is holistic, attractive, elastic but imprecise’ (2006, 3). This differentiated use has in fact, according to Marshall and Toffel, ‘nearly rendered the term sustainability meaningless’ (2005, 673). Those venturing into the literature will in fact find a breath-taking number of different understandings and definitions. In his non-conclusive going-through, Hasna (2010) lists 67 definitions.

Despite the apparent imprecision concerning the comprehension of the notion, a certain general agreement does nonetheless seem to exist. As Adams points out, the 'core of mainstream sustainability thinking has become the idea of three dimensions, environmental, social and economic sustainability' (2006, 2). Sustainability can be analysed with different aspects in mind, but the three dimensions can be used to categorise the identified sustainability factors or elements (Flores et al. 2008). For a discussion of the comprehension of the three pillars, their balancing act, and the different analytic levels according to which it seems necessary to implement them successfully, we refer to Haavaldsen et al. (2014).

It is easy to despair when faced with such seemingly impossible matters of precise knowledge and definition. If turning the question around, however, it takes another colour. If – rather than looking at the definitions, different understandings etc. of the phenomenon – we examine the reason for the term surfacing, the picture alters.

1.1 Sustainability and ethics

When examining the use of the sustainability, there seems to be a strong linkage between the concepts of sustainability and of ethics. A main ambition of this work is to outline what implications this linkage can entail, notably concerning the difference between rules and virtue-based approaches.

Ethics is commonly perceived to be the science that investigates what one ought to do. Moral, on the other hand, is typically considered as the practical mechanisms through which such behaviour is judged. In particular based on the common etymological roots of the two concepts, we in the following consider them as fairly synonymous, basing the exposé on the first of the two.

At a very general level, one main cleavage within the field of ethics can be found between so-called rule-based and virtue-based approaches (we do not here say that all ethical theories fall within a scope that is relevant for this distinction, solely that these occupy a primordial place in the field of ethics). What we here call rule-based covers in fact a variety of theories that are hugely diverse, the most influential today are probably deontology (in the tradition from Kant) and different forms of utilitarianism (such as presented by Mill, 2002). This distinction has been masterfully been described by Anscombe (1997).

What brings together these major intellectual currents is that they proclaim that action ought to be justified and considered ethical or not according to a rule of some sort. For Kant, this rule was formulated in the so-called categorical imperative. For the utilitarist, the idea of the greatest good for the greatest number of people tends to be the rule according to which one is to act in the world.

Virtue-based ethics, on the other hand, takes a different stance to the question of judging what is ethically estimable. Rather than focussing on abstract principles from which rules of conduct can be determined, virtue ethics in the tradition from Aristotle focuses on what it calls the character of the actor. The question haunting fourth century BC Athens – how can one assure that the inhabitants of the republic act in an ethically sound manner – in fact resonates deeply within today's societies in general – and within the professions that form the AEC-industry in particular. This character is typically sought developed using examples, to expose what is ethically good and blameworthy behaviour. To put this in contemporary engineering language, we can say that deductive top-down rules based approaches of the rule-based ethical systems are replaced by an inductive bottom-up approach in virtue-based approaches.

1.2 Rule-based vs. virtue-based understanding of sustainability

If then, we propose that the concept of sustainability ought to be understood as following closely that of ethics, it should follow that the cleavage between rule-based and virtue-based approaches should be as crucial within the context of sustainability as within that of ethics.

To undertake conceptually the implications this insight, however, seem to be rarely treated in the literature, and, to take the consequences of this into actual practice seems even further from the main research agenda, as we perceive it. Some notable exceptions exist; see for instance Helgadóttir (2008) for an example of an analysis inspired by Aristotelianism.

In order to address this general challenge, we address the following research questions:

1.) What are the main challenges to sustainable practice within the Norwegian construction industry today?
2.) What measures can be identified as reasonable to address these challenges?

Questions of this type are inherently difficult to examine from an empirical perspective. They are of a principal nature, meaning that their essence tend to slip from empirical investigations. Therefore, we in the following address these questions in a conceptual manner, illustrated with some general reflection upon general frameworks. The main point is to outline what – from both theoretical and practical perspectives (as understood by the authors of this paper) – can be identified as the main challenges to sustainable practices within the AEC-industry.

2. Methodological approach

The methodological approach constituting the research behind this paper is threefold in nature. First, a literature study was carried out in accordance with the procedures described by Blumberg (2011). A documentation study was conducted in order to provide an overview over the approaches chosen among 25 major actors within the Norwegian AEC-industry, notably an examination of their ethical frameworks. The reason for selecting the large companies was an anticipation of that they want to be in the forefront and show the way for smaller companies. The ten contractors was selected from top of the 2015 top 100-list (based on annual turnover) of the magazine Byggeindustrien (http://www.bygg.no/100-storste). The authors picked the five public owners based on their general knowledge of the Norwegian construction industry. The private owners are more randomly selected, but the selection criteria included visibility in the public debate of social affairs, membership in Grønn byggallianse [Green Building Alliance] and/or have recently developed projects that received BREEAM-NOR certificates for the design phase and/or completion. The engineers were the five most popular on the 2015 career barometer, a result from a survey among approximately 8000 students initiated by a private media house (http://www.karrierestart.no). All the examined companies describe their code of ethics on their web pages, but a few did not publish them there. Finally, we examined the so-called millennium goal of the UN in order to see what this general framework could imply for the understanding of the broad picture.

3. Findings – How actors actually address the challenges?

As Haavaldsen et al. (2014) outline, sustainability can be understood at several analytic levels, and according to several perspectives. In the following, we examine two approaches we perceive to be situated at a strategic level, notably the ethical frameworks of 25 major companies from the industry (national level) and the millennium goals of the UN (international level). These approaches differ in that the overall approach of the ethical frameworks to the subject matter is a relatively hard ruled-based approach; whilst the millennium goals stress a rather fluid approach open to interpretation. As we shall see, challenges of different natures follow each of these two main approaches.

3.1 Codes of conduct interpreted as intended to sanitise the AEC-industry nationally

Most major companies within the Norwegian AEC-industry have ethical guidelines or codes of conduct, the distinction between which is somewhat blurred. What is of interest in this context, is that they all ambition to codify the behavioural stance of members of the company. Ethical codes are adopted by organizations to assist members in understanding the difference between 'right' and 'wrong' and in applying that understanding to their decisions.

On their webpages, the public owners appear as engaged in ethical issues because of their own descriptions of their Code of ethics. According to their own descriptions, their Code of ethics consist of several layers, with for example guidelines for contact with property owners, ethical guidelines for suppliers etc. Despite their engagement, only one public owner has made the Code of ethics available through the webpage. One approach to increase transparency – as public owners should – would be to make the code of ethics easily accessible for all stakeholders. Two of the contractors have not published their Code of ethics at their webpages.

Private owners seem – at least on their webpages – to be concerned with ethics and ethical guidelines. Two private owners that form part of a larger mother organisation with international activities have extensive guidelines that reach for standards above the minimum legal requirements. Two private owners are mainly operating in the Norwegian property market, and their Codes of conduct describe the distinction between legal and illegal, but not the distinction between ethical and unethical. One of the private owners has not established an own Code of conduct, but is planning to do so within short time.

Among the engineers, four have published their Code of ethics on their webpages. The guidelines seem to have general formulations. The fifth one, which has not published their guidelines, describe on their webpage a procedure where their employees have to sign that they have read and understood the meaning of the Code of ethics. A scrutiny of these codes reveals a surprising level of divergence, as table 1 shows.

Table 1: Ethical codes of 10 contractors, 5 public owners, 5 private owners and 5 engineers within the Norwegian AEC-industry

Organisation	Distinction between legal/illegal	Distinction between ethical/unethical	Accessible on web	Number of text pages
Contractor 1	Yes	Yes	Yes	22
Contractor 2	Yes	Yes	Yes	10
Contractor 3	n/a	n/a	No	n/a
Contractor 4	n/a	n/a	No	n/a
Contractor 5	Yes	No	Yes	1,5
Contractor 6	Yes	No	Yes	2
Contractor 7	Yes	No	Yes	9
Contractor 8	Yes	No	Yes	1
Contractor 9	Yes	No	Yes	3
Contractor 10	Yes	Yes	Yes	8
Public owner 1	Yes	Yes	Yes	14
Public owner 2	n/a	n/a	No	n/a
Public owner 3	n/a	n/a	No	n/a
Public owner 4	n/a	n/a	No	n/a
Public owner 5	n/a	n/a	No	n/a
Private owner 1	Yes	Yes	Yes	10
Private owner 2	n/a	n/a	No	n/a
Private owner 3	Yes	No	Yes	2
Private owner 4	Yes	Yes	Yes	3
Private owner 5	Yes	No	Yes	10
Engineer 1	Yes	Yes	Yes	14
Engineer 2	Yes	Yes	Yes	20
Engineer 3	Yes	Yes	Yes	1,5
Engineer 4	n/a	n/a	No	n/a
Engineer 5	Yes	Yes	Yes	9

Most remarkably, their extent varies between one and 22 pages. Secondly, their availability on the net is variable; some are merely not accessible for the general public (without providing any clear explanation for this withdrawal), a fact that renders this analysis problematic. Thirdly, and most importantly, all available codes distinguish clearly between legal and illegal behaviour, condemning the last clearly, whilst the difference between what is ethical and unethical, however, is more blurry.

It is in fact this latter point that is of prime interest to our analysis: All of the examined codes of ethics describe the distinction between what is legal and what is illegal. Among the contractors, only Contractor 1, Contractor 2 and Contractor 10 describe the distinction between what is ethical and what is unethical. Five of the contractors have quite similar codes of ethics, which – roughly – tell their employees to follow the minimum legal requirements. It their employees want to, they can reach for stricter requirements, but that will be their choice.

In our view, this fact point to the weakness in rule-based approaches as observed earlier. There seems in general to be no limit to what you can do, as long as you stay within the limits of the law within these codes of ethics. It thus seems that actors not being aware of the difference between ethical and lawful behaviour has developed a majority of these codes of ethics. On a more general level, this points in fact to the shortcomings of such rule-based frameworks: actors operating within these frameworks can in fact go very far in acting in what can be called an unethical manner, without this action conflicting with the code.

3.2 The 2030 Agenda for Sustainable Development

On the 25th September 2015, world leaders gathered in New York to adopt the 2030 Agenda for Sustainable Development. The Agenda that was agreed upon comprises of 17 new Sustainable Development Goals listed in table 2. The objective was to produce a set of universally applicable strategic goals that balances the three dimensions of sustainability.

The main characteristic of these formulations is how general they are in nature. These are, in fact, policy statements, and it is clearly difficult to implement them directly in projects. Much can be said on the subject of their roundness, giving ample place for interpretation.

Table 2: The Sustainable Development Goals as proposed by the Agenda for Sustainable Development (UN General Assembly, 2015).

Goal 1: End poverty in all its forms everywhere
Goal 2: End hunger, achieve food security and improved nutrition and promote sustainable agriculture
Goal 3: Ensure healthy lives and promote well-being for all at all ages
Goal 4: Ensure inclusive and quality education for all and promote lifelong learning
Goal 5: Achieve gender equality and empower all women and girls
Goal 6: Ensure access to water and sanitation for all
Goal 7: Ensure access to affordable, reliable, sustainable and modern energy for all
Goal 8: Promote inclusive and sustainable economic growth, employment and decent work for all
Goal 9: Build resilient infrastructure, promote sustainable industrialization and foster innovation
Goal 10: Reduce inequality within and among countries
Goal 11: Make cities inclusive, safe, resilient and sustainable
Goal 12: Ensure sustainable consumption and production patterns
Goal 13: Take urgent action to combat climate change and its impacts
Goal 14: Conserve and sustainably use the oceans, seas and marine resources
Goal 15: Sustainably manage forests, combat desertification, halt and reverse land degradation, halt biodiversity loss
Goal 16: Promote just, peaceful and inclusive societies
Goal 17: Revitalize the global partnership for sustainable development

It seems hard to argue against these general formulations. What is of prime importance is their all-encumbering nature. This trait is often criticised in this type of policy documents. The analytic force of such general statements, however, is that they typically leave the actors free to apply the statements to their own context – within the boundaries of their semantic extension. The key element here, however, is the translation from policy statements to sustainable practice, in other words, how to translate the goals that indicate the intended virtue of our generation into practical, achievable project within the AEC-industry.

3.3 Translating the goals into practice

If we first look for the three dimensions of sustainability embedded in the 17 goals in this list, we may find direct or indirect traces of all three. The dimensions are taking on different nature depending on the goal in view. If we look at the first goal, for instance, it is obvious that the goal has a number of social and environmental challenges in addition to the economic dimension.

When planning such projects – that is, interpreting the way from the policy level to actual project realisation – we have found it useful to distinguish between three goal levels where all dimensions of sustainability may be determined from the given (broad) context. This provides a better understanding of the practical issues contributing to the complexity of sustainability.

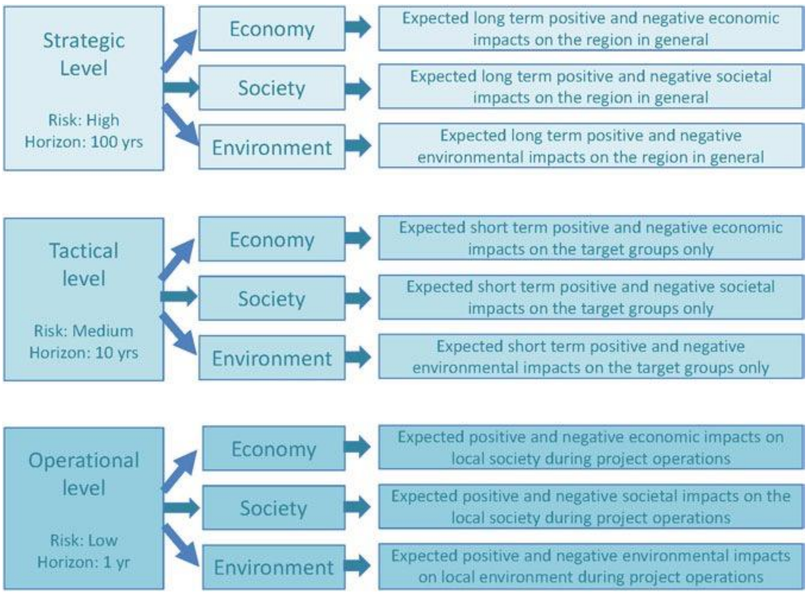

Figure 1. Suggested criteria for assessment of sustainability of projects (Lædre et al., 2015)

The figure outlines the three pillars of sustainability as sorted according to the three analytic levels of strategic, tactical and operational. It also underlines the risk elements pertaining to each of the analytic levels. Lastly, it stresses the differences in temporal horizon typically characterising the different analytic levels. Lædre et al. (2015) go far more into detail.

In other words, it seems useful to evaluate all goal levels of identified project concepts before finally deciding about them. The main reason for this is that the assessment of the three different dimensions of sustainability by addressing economic, social and environmental impacts will certainly vary with the goal level in focus.

4. Discussion and conclusions

The underlying argument in this paper has been to reconsider the recourse to rules as the unique prism through which trying to control activities of an industrial nature with multiple actors. The AEC-industry present a striking case of an industry where such rule-bound optimism stands seems futile – at least in the eyes of the authors of this paper, as the examples cited above clearly indicate. We set out to address what are the main challenges to sustainable practice within the Norwegian construction industry today and what are the corresponding reasonable measures to these challenges. On basis on this, we make the following claims: 1) There seems to be a near universal identified need for a sustainable practice within the industry. This seems to be reflected in the codes of ethics examined. In this paper, we have tried to illustrate how the virtue-based approach can help developing this. 2) The international approach, however, seem to take the virtue-based ethics too far in that their limits are too loose in that the need for translation into engineering practice becomes too complicated. A national strategy for concretising this overreaching might be a way to proceed.

It seems to the authors of this paper that there is a profound need for knowledge-based apprehensions of how to act. Virtue ethics in the tradition from typically recommends the use of examples to enlighten the actors of the correct choice in the specific situation. In order to render this a bit more concrete, we propose the following practical recommendations:

- Expand the understanding of the rules of the profession – and the limits of the rules.
- Expand the understanding temporal aspects of the endeavours you undertake
- Understand the analytical levels of sustainability assessments
- Enable students to learn from examples – people and projects
- All organisations need involve new employees in the ethical foundations of the organisation's practice – not just in ethical codes.

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Green Business Models and Organisational Changes: Lessons from the UK Construction Sector

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Abstract

Green business models (GBMs) can support green growth because they are based on green value creation and capture with emphasis on clients role. However, GBMs require substantial investment and strong change capabilities. This paper maps organisational changes associated with GBMs transformation. For this purpose, 19 semi-structured interviews are conducted with a heterogeneous sample of academics and managers from the UK construction sector. The interviews then are analysed by a means of thematic analysis with aim to capture any common changes and to form similar patterns of changes which occurred within the sample. Surprisingly, there are a lot of similarities that can be grouped broadly into three major themes: green profile development; structure; and operations. In addition, the change starts from the strategic level (policy) to the operational level but it may be triggered by the people at the operational level. Furthermore, GBMs not only change product/service and process but also catalyse broader systems change of the green value chain. Therefore, construction organisations have to accept that transition to GBMs will bring significant changes to the way they work if these models are to flourish.

Keywords: Change, construction, green business models, UK, and systematic change.

1. Introduction

As sustainability becomes an even more prominent matter of concern for the construction sector, the understanding and enactment of so-called green business models (GBMs) will become more pertinent (Boons & Lüdeke-Freund, 2013; Jing & Jiang, 2013) . Sustainability will lead to fundamental changes in the business world (Esty & Winston, 2009) with the construction businesses being no exception. Naturally, the resulting new business environment brings about enormous opportunities and challenges that can shake the competitive landscape of industries to the core (Boons et al., 2013; Sommer, 2012). *"Thus, hesitant managers should be asking themselves: How do sustainability issues influence the future success of our current business model? And: How can we adapt them to best mitigate the risks and take advantage of* *opportunities arising from sustainability issues?"* (Sommer, 2012 pp.5). GBMs can be a means towards competitive sustainability because they are based on green value proposition creation to customers and capture of profit and reputation. Henriksen et al. (2012) provided a definition for GBMs as follows: *"GBM innovation is when a business changes part(s) of its business model and thereby both captures economic value and reduces the ecological footprint in a life-cycle perspective"*. Therefore, the GBM concept can explain sustainability in terms of creating value and how value is defined (Abuzeinab & Arif, 2013). In addition, the GBM can help organisations to transform their abstract environmental strategies into viable business concepts (Sommer, 2012). Furthermore, concentration on the GBM can help better evaluation of current construction organisations BMs and assess their future suitability regarding sustainability aspects and competitiveness (Mokhlesian & Holmen, 2012; Sommer, 2012). However, it is vital for studies on this field to define GBMs explicitly to reduce the ambiguity around the concept (Abuzeinab et al., 2014).

According to Aho (2013), GBMs have the potential to transform construction organisations. However, this remains relatively unknown and the research is under-developed in this area. The aim of this paper is to investigate organisational changes associated with GBMs transformation in the construction sector. To achieve this aim, it is vital to choose an appropriate research method because little is known about GBMs and organisational change. The remainder of this paper is structured as follows: Section 2 presents the theoretical perspective of this study where sustainability within the construction sector is reviewed briefly followed by a review on sustainability and organisational change in general literature. The review has demonstrated lack of research dealing with organisational change and GBMs in the construction context. The justification of research method is presented in Section 3 where qualitative methods are deemed relevant for this exploratory study. By applying manual thematic analysis, three major organisational changes (themes) are found and discussed in Section 4. Conclusions are presented in Section 5 including limitations and future direction for the topic.

2. Literature review

In the UK, construction is a major sector of the national economy. Rhodes (2014) stated that the construction sector accounts for 6% of the economic output and provides employment for 6.5% of the population. According to Akadiri & Fadiya (2013), several initiatives supporting sustainability of the construction sector have been developed such as regulations, voluntary policies, economic measures and fiscal incentives. Examples of these initiatives include: changes to the Building Regulations; Aggregates Levy; Landfill Tax; and Renewable Grant Schemes. Assessment tools and demonstration projects have been showcased to demonstrate the effort of the government in addressing sustainability issues. Despite these efforts, sustainability in the construction sector is still lagging behind other sectors (Brennan & Cotgrave, 2014). A possible explanation is that the current research has focused on products and services but has ignored the organisations and their changes in responding to sustainability. This study aims to contribute to this gap by identifying major organisational changes associated with GBMs. Organisational change aims to move from the current state to a more desirable one ranging from evolutionary changes to revolutionary ones driven by internal and external factors (Lozano, 2013). Common organisational changes reported in the literature include: strategy, culture, politics, and operations with some overlapping changes (Lozano, 2013).

There are several studies linking sustainability and organisational changes within the general sustainability literature. For example, Lozano (2013) investigated barriers to organisational change related to corporate sustainability by using three case studies. He recommended that organisations need to plan the change to integrate technological and human changes to succeed. In addition, he summarised typical organisational changes associated with corporate sustainability: changes in mental models; the development of future vision for sustainability; management; structure; operations; and proposals of actions to achieve these. Hottenrott et al. (2016) examined the relationship between green technology adoption and organisational change in manufacturing firms. Their research provided new insights into increased productivity resulting from the complementarity effects of new green technologies and adaption of organisational structure. Furthermore, Lozano et al. (2015) advocated the importance of integration of organisational change for sustainability within higher education teaching curriculum. These examples demonstrate the emergence of organisational change for sustainability as a new discipline. However, similar studies and approaches within the construction sector are rare (Albino & Berardi, 2012).

Existing studies investigated sustainability requirements within the construction sector. For example, Akadiri & Fadiya (2013) studied the role of top management commitment, government regulations, and construction stakeholder pressures in determinig envionrmnetal sustainability practices to aid better decision-making for construction sector. Few studies have investigated the role of leadership and top management of construction organisations in driving sustainability (Brennan & Cotgrave, 2014; Opoku et al., 2015). The current study provides a new approach dealing with the organisational changes relevant to GBMs for the construction sector. Although there are studies available linking GBMs and the construction sector, none of these have examined the impact of GBMs on the organisational change. Examples include Aho (2013) who studied sustainable buildings from the BM perspective and Mokhlesian & Holmen (2012) who examined green construction using the BM as an analytical tool.

According to Sommer (2012), GBMs often require substantial investment of capital and other resources and are intertwined with the existing business environment in complex ways. GBMs therefore tend to conflict with conventional business practices and structures. For this reason, many business leaders, including those in construction, overlook the potential benefits of GBMs and fail to question their existing business logic and investment decisions with regard to sustainability issues. Identifying the organisational changes associated with GBMs will increase the uptake of GBMs because construction organisations will be in a better position to prepare for these changes. Albino & Berardi (2012) stated that studies focusing on organisational change relevant to green buildings are required becaue they will lead to a systematic tranistion of the sector towards sustainability. The current study is exploratory in nature owing to lack of similar studies within the construction sector. The next section presents the method used for data collection and analysis.

3. Research method

The aim of this paper is to empirically investigate organisational changes associated with GBMs transformation in the construction sector. Since the topic under investigation is relatively new, a qualitative method is deemed appropriate. The inherent flexibility of qualitative studies and their potential for revealing complexity were particularly relevant to this research, since the topic of investigation was complex in nature (Amaratunga et al., 2002). In addition, qualitative data has often been promoted as the best approach for discovery and exploring a new area (Amaratunga et al., 2002). These features are well aligned with current research aim. Detailed semi-structured interviews were conducted with 19 academics and managers from the UK construction sector. The target sample was purposive sampling to achieve representativeness of main actors of the construction sector value chain. A purposive sampling technique uses participants who are both accessible and willing to participate in the study (Renukappa et al., 2012).The profile of interviewees was chosen according to the following selection criteria:

- Senior/managers in the construction industry
- Relevant experience in sustainability strategies and practices
- A decision maker regarding sustainability issues, for example, being able to initiate and implement future plans
- Ideally, a sustainability manager, expert or officer.

Table 1 presents the details of the interviewees for further information.

Table 1: Interviewee’s details – Total of 19 participants

No	*ID*	*Type of business*	*Job title*	*Years of experience*	*Size of company*
1	*A1*	*University*	*Professor*	*15*	*2500*
2	*A2*	*University*	*Professor*	*15*	*2500*
4	*AR1*	*Architects*	*Architect & director*	*20*	*6*
5	*AR2*	*Architects*	*Associate architect*	*20*	*6*
6	*AR3*	*Architects*	*Associate architect*	*14*	*110*
7	*AR4*	*Architects*	*Associate director architect*	*9*	*12*
3	*CS1*	*Consultancy*	*Freelance consultant*	*36*	*1*
8	*CS2*	*Property and construction consultancy*	*Environmental manager*	*5*	*350*
9	*C1*	*Contractors*	*Director*	*50*	*50*
10	*C2*	*Contractors*	*Sustainability manager*	*17*	*800*

11	*C3*	*Contractors*	*Senior sustainability manager*	*14*	*5000*
12	*C4*	*Contractors*	*Senior sustainability manager*	*12*	*6000*
13	*O1*	*Others – Property development*	*Construction director*	*36*	*16*
14	*O2*	*Others* - *Procurements*	*Sustainability manager*	*8*	*50*
15	*CL1*	*Clients/ Local Authority*	*Capital programme director*	*40*	*10.000*
16	*CL2*	*Clients/ University*	*Associate director operations & facilities*	*36*	*260*
17	*CL3*	*Clients/ University*	*Building surveyor*	*20*	*245*
18	*CL4*	*Clients/Local Authority*	*Operational facilities manager*	*15*	*10.000*
19	*CL5*	*Clients/ University*	*Environmental & sustainability officer*	*10*	*250*

As shown in Table 1 above, all of the interviewees had considerable experience in the construction sector. In particular, they had relevant experience on green issues with some of them having 'environmental' or 'sustainability' within their job titles. The sample has covered major actors of the construction value chain including architects, consultants, contractors, clients, procurement, and property developer.

The analysis is focused on extracting meaning from the interviews which were analysed by means of thematic analysis. The thematic analysis refers to an analytical approach involving examination of discussions to establish meanings and intentions (Patton, 2005). It also refers to qualitative content analysis which has been used in construction research (Harty et al., 2007). The results are presented next and arranged into three subsections representing the major themes emerged from the data analysis.

4. Results and discussions

The Interviewees were asked to report all the changes in their organisations when they implemented green practices or initiatives. The aim was to capture any common changes and to form similar patterns of changes which occurred within the sample. Surprisingly, there were a lot of similarities that can be grouped broadly into three major categories. These categories are: green profile development; structure; and operations as shown in Figure 1.

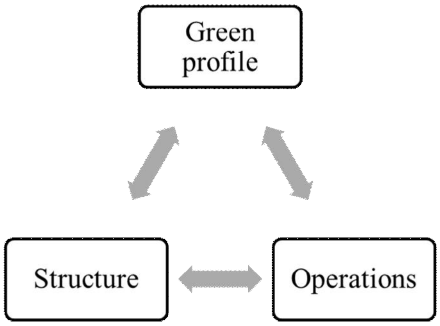

Figure 1: Major organisational changes of GBMs

Figure 1 above presents three major categories of organisational changes as emerged from the data analysis. Each of these major categories of changes is discussed in the subsections below.

4.1 Green profile development

It was evident that a green journey is usually initiated as a reaction to growing risks which can be regulations and uncertainties and it is characterised by discoveries. From the interviewees' answers, green decisions are based on two major reasons. Firstly, a compliance reason coupled with an ethical reason responding to the overwhelming scientific data about climate change and environmental degradation. Secondly, a market reason to seize the green opportunities and demonstrate capabilities in offering green solutions. Alternately, organisations may pursue the green issues for a combination of the above two reasons.

However, market opportunities including clients demand have dominated the interviewees answers as a major reason for offering green solutions. According to AR1 *"there are expectations for business in the marketplace today to have a level of environmental credibility."* This demonstrates the market drivers and the current and future expectations from businesses and organisations leaders. Therefore, it is better to start doing some changes and actions now before it is too late. It was also evident that some organisations within the sample started to deal with green agenda as a source of value creation instead of a legal imperative. These organisations have focused on building green profile starting by relevant training and in-depth knowledge. For example, the architects AR1, AR2, and AR4 have done various training on lower environmental impact buildings design such as offsite construction and code for sustainable home principles. This has some support in the literature. For example, Shiers et al. (2006) developed an environmental profiling system for construction products to aid designers in choosing relevant products. The authors suggested that availability of information and knowledge will encourage the practitioners to build their green capacity and track record. Furthermore, Albino et al. (2009) conducted a study of sustainability driven companies to understand their behaviours. The results showed a high relationship between the development of green products and the existence of environmental strategies. Therefore, it can be suggested that construction organisations need to start with a formulation of green strategies before they can move on to develop their green profile. A well formulated strategy will facilitate a systematic development of green profile to build a green brand and hence attract more revenues from similar projects and services.

Most of the participants suggested that a green profile should include quick wins or quick returns such as lighting upgrades and efficiency measures as well as longer-term, higher risk/higher reward strategies. Although they have agreed that GBMs in essence are long-term investment, they added that a collective approach is needed including policy and financial institution support. It can be suggested that long-term planning for GBMs requires major changes in current practices. The necessary investment to change can be financed by short-term profits or quick wins that will help build the green profile at the same time (Aho, 2013). In addition, the short-term profits can help alleviate the frequently cited barrier of environmental sustainability: cost (Brennan & Cotgrave, 2014). Developing a track record of green capabilities is vital for construction organisations to attract clients and to develop their awareness and appreciation of GBMs. According to Brennan & Cotgrave (2014), clients education and awareness are essential for sustainable construction. However, it is the responsibility of the construction sector to educate clients. We argue that before educating clients, the green profile has to be developed by the organisations to gain credibility. Akadiri et al. (2012) emphasised the role of top management in developing green buildings to build brand equity, innovate, and grow revenues. Consequently, building a green profile will require leadership and champions from top management hierarchy.

4.2 Structure

The results showed that most organisations are not embedding green-oriented resources into pre-existing organisational structure. They are instead adopting new structure and developing new performance indicators.

For example, most of the organisations within the sample established a specialist unit or environmental/ sustainability officer's position to drive the agenda. Some organisations have a large dedicated unit and others have a dedicated individual. This merely depends on the size of the organisation. Not only can there be the specialist unit or individuals, but also some voluntary roles within the staff such as an environmental champion and then it is made part of each individual's job description. The voluntary roles can be seen as empowerment for staff that can promote the green solution and allow them to participate in finding innovative solutions. This view is echoed in other empirical findings in companies in which sustainability practices are contributing to profits and so called "Harvesters." The findings reported lessons learnt such as: Harvesters usually change the organisational structure or adopt new structures and establish the position of sustainability officer (Kiron et al., 2012).

The dedicated environmental/ sustainability units or individuals have a major role to play on green business intelligence. In this role, they focus to identify clients with green agenda to work with and to offer them tailored services. C3 from the contractor group gave an example where they worked with an existing client to offer energy efficiency services. C3 stated that *"as part of* *a facility bid for a local authority we offered them energy investment where we pay the up-front costs and they pay us back from the savings."* This was possible because of the green intelligence staff that had good client knowledge and understood their aspirations and strategic targets.

Additional role of environmental/ sustainability unit or individual is to be able develop and communicate the business case of green practices internally for different departments and externally for clients and supply chain. For example, C3 from the contractor group stated that *"as long as it [referring to new green initiative] works financially you can find away and you can evolve it to client saving them money and saving you money they it is going to have a very good chance of going forward."* Nevertheless, an important issue has been raised by the interviewees that it is not always possible to make the business case in financial terms therefore construction organisations may look at alternative areas such as enhancing the reputation, making a clear statement of commitment to green issues, and social benefits.

The participants described another change in the structure where the operational units or individuals responsible for environmental sustainability have to report at the strategic level. In many cases there will be a strategic board manager responsible for the operational levels. For example, C2 from the contractor group indicated that *"at the moment the sustainability managers reporting to the health and safety director but some more senior appointments will be made so the sustainability managers will be reporting to head of sustainability"* .This strategic backing demonstrates the leadership commitment towards green agenda and empowers the position of environmental/ sustainability units or individuals to have a stronger influence on the organisation. However, CL5 from the client group stated that her current position as environmental and sustainability officer should be diminished over the time as a result of true embedment of environmental objectives within the organisation where this position should be part of everyone job responsibility.

4.3 Operations

The participants explained that the operations have changed significantly across many areas such as collaboration, technology embedment, procurement, and working patterns.

Organisations not only change themselves in response to environmental considerations, but they also become more collaborative inside and outside the organisation boundaries. It was evident within the sample there was a great collaboration and team work across the different organisation units. For example, C3 stated that he works closely with the financial department in developing and identifying green opportunities. Some of these organisations work more closely with their clients and suppliers to develop their green practices compared to their past experience of standard practices. Some of the participants explained their collaboration with certain professional networks that have specialised expertise in environmental issues and their work with the supply chain to ensure that green values are embedded within all activities. A typical comment was, *"If you think that in your company you have everything you need, you are totally* *self-sufficient you need nothing from the outside world then you are mistaken. You have a false view because you start to believe you have the right answers."* Consultant (CS1). Therefore, construction organisations should work more closely with their supply chain to ensure that they adhere to the same principles. Larger organisations may provide support for their supply chain and partners for better results. This vital because of the unique nature of the construction sector where there is a chain of actors involved to deliver products and services (Ballard & Kim, 2007; Kohler, 2008). Albino & Berardi (2012) noted that structure of the construction process is a major barrier to green practices because it is based on temporary arrangements between multiple organisations to deliver a project. Bossink (2007) highlighted the importance of studying the changes of organisational relationships in green practices. Therefore, the findings of this study are a means to overcome this barrier by encouraging collaboration between organisations. Another possible solution is to focus on integrated green projects delivery because it facilitates long-term relationships and shared value delivery.

The operation becomes more reliant on technology because it facilitates work efficiency. For example, the architects within the sample stated their movement to paperless documents. In addition, AR1 and AR2 explained the advantage they have by establishing a strong ICT documentation and automation services. They have a strong knowledge repository to facilitate communication and learning across the organisation. Furthermore, technology has a vital role to play in the changing process such as sensor technology which can help achieving more efficient consumption of energy and water and influencing behaviour to promote low carbon culture and efficient practices. Energy display is also seen as important technology advancement in raising awareness and encouraging lower consumption levels.

Moreover, CL1 and CL4 from local authorities stated that their organisations have changed the way of procurement where they started to procure only from suppliers who match specific criteria to ensure those suppliers are committed to the green agenda. This has some support from the literature where Albino & Berardi (2012) invetsigated relationships between construction organisations in sustainable practices. The results suggested that orgniasations tend to work with others that have green portfolio to show their commitment to sustainability.

Finally, some of the organisations within the sample introduced more flexible working patterns to reduce the travel miles and invested on online facilities to work across geographical regions. For example, CS2 stated that they communicate with their head office through online conferencing and thus reducing the need to travel and lowering their carbon footprint.

The results showed that GBMs can lead to major organisational changes therefore construction organisations should be prepared to accommodate these changes. In addition, it is vital to deal with these changes systemically and to embrace the close relationship between them. This study highlighted the role of supply chain in delivering GBMs and its impact on operational change. Consequently, construction organisations will need to work closely with their supply chain to achieve wider progress towards GBMs.

5. Conclusions

This paper has focused on investigating organisational changes pertinent to GBMs transformation in the UK construction sector. As the subject under investigation is a relatively new, qualitative method is chosen to better understand the subject. 19 semi-structured interviews are conducted with a varied sample representing academia and the sector practitioners. Thematic analysis is then applied to extract the results.

The results showed that organisational changes were grouped into three major themes. Firstly, green profile development where construction organisations start to build and market their green credentials. As the public awareness grows, organisations will find this is a pressing issue to survive in the market. Secondly, organisation structure by establishing a specialist unit or a member of staff to lead green practices and strategies. This position is vital drive the agenda and to make a clear statement of commitment towards GBMs. Finally, a major organisational change rests on the operations practices such as increased levels of collaboration internally and externally, technology embedment to drive efficiency, procurement, and working patterns. Therefore, construction organisations have to accept that moving to GBMs will bring significant changes to the way organisations work. This study contributed to better understanding these changes hence construction organisations can be prepared to address these and channel their resources and capabilities toward the identified areas of change.

Although this study has provided new insights on the relationship between GBMs and organisational changes for the construction sector, it has some limitations. First, GBMs remains fundamentally under-researched topic particularly in the construction context. This has implication on finding comparable construction studies that would have influenced the results of the current research. Second, the research is focused primarily in the UK construction sector and is relied on empirical data from UK only. Therefore, it is difficult to generalise the findings beyond the investigated context. A wider qualitative inquiry as to how GBMs change construction organisations is recommended for future research. Furthermore, the possibility to compare findings of the present paper with organisational changes in other European countries remains desirable.

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Performance Based Building by U.S. Architects: An Investigation into Attitudes and Adoption

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Abstract

Performance Based Building (PBB) was initially developed alongside sustainability to resolve separate but related issues. Work in the field began with attempts to harmonize design and construction methods and products across national and cultural barriers. Reduction in energy and water consumption, additional added value to the owner and novel, responsive design forms become later goals of PBB efforts. Regulatory, technical, cultural and process-oriented barriers to adoption have been identified within specific disciplines.

There are a number of PBB tools that integrate the full lifecycle of building design and occupation. These tools offer the potential to address many of the causes of the gap between the predicted and actual performance of buildings seeking high levels of sustainability. The mixed-methods research design began with a questionnaire for participant identification and proceeded to in-depth explanatory interviews that explored the barriers and drivers to adoption encountered in daily practice.

Awareness appears to develop slowly, sometimes organically through the firm's interests, but more often via pilot projects and committed pathfinder clients. Opportunity and demand subsequently build. Some firms capitalize on this as a market differentiator while others are pulled along by mandates or more mainstream clients who have recognized the business value. These experiences build basic functional knowledge which, in turn, is developed with the involvement of specialist consultants and software tools into more sophisticated technical knowledge. Levels of sustainability and performance previously seen to be impractical are slowly transformed into standard practice. This process renews itself as committed clients and organizations seek again to demonstrate their values beyond conventional business.

This information can guide the efforts of those seeking to advance the adoption of PBB among U.S. architects. Additional research into the effects of firm culture and the role of committed clients in developing new processes appears warranted.

Keywords: architecture, design, performance, sustainability, values

1. Introduction

The traditional architectural design process begins when the owner hands a complete program of spaces to the architect and ends when the building is ready for the owner to move in. Pre-design and post-occupancy evaluation have emerged more recently as formal services (American Institute of Architects Staff 2013). As the fields of sustainable and high performance design have become mature, a multitude of technical tools and rating systems have emerged to address individual aspects of design. A smaller set of tools and techniques have also been developed seeking to guide the design team in how decisions are made and which goals are pursued.

This research began with the conjecture, based on the author's personal experience, that awareness and adoption of Performance Based Building (PBB) among U.S. architects is low. This research then focused on identifying the barriers and drivers within the specific context of architectural practice and the first-hand experiences of those practitioners. By exploring those experiences, both actual and perceived barriers were identified for further research.

A review of the literature revealed a number of actual and potential barriers, but few explanatory models. Awareness is a barrier that can be measured directly via surveys and questionnaires. However, it is not likely for one to be able to give an insightful answer to the circumstances of his or her own ignorance. The popular Leadership in Energy and Environmental Design (LEED) program served as a proxy for the less well-known concept of PBB. Empirical studies into different delivery systems have centered on project performance during construction (Konchar and Sanvido 1999) but are more recently beginning to investigate how those methods influence operational outcomes (Esmaeili et al 2013). Those relationships are complex and beyond the scope of this research. A two-step mixed-methods approach was able to illustrate the transition of sustainability and building performance from an expression of a small group of clients' values to the design mainstream. The value of these insights lies in their ability to aid the work of those pursuing broader adoption of PBB among U.S. architects.

2. Literature Review

2.1 Conceptual Background

The essentials of contemporary PBB were defined in the 1982 report to the International Council for Building (CIB), "Working with the Performance Concept in Building." The report begins, "The performance approach is, first and foremost, the practice of thinking and working in terms of ends rather than means. It is concerned with what a building or building product is required to do and not with prescribing how it is to be constructed." (Gibson 1982, p. 4) The other key concepts that Gibson (1982) outlines are testing the proposed solution against those requirements and evaluating the final constructed work against the original benchmarks. The CIB continued to develop a research program for PBB through the 1980s and 90s.

This laid the groundwork for a multinational research effort that gave rise to the Performance Based Building Thematic Network that ran from 2001 to 2005 (International Council for Building 2013). That work culminated in a series of final reports intended to establish a consensus for PBB throughout Europe and the United States. Performance standards then become the means by which to judge the productivity of the discourse between supply and demand. Technical applications have developed in step with the advance of technology and computing. The US Department of Energy now lists 411 software applications for measuring and comparing differing aspects of building performance (Building Technologies Office: Building Energy Software Tools Directory 2013).

2.2 Benefits and Barriers

These tools and practices offer an array of potential benefits; increases in Key Performance Indicators (KPIs) with Gross Value Added (Barrett et al 2007), dynamic links between performance parameters and building geometry (Oxman 2008), and even carbon absorbing cities (Geyer & Bucholz 2012). Fowler (2011) and Hammond (2005) point to mandates Federal organizations have enforced as an important determinant of the successful adoption of PBB.

Despite these benefits, many barriers to adoption remain. The lack of acceptance among regulatory bodies was one of the first to be identified (Gross 1996). The increasing technical complexity of the design process limits who can perform more sophisticated performance simulations (Shi and Yang 2013) and the number of simulations that can be performed (Flagler, Haymaker 2007). Outside of large property portfolios managed by a single entity - namely governments and a few large private companies - smaller organizations have not been able to demonstrate the business value that PBB offers successfully (Barrett et al. 2007). Sexton and Barrett (2005) and Panuwatwanich et al. (2009) found that PBB must explicitly address business logic and value in order to find broader acceptance. Seeking to explore the limits of performance across many domains creates fragmentation of the design process. For example, daylighting, facade design and energy performance have become independent consultancies at the same time that the need for the integration of those systems into the whole of the building has become increasingly apparent (Satterfield et al. 2009). Perceived liability, adversarial relationships and the lack of a skilled workforce also constitute cultural barriers (Wright 1996). An organization with a culture that values performance will learn how to express that value to others by integrating the myriad available technical tools. In the case of hierarchically structured federal agencies, that cultural change has been mandated from the top. Without such a mandate, there seems to be no consensus within the reviewed literature regarding the tools or methods that would most effectively address this issue.

2.3 Integration

In contrast to fragmentation of the design process, integration was identified as the primary means by which barriers to PBB can be addressed (Bakens et al. 2005, p. 155):

> *Fixed classification or inflexible separation of the demand and supply sides also do not help. Instead, a programme structure and activities that promote maximum interaction of up- and downstream stakeholders, and of participants in the different phases of building life, should be encouraged to promote integration and remove barriers.*

Lützkendorf et al. (2005, p. 13) created a typology of performance instruments and tools that maps their application across these phases of a building's life. Few of the tools they identified are intended to span all phases of design. All but the ASTM Standards and Design Quality Indicators (DQI) are intended for residential design or are limited in scope by region-specific database information. Similarly, the Soft Landings framework grew from a desire to incorporate user feedback from the end of the design cycle, rather than front-loading technical information before design begins (Way 2004; Bordass, Leaman 2005). Because these systems have the capability to be broadly inclusive of the design process, they are referred to as integrated tools for the purposes of this research.

Highly optimized building performance concepts tend toward complex, multi-dimensional trade-offs that are embedded deeply within the final built solution. This makes identifying the benefits derived from any specific design decision guided by PBB principles particularly challenging. Tools that integrate PBB throughout the design life-cycle offer significant potential benefits. However, their adoption may hinge on the internal dynamics and culture of the organizations seeking to make use of them.

3. Methodology

3.1 Research Design

Given the complexity of the performance-based landscape, is it reasonable to expect the practicing professional to be knowledgeable about the use of these tools? The reviewed literature suggests there has been little formal investigation into the state of knowledge among architects practicing within the U.S. While many barriers and drivers were identified during the literature review, correlations between these variables were not suggested. Without those correlations to explore in a quantitative manner, an alternative method was selected. A two-stage process was developed to first narrow the field and then explore it in greater detail. The first stage was a brief questionnaire only seeking to identify individuals with experience in the systems in question. The second stage was developed as an open-ended and exploratory interview to reveal the specific context of each firm in which the interviewee operates (Weiss 2004). In this mixed-methods approach, the questionnaire is not intended to be a statistically reliable tool. It is used to enhance the qualitative exploration of the interviews. This method aligns with the participant selection variation of the explanatory model for mixed-methods research (Creswell, Plano Clark, 2007).

3.2 Questionnaire

A brief questionnaire was developed to identify individuals with experience in the systems in question. To maximize results, the questionnaire was sent to individuals whose expertise was known to the author or whose qualifications were readily available through published resources, including the United States Green Building Council directory and past members of the AIA national Committee on the Environment. The questionnaire was restricted to three questions: awareness of the subject PBB systems, experience with those systems, and willingness to participate in an in-depth interview. LEED templates and forms were included to ensure a baseline of familiarity with sustainability and building performance. Due to the small sample size relative to the potential total population, statistical analysis of the questionnaire results was limited to internal comparisons.

3.3 Interviews

Interview participants were self-selected through the questionnaire process. After establishing basic facts, the majority of the interview was structured in a biographical arc, beginning with personal history of the subject, working towards present experience, and finally projecting into the future. The method of focusing on a single, specific time is referred to as the Critical Incident Technique, which Chell (2004) asserts is an effective method to elicit more detailed and accurate recollections of past experience. This was also intended to establish a flow that would produce a more active and engaged conversation. This appeared to have been successful as the responses grew longer and more detailed as the interviews progressed.

The analysis of the interviews followed the model outlined by Seidman (2013). Recordings were transcribed and those transcripts were coded for keywords based on the barriers and drivers identified in the literature review. Other keywords emerged as repetitive themes across multiple interviews. The frequency of these keywords was charted and the strongest concepts were grouped together along with any counter-examples.

4. Results and Analysis

4.1 Questionnaire Results

Seventy-two professionals were contacted via e-mail with 20 responding over a period of 48 days. Six of those 20 were aware of one of the subject systems and only two had first-hand experience. All had first-hand experience with the LEED templates.

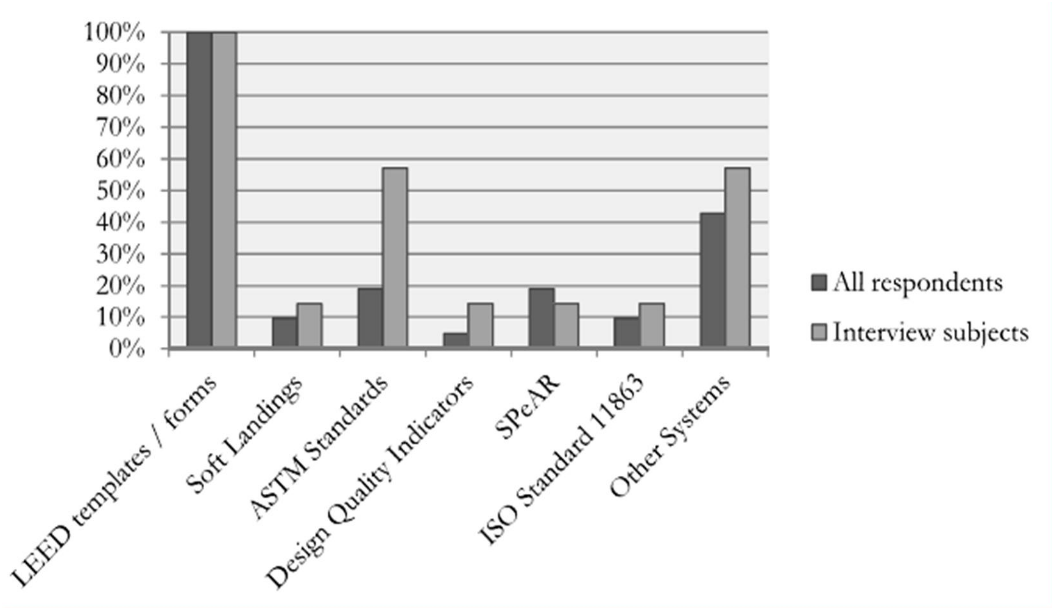

Figure 1: Have you evaluated any of the following systems for use in your practice?

Green Globes and the Living Building Challenge where the two most commonly mentioned of the other systems. Two trends are readily discernable from this data; LEED is ubiquitous among respondents and, while not completely unknown, awareness of the other subject systems is not as pervasive. The interview subject's experience appears to be consistent with the larger group of respondents with the exception of the ASTM Standards.

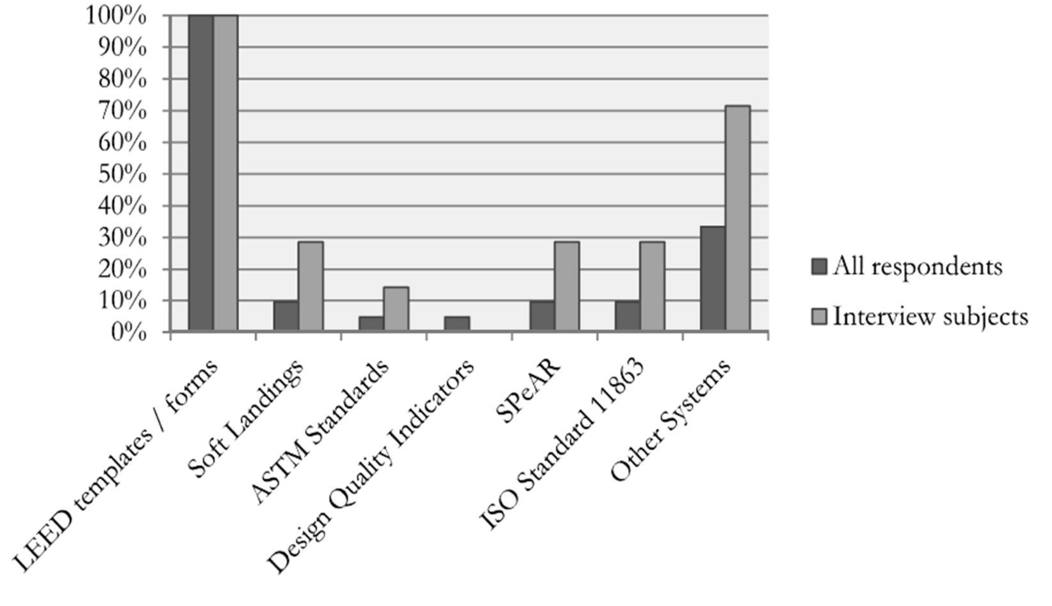

Figure 2: Have you been involved in a project that used one of these systems?

The same two trends were demonstrated by the results for first-hand experience with the low levels of adoption of systems other than LEED being even more pronounced. In this case, it appears that the interview subjects may have slightly more experience with alternate systems than the overall group.

4.2 Interview Results and Analysis

Twelve of the questionnaire respondents elected to provide contact information for the purposes of scheduling interviews. Ultimately, interviews were arranged with seven of those individuals. When asked to reflect upon their earliest experience with PBB, a strong trend emerged. Six of the seven had been involved in the LEED pilot program to varying degrees. For five of those six, a non-profit organization, governmental body or another pathfinder client was mentioned in reference to this initial experience. When asked about barriers to PBB that had been encountered during the course of these initial experiences, financial cost was identified by five of the seven subjects. However, several related concepts were specified: increased design fees, rating system certification fees, actual construction costs, and uncertainty in the bidding process leading to inflated costs. The perception of increased cost was described as having outlasted the reality among some clients. Education of both the design and construction teams was also cited as an early barrier. Responses to the question of what values drove the design team to push through and overcome the barriers that were encountered centered on three ideas: market differentiation, firm values, and client values.

Asking interviewees to identify the benefits the design team had realized from the inclusion of LEED or PBB strategies proved more difficult to frame in a manner that elicited useful feedback. For the four that did address the question directly, one response serves as a succinct summary: *"There are really three prongs of what we received from that [experience]. One was how to do the LEED documentation, but also our reputation as a firm doing sustainable design and our ability to design a building that was at a higher benchmark than what we had done before."*

At this point in the interviews, the focus shifted from present-day experience to speculation regarding the future. Mandates were identified as particularly powerful tools in this regard, especially when tied to funding mechanisms. The specific example of federal and local government adoption of LEED certification was cited by three subjects. A similar state level program, also tied to bond funding for construction costs, was also cited. The business case for performance was also cited: *"…there would have to be a policy or mandate or there would have to be, basically, undeniable quantitative return on investment…"*

The role of building standards or rating systems that reach beyond the conventional also emerged. In particular, the difficulty of achieving the Living Building Challenge was cited as a driver for those organizations seeking to express a qualitative commitment to sustainability that goes beyond what can be evaluated in traditional quantitative terms. It was suggested that this may be intentional on the part of both the clients and the rating organization. One subject questioned the premise of the question and responded:

The path to make anything go on an upswing is instead of making it voluntary, make it compulsory, which then, sort of diminishes the altruistic nature of going after it, which is why Living Building Challenge and various other projects aren't actually interested in having more projects but rather a number of demonstration projects.

This suggests that the creative tension between aggressive rating systems that go beyond the industry's current abilities to measure value and the widespread, tested and proven systems forms a mechanism by which the qualitative values of some organizations are made quantitative and revealed to the broader market.

5. Discussion

5.1 Pathfinders and Mandates

The initial experiences of the interview subjects were defined by pathfinder clients and mandates. The pathfinder client plays a critical role in the adoption of new performance standards by pushing through barriers based on their values rather than waiting for a demonstrable return on investment to justify their efforts. This contradicts Barrett et al.'s (2007, p. 16) assertion that *"…project teams can only really achieve incremental change without this lead [mandates]."* Regulatory obstacles were scarcely mentioned in the interviews, which suggests the concerns voiced by Gross (1996) may have lessened in the intervening years. The role of the pathfinder client appears to shift the need to quantify building performance in business terms identified by Sexton and Barrett (2005) as well as Bakens et al. (2005) from the initial adoption phase to later stages of the process. Adoption of PBB may be better served by including or marketing to those clients rather than focusing on design professionals. This finding parallels the "innovation champions" Brandon (2006) describes as driving technological and design-process adaptations. Pathfinder clients are distinct from innovation champions insofar as Brandon ascribed their efficacy to the force of individual personality and not organizational values. In both cases, however, industry does respond to client demand. This research did not contradict prior findings that mandates are powerful tools for driving the adoption of new systems to the broader market, but it does suggest they follow pathfinder clients in the overall process.

5.2 Process

The emergence of software tools and specialty consultants to serve the architectural profession pre-dates the PBB concept. Four subjects agreed in principle with the concerns and difficulties voiced by Shi and Yang (2013), Reinhart and Fitz (2006), and Crawley et al. (2008). However, the magnitude of these issues and their impact on the final output were both downplayed. It appears that firms have grown comfortable evaluating those tools and consultants and have developed ongoing processes, whether formalized or not, that allow them to adapt to the proliferation of both specialties in the normal course of operations. This incremental approach echoes Yetton et al.'s (1994) findings regarding the initial adoption of CAD technology in the late 1980s and early 1990s.

The same institutional inertia could be a barrier to the adoption of process-oriented tools that do not match the organization's current design methods. This supports Hammond et al.'s (2005) claim that *"...successful implementation of a performance-based approach for Facilities and Constructed Assets is best if embedded in an overall performance-based approach for the whole organization."* However, the lack of awareness of those specific tools appears to have manifested itself in an absence of specific information on this topic within the interviews.

5.3 Feedback

The need to incorporate feedback is growing in recognition of the continued uncertainty of outcomes, otherwise known as the performance gap. Two contributing factors were identified by interview subjects. First, modeling tools are developed and used for documentation and standards compliance, not necessarily for their predictive capabilities. Second, occupant behavior, both at the organizational and individual levels, can be very disruptive to optimizing building performance. Some clients and firms are now actively seeking feedback which may indicate that the adoption of this practice is beginning to grow along a similar arc as LEED. The AIA 2030 Commitment, a single-attribute system comparing predicted and actual energy use intensity, has recently emerged as another example currently adopted by 99 U.S. architecture firms (American Institute of Architects Staff 2013).

5.4 Other Issues

A handful of other issues emerged through the course of the research. It appears that LEED's ubiquity drowns out many other systems. Green Globes may be a viable alternative to LEED but is still far less prevalent. PBB in the U.S. may be dependent on recognition by and incorporation into one of those two systems. Liability is seen as a barrier by some and a driver by others. Performance guarantees and the health impacts of chemicals within building materials were specifically identified. These are significant to the issue of PBB, as they represent potential changes to the professional standard of care for designers that relate directly to specific dimensions of building performance. The findings appear to confirm Wright's (1996) assertions regarding performance, while the topic of chemical health impacts may be a more recent emergence not addressed as thoroughly in the existing literature. International work, where design oversight of contractor activities is prevented by contract or practice, is an area of promise for the PBB concept. Design documents that do not rely on prescriptive methods could help ensure that the final built product meets the intent of the design and needs of the user across significant cultural and technical divides.

6. Conclusions

This research sought to identify barriers and drivers to the adoption of PBB amongst U.S. architects so that those tools may be more commonly brought to bear upon the gap between predicted and actual building performance. The specific context of architectural practice and the first-hand experiences of those practitioners were explored to yield insight into the practical judgement that guides their work. The picture that emerges is of a progressive process that builds over time.

From the data gathered from the interviews, it appears that awareness has developed slowly, sometimes organically through the firm's interests, but more often via pilot projects and committed pathfinder clients. Opportunity and demand subsequently appear to build. Some firms capitalise on this as a market differentiator while others are pulled along by mandates or more mainstream clients who have recognized the potential value in business terms. These experiences build basic functional knowledge which, in turn, is developed with the involvement of specialist consultants and software tools into more sophisticated technical knowledge. Levels of sustainability and performance previously seen to be impractical are slowly transformed into standard practice. This process renews itself as committed clients and organizations seek again to demonstrate their values beyond conventional business. While the sample size of this research cannot be considered broadly generalizable, the coherence of the story told by the interviewees suggests these conclusions represent one thread of experience within the industry.

The implication is that PBB cannot be pursued as an end of its own. PBB is, by definition, focused entirely on what can be measured, demonstrated, and improved. This leaves no space to include the more far reaching and ambitious concepts that capture the imagination of pathfinder client organizations, but have not yet demonstrated a reasonable return on investment. Without that intrinsic driver, those seeking to extend the use of PBB must find another path. Adoption can be most readily furthered by embedding PBB principles as deeply as possible into the rating systems and standards, such as the Living Building Challenge, that do offer this existential demonstration of commitment.

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Designing LCCbyg: A Tool for Economic Sustainability

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Abstract

The principles of lifecycle costing or whole-life costing has been around for decades, but the implementation of the principles has been modest or even weak despite the obvious advantages of integrating maintenance, operation and management aspects into the design of new buildings and facilities. Several explanations to this apparent paradox have been offered including the absence of robust tools, cost key figures and commonly agreed calculation assumptions along with weak economic incentives, the inherent project focus of designers and contractors etc. In early 2015, the Danish government launched a new package of tools for sustainable construction. The complete package includes a general guideline to sustainability, two specific guidelines on lifecycle costing (LCC) and lifecycle analysis (LCA), a general introduction to the lifecycle of construction and two new tools for doing lifecycle costing (LCCbyg) and lifecycle analysis (LCAbyg). Based on the methodology of structured analysis and agile software development methodology, this paper will review existing tools, discuss (some of) the design choices made and summarise lessons learned from the development of the tool LCCbyg for lifecycle costing. First, this paper will provide a typology of existing tools into three categories with distinct characteristics and associated benefits and drawbacks: 1) Spreadsheets, 2) stand-alone applications, and 3) web services. Second, while the software interface only displays limited unique features and functionalities compared to other available tools, the inherent data model applied in the tool provides a number of unique design choices. These design choices make the tool highly robust to future development; incorporate a fully open standard in XML format for easy exchange with other applications; provide the users with a high degree of adaptability to their specific requirements; and reduce the need for an elaborate classification scheme for cost and building components that would otherwise severely restrict the adaptability of the tool.

Keywords: Sustainable construction, lifecycle costing, agile development, open standard, data model

1. Introduction

The challenge of sustainability has been around for decades. The Brundtland report (1987) introduced sustainability as the balanced development of three pillars: environment, social and economics. Despite progress, there still is a long way to go for governments, businesses, academia and civil society. In 2014, the Danish government (Regeringen, 2014) issued a new building policy with five strategic actions including one action on sustainable construction. This strategic action included a series of initiatives to promote sustainable construction, among others a guidance package. This package was launched in early 2015 and includes a general guideline on sustainable construction (Energistyrelsen and Birgisdóttir, 2015), two guidelines on environmental assessments (LCA) (Birgisdóttir and Nygaard Rasmussen, 2015) and lifecycle costing (LCC) (Haugbølle, 2015), a foundational report on the building's life cycle (Nygaard Rasmussen and Birgisdóttir, 2015) and two tools for environmental assessments (labelled LCAbyg) respectively economic assessments (labelled LCCbyg).

The principles of lifecycle costing or whole-life costing has been around for decades, but the implementation of the principles has been modest or even weak despite the obvious advantages of integrating maintenance, operation and management aspects into the design of new buildings or refurbishments. Several explanations to this apparent paradox have been offered including the absence of robust tools, cost key figures and commonly agreed calculation assumptions along with weak economic incentives (see e.g. Haugbølle, 2015).

Applying the principles of lifecycle costing has for several years been mandatory for both social housing and governmental buildings. While the social housing sector has developed sector-specific tools, the government building agency has effectively neglected its obligations to apply and to disseminate knowledge on lifecycle costing. This negligence was criticized in strong terms by the Danish National Audit Office (Rigsrevisionen, 2014) and the Danish Public Accounts Committee (in Danish, Statsrevisorerne) putting pressure on the building agency to take action on lifecycle costing. Meanwhile due to unfortunate circumstances the building agency had to employ a new CEO, who came from a municipal building agency with a high profile on sustainability and lifecycle costing. Further, three new trends have in recent years actualised a wider use of lifecycle costing in construction (Haugbølle, 2015):

1. New governmental regulation issued in 2013 on quality assurance, public-private partnerships and lifecycle costing in public construction, which requires all public clients (not only governmental) to apply lifecycle costing in projects above certain thresholds.
2. The establishment in 2012 of the German certification scheme DGNB adopted by the Green Building Council Denmark for sustainable buildings and urban areas where economic quality has a very prominent position.
3. The new European procurement directive from 2014 that makes it easier to use total cost of ownership (TCO or lifecycle costing) as an award criterion in competitive tendering rather than just lowest cost.

With these new dynamics in mind, the time seemed ripe to consider how lifecycle costing may be addressed and operationalised. The objectives of this paper are 1) to provide a typology of LCC tools and discuss benefits and drawbacks of different types of tools, and 2) to reflect on the design process of LCCbyg and share lessons learned during the software development process.

2. Methodology

The tool LCCbyg was developed for the Danish Transport and Construction Agency (Trafik- og Byggestyrelsen, 2016) by the Danish Building Research Institute in collaboration with a small software firm. The combined competence of the project team members covered lifecycle costing, data modelling, software architecture and user interface design.

This study is based on a combination of the structured analysis approach and the agile approach for software development. The development has been divided into two main stages: the development of version 1.0 in 2014 and the development of version 2.0 in 2015. Due to conference deadlines for paper submission, this paper primarily addresses the development of the first version. This process can be subdivided into three main phases: Analysis of present situation; formulation of requirements; and development and testing of the tool.

The analysis was carried out using so-called ‘structured analysis’ (Delskov and Lange, 1999). As spreadsheets are effectively the industry standard of performing LCC calculations, it was relevant to analyse the design, inherent data model and calculation procedures of spreadsheets more closely. The methodology was adapted to only include the Data Flow Diagrams, Data Dictionary and Process Descriptions. The second phase covers requirement specification, which the customer writes on the basis of the analysis and own requirements and wishes. In this case, the specification of requirements was developed in parallel with the second half of the analysis as well as the early design stage. The third phase covers the actual design of the application. In addition to structured analysis, this work was in part based on the 12 principles of agile software development (Fowler and Highsmith, 2001). To mention a few of the principles being followed in this project, the project team was a self-organising team with a flat organisational structure based on a recognition of complementary competences among team members; the iterative development process was based on frequent sprints; intensive face-to-face conversation took place through weekly project meetings; changing requirements was welcomed (even late in the process) and adapted regular to changing circumstances through close interaction with a highly knowledgeable reference group and potential users; and the team focused intently at delivering working software as the principal measure of progress.

The approaches of structured analysis and agile development were supported by empirical evidence from a range of sources. The analysis phase provided an overview of existing national and international tools. Based on this overview, the LCC tool for DGNB certification developed by the Danish Building Research Institute was selected for closer scrutiny as this is a very recent example of this development path, the project team had easy access to the coding, and the tool closely follows the approach in similar tools. The purpose of the analysis phase was to explain and document the DGNB system’s use of variables and rules of calculation in order to support the subsequent design phase. The analysis phase also included participation in industry courses on LCC and interviews with and observations of practitioners using LCC tools. During the requirement setting phase extensive dialogue with the funding agency and the reference group was carried out based on e.g. the presentation of mock-ups and draft versions of the tool's reporting schemes. The development and testing phase further extracted empirical evidence through e.g. the use of a structured test protocol by the test persons.

3. Analysis of existing tools

3.1 Existing approaches

A number of different approaches and tools to manage whole-life costing or lifecycle costing already exist both nationally and internationally. Two standards are relevant here: the international ISO15686 series on service life planning (ISO, 2008) and the European EN15643 series on sustainability of construction works (CEN, 2012). Several instructive books and guidelines have also been published over the years. These include among others the very first publication by the Danish national building research institute on economic optimisation of insulation (Becher, 1949), strategic investment and financing (Hedegaard and Hedegaard, 2008), a practical guide to selecting materials from a whole life costing perspective (Caplehorn, 2012), a comprehensive overview of different LCC models and engineering design issues within various business areas of application (Dhillon, 2010) as well as a textbook for engineering students on economic analysis, estimation and management in product development of complex systems (Farr, 2011).

The most widespread type of tools is based on the spreadsheet platform available in most standard software packages for office use (typically Microsoft's Excel spreadsheet). These include among others a low-energy optimisation tool for Danish social housing, the Norwegian government's building agency's tool LCProfit, the LCC tool used in the Danish DGNB certification scheme as well as a range of internal company-specific spreadsheets. Another but less frequent type of tools includes stand-alone applications. These include among others the tool BLCC offered by the US Department of Energy. A third type of applications is web services where calculations are made online using some kind of web browser linking to a server hosted by the service provider or a web hotel. These include among others the mandatory tool for doing LCC calculations in Danish social housing with regard to new buildings and major refurbishments as well as a web service version of the Norwegian LCProfit. A fourth type is apps for tablets and smartphones, but these are currently non-existent.

3.2 Characteristics of different technical solutions

While a spreadsheet solution offers a number of benefits including relatively low development costs, spreadsheets are notoriously fraught with errors. As pointed out by Panko (2008) *"…the issue is how many errors there are, not whether an error exists. And out of 113 investigated spreadsheets 88 % are found with errors."* A web service solution makes it possible to have one common interface, but requires additional resources for optimisation to different browsers as well as extensive management resources. Apps for smartphones and tablets are spreading fast and offer great value for the user "on the move", but are often cumbersome for daily office use. A desk top application is the main platform for the user groups, but desk top application may need to be available for three different operating systems (Windows, OS X and Linux). Linux is used to a very limited degree (around 1 % of the market), while OS X is used to a larger degree (some 8 % of the market). The Windows operating system in its different versions is by far the most widespread operating system, accounting for around 90 % of the market (StatCounter, 2015). Since the operating system OS X has various options for running Windows applications, solutions based on the Windows operating system would potentially cover the vast majority of all desk tops. Table 1 provides an overview of the benefits and drawbacks of each of the four technical platforms for developing LCC calculation tools.

Table 1: Characteristics of technical solutions

Characteristics / *Type*	*Benefits*	*Drawbacks*
Spreadsheet	*Great flexibility* *Wide spread use* *Integrated in office suites*	*Many possible errors (often hidden)*
Web service	*Same interface on all platforms*	*Optimisation to different browsers* *Require fast internet connection* *File handling requires extensive management of servers, security etc.*
Mobile/tablet	*Wide spread and increasing use*	*Cumbersome for extensive office use* *Customised solution required for each mobile platform*
Desk top application	*Mature and open source libraries for XML, PDF and graphs* *Main platform for user groups* *Integrated in work processes, including backup and storage*	*Three operating systems (Windows, OS and Linux)*

3.3 Structured analysis of a spreadsheet tool

An important difference between a software application and a spreadsheet is not the technical difference, but rather that the user is developing calculation solutions. Where the programmer has learned to follow a strict methodology that involves an ongoing focus on troubleshooting, the spreadsheet developer rarely follows any method other than increasingly adding cells. Where a spreadsheet developer sees a variable as a position in a given layer or cell in the spreadsheet, the programmer will see the variable without position. In practice this means that the variables are all unique in their naming, and are available in a variable list. For the programmer the outcome of two interacting variables becomes a new variable, described and reportedly named in the variable list. For the spreadsheet developer an interaction between two positions leads to a third position. In both cases, the calculation will be correct, but in a further development of the application, the programmer would only have to control the variable list. The spreadsheet manager must ensure all rearward positions, which gives a large number of corrections, particularly when multiple columns or rows need to be inserted. References in data, x-refs, are often troublesome because they tend to break.

In order to decipher the logic of the system the starting point was to note the responsibility of data entry and the resulting variables in the DGNB LCC-tool. The tool's calculation views and balances were then reviewed in order to document the use of input variables and to find and explain the resulting calculations (system variables) included in later calculations.

The variables were described in a 'Data Dictionary', and calculation routines were described in 'Processes'. The variables used in the processes were double-checked with the data dictionary, and the processes themselves independently described. Finally, the variables were taken directly from the spreadsheet and listed alphabetically and in conjunction with process variables and data dictionary. Figure 1 shows the result of this analysis as a high level view.

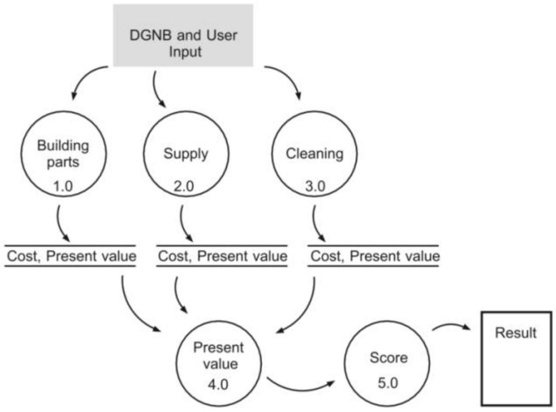
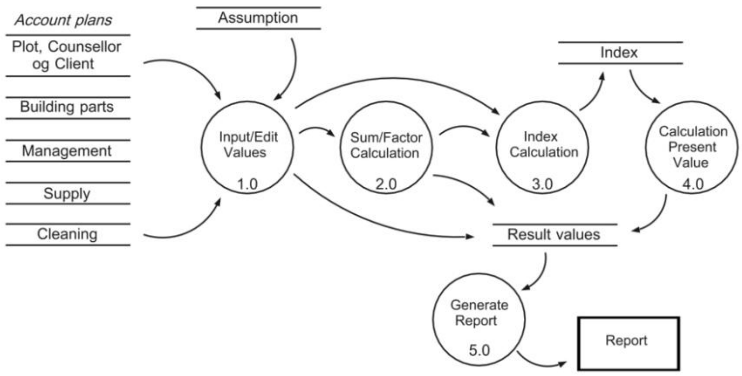


Figure 1: The system's procedural context (High level)

4. Setting requirements

Figure 2 shows the principle of the system where account plans will be completed and customized by the user (Process 1.0), after which the values are used in the subsequent calculations. 'Account plans' contain a number of items the user can select as needed. Interest rates are not implicit in account plans, but located in the register 'Assumptions'. The values entered by the user are stored both in the register 'Result values' and transferred to the calculation processes. The system calculates totals and factors (Process 2.0), which is later used in the calculation of the index values (Process 3.0). Some values are not included in the calculation of factors and sums, and used directly in the index calculation. The purchase will not be calculated as index or present values, and therefore saved directly in the register 'Result values'. The index values are saved for each year of the chosen calculation period. On this basis the present values are calculated (Process 4.0). All input, used standard values, and the calculated present value are placed in the register 'Result values', which forms the basis for generating a ‘Report’ (Process 5.0). Process 1.0 and 5.0 are ‘semi-manual’ while Process 2.0, 3.0 and 4.0 are automated.

Figure 2: Outline of the system



Each of the predefined building parts has been associated with values for ‘Lifetime’, ‘Maintenance rates’ and ‘Replacement rates’. The values are taken from a report on lifetimes by SBi (Aagaard et al., 2013) and supplemented with maintenance rates and replacement rates from the price calculation database V&S Prisdata and the Green Building Council Denmark (2014). Lifetime is indicated as number of years the building component is functional and does not need replacement. When the estimated lifetime of a building component expires, the building component is replaced. Maintenance of the building components is specified as a percentage of the purchase price (the construction of the physical building components). Maintenance is calculated for each year of the calculation period, so the value represents an annual maintenance cost. Replacement is also a percentage of the purchase price of the building components, but appears only in the calculations of the year in which the lifetime expires.

The account plan for ‘Building parts’ calculates acquisition cost of the building, maintenance of the building components and replacement at end of life (Figure 3).

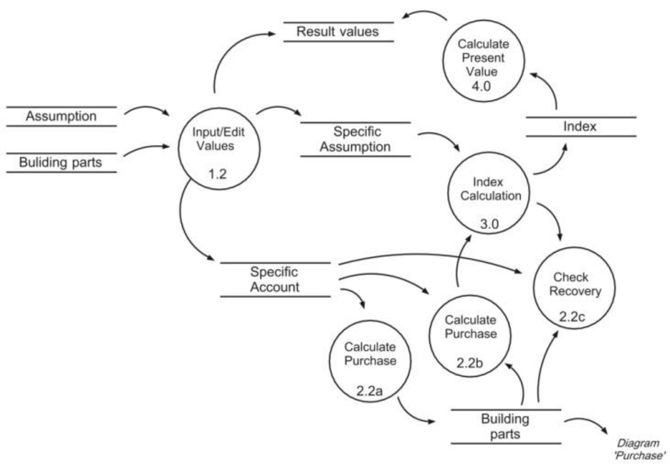


Figure 3: Calculation of building parts

For each year during the calculation period an indexed value and a present value is calculated. The input and editing made by the user in Process 1.2 is used in the calculations and saved simultaneously in the ‘Result values’. The register called ‘Acquisition of building parts’ is also used in ‘Acquisitions’. The account ‘Building parts’ contains parts classified under SfB group 1-6 (Byggecentrum, 2012).

5. Converting requirements to a solution

5.1 XML as data format

Data – and specifically data related to building structures with a long life – must be stored in a manner that allows data to be retrieved over time independent of specific tools, software, operating systems and hardware. The unique properties of the XML format makes it ideal for storing hierarchical data directly in a data tree, thus avoiding the need for the often troublesome references. It also allows adding and deleting posts where needed and belong in the logical structure. Consequently, the system store and exchange data in XML, as it makes it possible to store data in clearly defined structures without sacrificing flexibility. Storing data in a human readable format also allows data files to work outside the tool and it allows project file authors to create new project types by hand and merge outside data by using existing XML tools.

In naming the XML elements, tags and attributes are exclusively in English to avoid future problems with external XML tools. All tags and attributes are written in lowercase. Although it is possible to achieve a slightly higher human readability by using letter casings such as Camel-Case, the benefits are outweighed by the many trivial errors that can arise later when trying to figure out the correct casing for an element or attribute. The choice also allows the software code to define software objects as Camel-cased and XML elements as all lowercase, making it easier to identify what is referred to when working on the code base.

Many automatic XML-to-code generators will default to serialising data into elements rather than attributes. In order to preserve human readability, and make the XML correspond to the logic behind, it was chosen to handcraft the XML/Data Object conversion. This allows for values to be stored as attributes inside the relevant tags and reserve element creation for bearers of the hierarchical information. Making this distinction is helpful for deciding how the XML structure should look like when adding and refactoring the data format.

5.2 Development platform

In order to contain, edit and standardise the use of the aforementioned XML file, the project team chose to write a software program. In order to do that, an execution platform and one or more programming languages must be selected. A number of considerations were taken into account including use on the web, multi-platform compatibility, mobile and desktop use, industry standards, prevalence of programming languages, and availability of free, open source third-party extensions. As a consequence the application was created in C# as a Windows Presentation Foundation (WPF) application.

5.3 Graphical User Interface (GUI)

The general approach has been to design the application as a series of steps represented by tabs in the project pages. These are bound to the underlying software objects that are updated directly and with a minimum of filtering. An update of a value in the GUI triggers a complete recalculation of all results in the model. This allows showing in real time the effect of a specific change in value on the calculation. The cost data breakdown structure holds the account plan elements. These are shown in two tabs: one for editing structure and setting key values, and one for entering the main body of user values. The overall calculative results are shown in a tab labelled ‘Conclusion’. The application can deliver output in three different forms: 1) a PDF document for circulation to decision-makers, 2) an XML file for others to continue working with, and 3) a spreadsheet.

5.4 Software structure

The software started its life as a relatively “thin” wrapper around the XML file, the idea being that calculations and formulas where held in accompanying XSLT style-sheets, and XSLT transformations made the calculations. The idea was that formulas and calculations could be shared as XSLT files allowing for future expansion and flexibility. The software lived through quite a few iterations in this form. In the end it proved too slow to execute and too cumbersome to maintain. Thus, it was decided to rewrite the core of the program using a more “classic” approach. The XML file is now serialised and de-serialised from/to software objects, each XML element getting a corresponding code class with the necessary fields and members. The rewrite resulted in a core that can now update its results in real time.

The model that was finally settled on was in part a result of the initial analysis of the existing spreadsheet solutions, and in part a result of realizations that took place while implementing the model and features. A great deal of work went into modularising parts of the calculation and the different functionalities. By standardising the calculation at the lowest possible level, calculations at higher up levels avoid having to deal with ‘if/then’ scenarios, where the source of the data has to be accounted for. The exclusion of references makes it easy to edit the structures without having to synchronize with an external reference. External references are not entirely excluded as the format has a ‘code’ attribute meant to identify the account plan row in another context such as SfB or similar.

The reporting feature is based around the idea of a clear separation of data and presentation as it is known in HTML and CSS. It has been important to limit the intertwining of presentation data, and data needed for the presentation, so where presentation data is necessary in the project file, it has been moved to separate elements. Table 2 shows the elements that both the XML file and the internal software model shares.

Table 2: Description of the system elements

Elements	***Description***
accountplans	*Account plans are structured in main-groups, sub-groups and rows.*
basevalues	*Each row comes with the possibility to store key values obtained from real life use, used as a common starting point of the calculation.*
costdatabreakdown	*This element holds the account plans.*
inputvalues	*The input-values store the specific user data. There is one set of input-values per row per version.*
periods	*The general prerequisites are stored inside periods, the main one being "period-of-analysis". Future periods can exist next to the main "period-of-analysis".*
project	*A collection of the elements below.*
projectcollection	*A collection of projects. Typically describing the same building(s) in different development stages.*
projectcollectioninformation	*Metadata and comments, some of which are output to the report.*
projectinformation	*Metadata and comments, some of which are used in the report function.*
results	*Results are stored inside their relevant parent element.*
resultgroups	*A list of and labels for the common way calculations are posted.*
viewdefinitions	*A list of selectable views including their names and accompanying texts. The views are the parts that make up the PDF report.*
versions	*Calculation and value sets. The names and description of alternatives are listed here.*
versionresults	*The common calculation results are stored here. Because the results at this level are standardised into specific result groups, it is possible to compare results from projects structured differently structured.*

The calculation flow starts at the account plan <row> level and follows a bubble-up method:

1. Resolve the origin of values, and pick the correct set for the row + version calculation. Different account plans will have different value sets. As an example an "acquisition" account plan, will only have a "unit-price" value, while a "maintain-renew-and-restore" plan will have the values "amount", "unit-price", "lifetime", "maintenance" and "restore" values to calculate from. It is at this level that prerequisites and inflation rates are applied.
2. Calculate the acquisition cost (if relevant), and the indexed values, throughout the calculation period. Repeat this for each selected version.
3. While there are differences on the row level, results can now be treated uniformly from here on up. Sub-group results are simply sums of the underlying rows, main-group results sum up the sub-groups, and on the account plan level, main-groups are summed up as the top level of results of the plans.
4. The account plan results are then summed up and posted in the categories as described in the result groups.

Although the application has at the outset adopted the SfB classification scheme, the application is fully open to other classification schemes. Rather than waiting for a national committee to form consensus on a new national classification scheme for building parts, a choice was made to store data in an editable structure that can be customized at run time by the user. Consequently, the data files has been flagged in order to mark elements as 'locked', and the GUI edit features are turned off accordingly.

6. Conclusion

The principles of lifecycle costing or whole-life costing has been around for decades, but the implementation of the principles has been modest or even weak despite the obvious advantages of integrating maintenance, operation and management aspect into the design of new buildings and facilities. Based on the methodology of structured analysis and agile software development methodology, this paper reviewed existing tools and discussed (some of) the design choices and summarised lessons learned from the development of LCCbyg – a new tool for lifecycle costing launched in its first version by the Danish government in early 2015.

First, this paper provided a typology of existing tools into three categories with distinct characteristics and associated benefits and drawbacks: 1) Spreadsheets, 2) stand-alone applications, and 3) web services. A fourth type – apps for mobile platforms – is not yet relevant as a calculation tool.

Second, while the software interface only displays limited unique features and functionalities compared to other available tools, the data model inherent in the tool provides a number of unique design choices. These design choices make the tool highly robust to future development; incorporate a fully open standard in XML format for easy exchange with other applications; provide the users with a high degree of adaptability to their specific requirements; and reduce the need for an elaborate classification scheme for cost and building components that would otherwise severely restrict the adaptability of the tool.

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Business Model Innovations for Low or Zero Carbon Building: An Analysis of Empirical Research from 1996 to 2015

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Abstract

The low or zero carbon building (LZCB) approach has been promoted in many countries, however, the claimed environmental, social and economic benefits from utilizing this approach are often impaired or unrealized. Traditional organizational business models face challenges in the delivery of LZCBs, and require re-thinking in order to create and sustain competitiveness and economic value. However, there is a deficiency of previous research into the commercial viability of LZCB from the perspective of business model. The aim of this paper is thus to develop a conceptual model of business model innovation for LZCB, and to identify archetypes of business model innovations for LZCB and their general development trend over the study period. The research was carried out through a meta-analysis of the literature of business model and LZCB. Evidence was collected and examined from 98 empirical studies of business strategies and processes for LZCB and industrial or corporate reports on LZCB published during the period 1996 - 2015. Through analysing the collected qualitative data using Nvivo 10 and HistCite^{TM}, the paper develops a conceptual framework of business model innovation for LZCB, which compasses three core components: value proposition, value delivery and creation, and value capture. Business model innovations are explored from these three core components respectively to describe common patterns and mechanisms of business model innovations for LZCB. The evolution of business model is tracked based on the qualitative analysis of LZCB projects of industry players over a twenty-year period (1996-2015). The results show that organizations generally adopt three interrelated innovative approaches to promoting LZCB, namely, reconfiguration of value proposition for customers, reconstruction of delivery mode and stakeholder network, and innovation of revenue generation logic. The archetypes of business model innovation and business model evolution path support the successful delivery of LZCBs. The findings contribute to a systematic understanding of the relationships between business model and LZCB.

Keywords: Business Model, Low Carbon Building, Zero Carbon Building, Innovation, Data Mining

1. Introduction

The term ‘business model’ has gained substantial attention in literature and industry since the emergence of e-business and the so-called new economy boomed. Recent management and business literature has widely used this term as an effective management tool for companies’ value creation and company performance (Osterwalder, Pigneur et al. 2005, Bocken, Short et al. 2014). Broadly speaking, two types of uses of this concept are identified. On the one hand, the concept articulates a series of activities between different ‘building blocks’ to produce a proposition that can generate value for customers. Business model is closely related to a company’s competitive advantage and expresses the business logic of a specific company through designing business products, services and activities (Rasmussen 2007, APEC 2009). One the other hand, the business model construct has been utilized in the facilitation of technologies or innovations (e.g. Chesbrough and Rosenbloom 2002, Zott, Amit et al. 2010). An appropriate business model can increase the market attractiveness of a technology and transform certain attributes of innovation into sources of the economic value creation (Bohnsack, Pinkse et al. 2014). In this view, “progressive refinements” to business model (Demil and Lecocq 2010) i.e. business model innovations are required to adapt to the external environment and/or to create a competitive advantage.

The construction industry, nevertheless, is a sector where the concept of business model seems to be far underdeveloped. Discussions of business model in the construction industry are mostly embedded in the literature of competitive advantage, strategic management, and innovation. The building industry holds the promise to reduce carbon emissions and improve energy efficiency due to the enormous energy consumption the industry accounts for. According to IEA (2014), building blocks consume 32% of the total energy use worldwide. The carbon emissions of buildings are predicted to reach 42.4 billion tonnes in 2035 due to the continuous increase of buildings and the growing expectation of building services by occupants (USEIA 2014). A wide range of technological innovations, such as energy efficient technologies, renewable technologies, and microgeneration technologies, can be potentially used as a part of the solution for achieving low or zero carbon targets. Despite the conceptualisation of technical rationality, low or zero carbon buildings (LZCBs) still face challenges in penetrating mainstream building markets. The problems faced by business practitioners include that LZCBs challenge prevailing construction practices (Johnson and Suskewicz 2009), the lack of customer preferences and market attractiveness (ZCH 2010), and the requirement for new knowledge, experience and managerial expertise associated with LZCB (Pless, Scheib et al. 2014). It has been argued that, firms need different business models to address these problems and come up with new sources to generate economic value in addition to their contribution to environmental sustainability (Chesbrough 2007). However, the emerging ‘LZCB sector’ is still in search of viable business models. Various business models are being simultaneously experimented, trial-and-error learned within and across early adopters (Sosna, Trevinyo-Rodríguez et al. 2010, Teece 2010).

Compared to the widely reported benefits and up-take barriers of LZCBs, there is quite limited understanding of the building companies’ business models for the uptake of LZCBs. Firms’ processes of business model innovation and evolution is still vague. This paper thus aims to address these knowledge gaps by exploring the general development trend of literature in the fields of business model and innovation, the conceptual framework of business model innovation and its main constituents, main archetypes of business model innovation for LZCBs, and the evolution roadmap of business model evolution for LZCBs. The paper develops a structured approach to extracting and creating value from LZCBs by innovative business models. The research on which this paper reports was carried out through a meta-analysis of scholarly publications and LZCB project reports of key industry actors in the field of business model.

2. Methodology

This section describes the methodological approach which systematically locates and analyses the research related to business model in the field of LZCBs, from both academic journal publications and reports and magazines of industry and key project players. As shown in Figure 1, the research on business model not only explored and identified research thematic objects with classical approach, but also processed and structured the thematic objects and bibliographic data with text mining techniques. The two approaches are interrelated and mutually enforced with continuous feedback loops.

At Stage One, four criteria were applied in the literature survey to determine the research scope and time framework. To retrieve the bibliographic data, first, the term ‘business model’ is included in the title of the paper. In view of massive articles on the subject of business strategy and business management, the search eliminates papers that only make an incidental references to business model. Second, to ensure the quality of the data, scholarly peer reviewed articles were retrieved from the Web of knowledge database, while proceedings, book reviews, commentaries, reports, and working papers were excluded. Third, since the research focus is LZCBs, the research areas were limited to “business economics”, “engineering”, “operations research management science”, “energy fuels”, “environmental sciences ecology” and “construction building technology”. The journals that have no concern on the construction sector were eliminated from the search results. Fourth, since the nature of the research is primarily empirical, the paper searched for and extracted business cases for LZCB projects, covering trade magazines and corporate/project reports, which provides detailed descriptions of LZCB projects and associated business models, and offers insights into perceptions and business strategies towards LZCBs. The search period starts from year 1996 when the number of LZCBs increased at a clear growth rate (see Pan and Ning 2014).

To conduct meta-analysis of the data retrieved at Stage 1, a two-phase approach was applied in the following 3 stages. At the first phase (Stage 1 and 2), the bibliographic data from Web of Knowledge was analysed with HistCite^{TM} software to give an overview of the research field over the study period. The abstracts and author keywords were further analysed to extract the most frequent terms and phases. The results indicate the main themes and components of business model innovation, which provide a comprehensive basis for the development of the conceptual model of business model innovation.

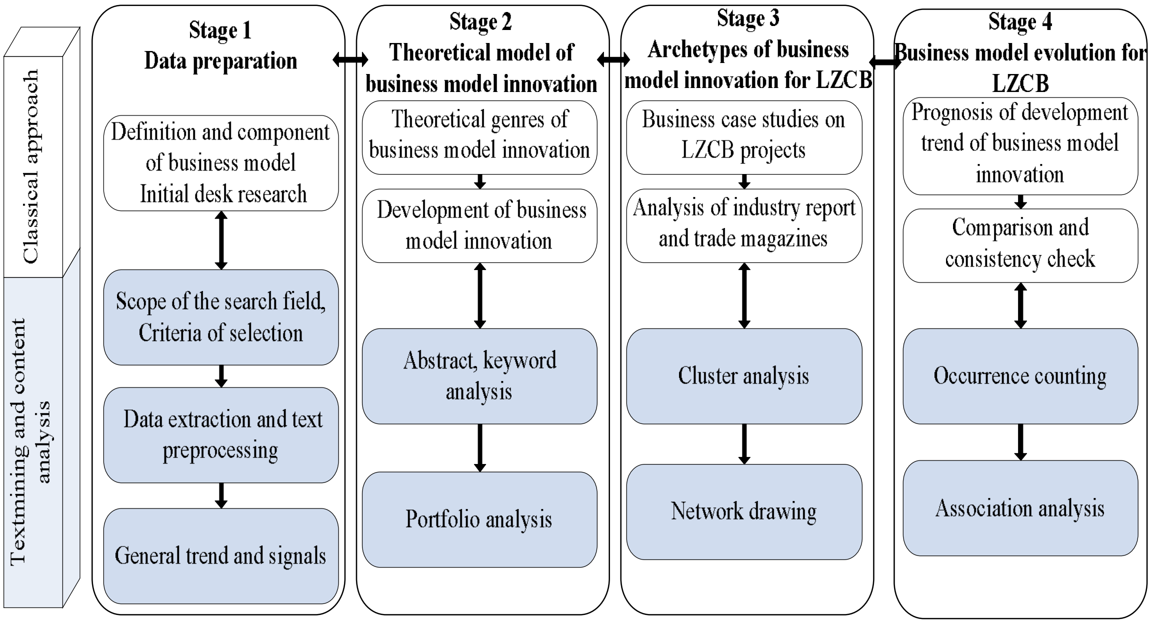

Figure 1. A meta-analysis-based process model adopted in the paper

At the second phase (Stage 3 and 4), qualitative data analysis software Nvivo 10 was used to organize and analyze data of empirical studies from academic articles and trade periodical/reports. First, the information that connects to the main components of business model innovation was labelled and structured according to the conceptual model. The objective of this step is to derive the archetypes of business model innovation in the context of LZCBs. Second, the occurrence number of business model innovations at the core themes of business model innovation will be counted and statistical analysed to give an overview of the development trend of the identified archetypes of business model innovations. Business models of large firms and small and medium enterprises (SMEs) that have delivered LZCBs were traced over the timeline in order to generate the roadmap of business model evolution regarding LZCB development. The contingent events were also identified, the effects of which were examined by exploring the explanatory power of the events on the LZCB market evolution in chronological order.

3. Findings

The main findings of the study are presented in this section, which are centered on the general trend of business model, the conceptual model of business model innovation based on the dominant themes emerged from bibliometric analysis, and the archetypes of business model innovation for LZCB and their evolution.

3.1 Profile of research on business model and LZCB

Before exploring the theoretical framework and archetypes of business model innovation for LZCBs, the paper detects the origins and particularly the surge of the business model documents. The paper searched the titles of scholar articles in the Web of Knowledge database for the word string "business model". The number of the search results is shown in Figure 2.

According to the search criteria and screening process, the search results include 483 articles published in 299 journals in the field of business model in total from 1996 to 2015. The query suggests that the term "business model" rose to prominence until the middle of 1990s in the construction sector, though it appeared in an academic article in 1957 (Bellman, Clark et al. 1957). A general growth trend can be observed in the publications on the topic of business model.

In the field of LZCB, the paper identified 639 papers that featured "low OR zero carbon OR carbon neutral* OR sustainab*" and "building OR home OR hous* OR project" in their titles. There is a significant trend of growth of the number of academic articles during year 1986 and 2005. Most of the articles that reported the environmental aspect only focused on the element of carbon emissions or energy consumption. The contribution of LZCBs on the environmental aspect was consistently the main theme of the majority of the articles.

In the field of intersections between business model and LZCB, however, a limited number of articles can be obtained from the database. After the screening process, a total of 98 articles were retrieved from the database, which were validated to be concerned with the business models of LZCB. The results of this step illuminate the knowledge gap on business model for LZCB, and generate the first inputs for generating a conceptual framework of business model innovation.

3.2 A conceptual framework of business model innovation

The components and process of business model innovation have been emphasized and widely studied in the recent decade. In the business and management discipline, the literature in this stream examines the innovations of business model from two perspectives: activity-based approach and value chain-based approach. The activity-based approach characterizes the innovations of business model as a system of interdependent activities reacting to environmental changes. Afuah (2004) described a business model as the set of activities a firm performs, the way the company performs them and complemented assets supported these activities. Zott and Amit (2010) defined the term 'business model' as an activity system supported by the focal firm and its partners. Artto, Wikström et al. (2008) analyzed business models of project-based firms, and identified the impacts of services on business model innovation from the project delivery process.

The other stream of research conceptualises business model innovation as a flow of value chain. Osterwalder and Pigneur (2010) described a business model as "the rationale of how an organization creates, delivers, and captures value". Lenssen, Bocken et al. (2013) developed a value mapping tool for sustainable business model, and examined the business model innovation by mapping the value captured, missed, destroyed and opportunities of sustainability. Demil and Lecocq (2010) developed a RCOV framework of business model (resources & components, value proposition, organization) and viewed business model evolution as fine-tuning process involving changes both within and between its main components.

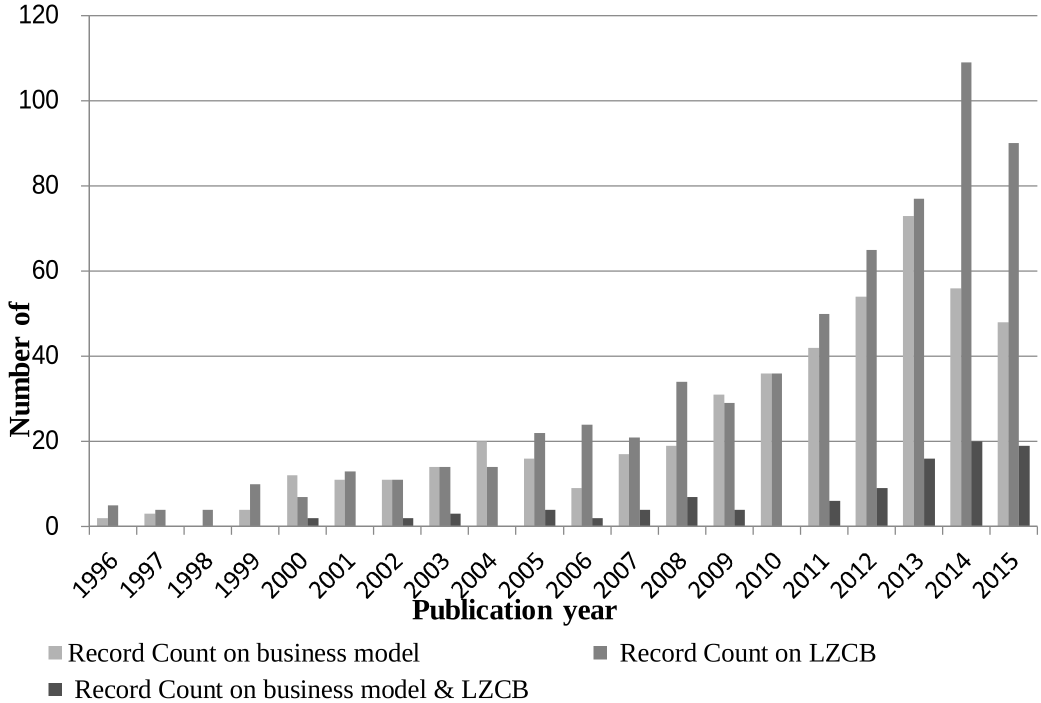

Figure 2. Recent development of research in the field of business model and LZCB over the timeline

While the two dominants logics of business model innovation have been established in the management discipline, the novel part of this section is to verify the theoretical assumption in the field of LZCBs through text mining of abstract phases and keywords in the bibliographic data derived at Step 1, and to identify recent themes/components of business model innovation for LZCBs. Figure 3 shows a word cloud map and a frequency table of the top 50 terms.

Figure 3 and Table 1 show the key areas of business research on LZCBs. Topic related words (sustainable, building, business, model, innovation, project, green, etc.) and stopwords (using, based, provide, study, paper) were removed since they are general and display no content.

Figure 3. Word clouds of top frequent terms from 1996 to 2015

Table 1. *Frequency table of top 32 terms in abstracts and keywords*

Terms	*Frequency*	*Terms*	*Frequency*	*Terms*	*Frequency*
develops	*194*	*production*	*61*	*operation*	*49*
design	*115*	*service*	*59*	*household*	*49*
environmentally	*93*	*cost*	*56*	*urban*	*49*
managing	*71*	*systems*	*55*	*construction*	*48*
industry	*66*	*economic*	*55*	*city*	*47*
value	*64*	*social*	*54*	*markets*	*45*
technology	*62*	*efficiency*	*53*	*environments*	*44*
policy	*62*	*governments*	*53*	*organizations*	*44*
pricing	*62*	*process*	*52*	*engineering*	*39*
performance	*57*	*plans*	*49*		

The terms "household", "market", "value", "performance", "service", and "environmental" closely relate to products/ services that are provided to the customer/occupants sector, i.e. 'value proposition'. Terms such as "plans", "develop", "design", "manage", "construction", "organization", "engineering", and "process" describe the delivery process of LZCB projects, and organizations and stakeholders that are involved in the value delivery process. This category of terms can be attributed to "value delivery and creation". 'Value capture' is another element that was emphasized in Table 1. "Pricing", "cost", "economic", "urban", "government", and "market" portray the structure of cost and revenue, which include building scales, pricing and financing strategies, government incentives, and any additional incomes. Combining the analytical results above, the paper structured the conceptual model of business model innovation for LZCB as three interrelated components: value proposition, value delivery and creation, and value capture, as shown in Figure 4.

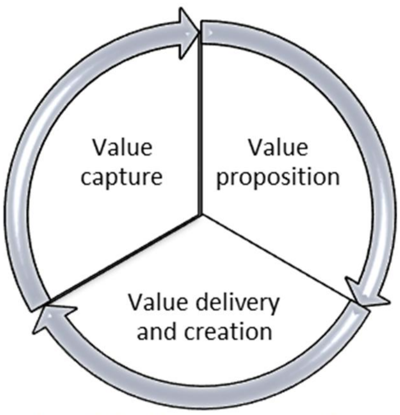

Figure 4. Conceptual model of business model innovation for LZCB

3.3 Business model innovations for LZCB: archetypes and evolution

Firms' experiences and related complemented resources and networks in empirical studies were examined in this section. Based on the developed conceptual model mentioned above, archetypes of business model innovations have been identified from the three main components respectively. The archetypes in the category of 'value proposition' (LZCBs and related services provided to target customers) can be distinguished from variations in building types/purposes, scales and contents of product/service. For the 'value delivery and creation', this paper tracked changes in the modes of LZCB development and delivery, and associated stakeholder networks. The activities in the value creation process depend upon the range of value proposition, may cover the land acquisition, design, preconstruction, construction, operation, demolishment and recycling phases. With regard to the 'value capture', this paper explores how LZCBs were brought to the market, how firms compensate cost from the revenues schemes, and whether there were financing reimbursements and government incentives supporting LZCBs. The archetypes in the three categories are summarized in Figure 5.

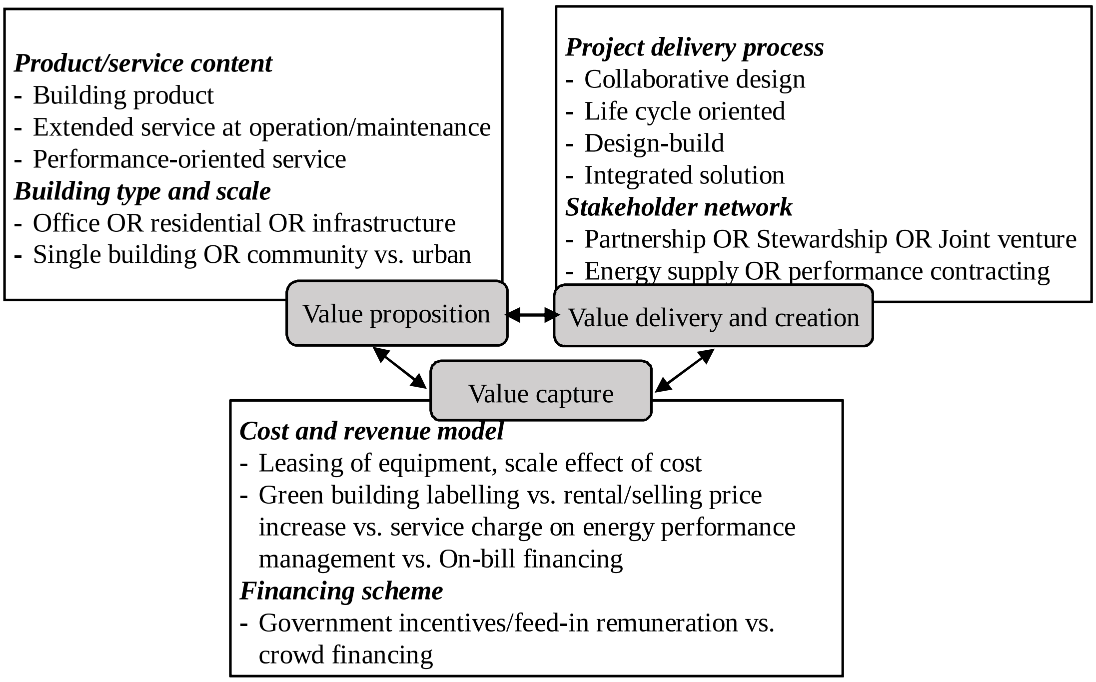

Figure 5. Main archetypes of business model innovation for LZCB

Value proposed to building owners and occupants locates at the centre of a business model structure. Evidence from studies proved a range of -0.4%-12.5% higher building cost for LZCB compared to conventional code-compliant buildings (WGBC, 2013). To prove the LZCB assets value to customer and improve customer acceptance is therefore the foremost issue for developers. Depends on the building type and purpose, higher sale prices/lease rates, lower life cycle cost, and improved indoor air quality and resulted improved productivity have been demonstrated in various resources. In addition, supported by product service system theory, companies have extended their value proposition from building itself to a combination of building products and services in operation and maintenance stage. In this way, developers have shifted customers' focus from building ownership to use-based functionality. Measured by the building scale addressed, the majority (63%; 75) of the identified articles targeted their research object to a single building, and some (17 and 21 respectively) examined community scale LZCB and urban scale LZCB. The identified research by building type was mainly contributed by the articles examining residential buildings (38%; 45) and the commercial buildings (35%; 41), with marginal contribution from those studying multipurpose buildings (7%; 9). Among the studies addressing the product or service provided to end-users, aside from the vast majority of research addressing LZCB itself, one half (50%; 59) examined the extended service provided to customers in a building's life cycle process. This result reveals the significance of customer-oriented service after commission, which is consistent with the emphasis of the group of articles regarding users' concerns on building performance (47%; 56).

To successfully deliver LZCBs in the value creation process, companies should make full use of available resources and capabilities within project delivery processes and stakeholder networks. Key strategies in the delivery process identified from the dataset include: collaborative design, integrated solution, proactive contracting, value recycle from 'waste', and design-build mode etc. Since most building stakeholders' knowledge on LZCB is minimal at current stage. To design functionally low or zero carbon, the collaborative inputs of all specialists are proved to be successful in multiple projects. Opinions are sought from clients, designers, architects, community and end-users to optimize design solution for best performance. In addition, proactive contracting such as design-build mode has been adopted in LZCBs project to maximize contractors' inputs and improve the project time performance. Correspondingly, firm actively expand its stakeholder network through partnership, stewardship and Joint Venture. To proactively engage with stakeholders and keep a stable long-term relationship, companies have managed to improve the cost efficiency, and maximised its positive societal and environmental impacts.

By project delivery process, the largest group of the business model articles for LZCB focused on the examination of design stage (52%; 61), followed by the group mentioning the construction stage (38%; 45), and operation and maintenance stage (24%; 61), while very few examined business models of LZCB from the supply chain and project planning stage. The collaborative design and integrated solution are emphasized in the articles examining design stage and delivery mode, the number of which reach about two fifth (52) of articles. Moreover, the life cycle oriented solution is another salient point in the literature, almost one third of the articles were concerned with the lifecycle impact of LZCB and life cycle oriented design.

Innovative financing and revenue schemes help create LZCB case if these innovations help to overcome the relatively higher upfront cost. Aside from loans and government incentives for low or zero carbon, new schemes have been employed, such as equipment leasing, crowd financing, pay-per-use, ESCO model, and green building benchmarking. Over one third (44; 37%) of the articles addressed the governments' role in the delivery of LZCB, which includes government incentives, feed-in tariff schemes, and remuneration. While a relatively small number of articles have reported the use of utility manager (17) (such as ESCO) in the operation stage and the green building labelling (11) as innovative revenue models.

From qualitative analysis of LZCB practices of key industry players over the timeline, firms generally take their existing business model for conventional building projects as a starting point to incremental adjust and refine, in order to bring LZCBs in their business domains. Due to variations of firms' scales, history backgrounds and complemented assets, firms have different abilities to tap into LZCB business and react to change initiatives at external environment. Incumbents and entrepreneurial firms adopt different. Relying on the economies of scale and well-developed partnership network, large established firms have ability to experiment LZCB projects with multiple business models simultaneously, fine-tune and select the standard business model for LZCB in future. The future target of these firms is to achieve production scales with LZCB and optimize cost efficiency.

Compared to large incumbents, small and medium-sized enterprises (SMEs) in the building sector are less constrained by their dominant business model. The novelty is their main value proposition for customers. However, due to the relatively vulnerable customer base and assets, they are more susceptible to external incentives and contingent events. Generally, SMEs are most likely to test a single business model at one time. In the value delivery process, SMEs are more agile to cooperate with outside partners, and make use of their expertise and knowledge. For the value generation logic, SMEs have to explore innovative ways to fund the projects. Aside from loans and capital investment, green building certification, on-bill financing, and government incentives such as feed-in remuneration schemes and have been applied in the financing and revenue strategies.

4. Conclusions

This paper has examined the literature of LZCB and business model and industrial practices of LZCB during the period 1996-2015 through a structured meta-analysis. One conclusion of this paper is that a significant knowledge gap has been identified between the fields of business model and of LZCB with regard to their general development. This knowledge gap is evidenced by the remarkable difference in the quantity of relevant publications. Although there has been a general growing research interest in both the fields of business model and LZCB separately, research that integrates the two is limited. Another conclusion of the paper is that from the analysis of the key terms used in abstracts and keywords, three thematic focuses have emerged, i.e. value proposition, value delivery process, and value capture. These themes together form a conceptual framework of business model innovation for LZCB. A further conclusion of the paper is that through the analysis of the detailed contents and empirical data, archetypes of business model innovation have been explored from the three emerged core components. Two different paths that large firms and SMEs have adopted to evolve their business models for LZCB have then been identified over the timeline.

The findings of this paper illuminate effective mechanisms that firms can adopt to promote LZCB and help detect the future trend of LZCB development. Future research should explore the interdisciplinary field of business model innovation for LZCB, which has been identified as a knowledge gap. It should help to track the trajectory of business model innovations and examine their relevant impact on the delivery of LZCBs.

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BIM Product Libraries for Life Cycle Support

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Abstract

Building information modelling (BIM) is believed to improve the information management flow through the whole life cycle of the building. In current practice, benefits of BIM are generally used at the design and construction phases. Despite the progress of BIM technologies and practices, product data management (PDM) is neither well known nor common in the industry. There is a need for product libraries that are software neutral including standardised data content and structure, in order to provide consistent and unbroken flows of information through the whole life-cycle of buildings. Examples from other industries (e.g. mechanical engineering) could encourage the development of product libraries. The product libraries that exist today for construction projects are primarily software specific and directed to various user groups and cause interoperability issues when used over time and between actors. Enhanced and standardised libraries would potentially increase sustainability in the construction. This paper presents the current state of BIM product libraries for the construction industry (in BIM mature countries) in the context of information format (proprietary or open), content (generic or manufacturer specific), structure (level of granularity for geometry and information), provider (software vendor, commercial, or in-house), and usage (project phase, contract type). Finally a proposed framework with through life support is presented based on existing open international standards, life cycle phases and the high level building classification framework standard ISO 12006-2.

Keywords: BIM, Product Library, Level of Detail, Level of Information, Life cycle support

1. Introduction

There is a growing interest in developing product libraries internationally. The actors are national bodies, manufacturers and specialist companies who see a potential in the market, but do not address the issue of production and distribution of product information for the emerging open BIM software systems. The main developments of library objects, called BIM objects in this paper, are addressing proprietary formats supporting only one or few software systems. This increases the cost of populating product libraries as multiple formats must be supported and also increases the difficulties maintaining them over different platforms and over time (Duddy et al., 2013). Different contract types use generic and manufacturer specific BIM objects differently over the life cycle of the construction projects – and possibly also during operation and maintenance, see Figure 1, which illustrates when generic and manufacturer objects are generally used in different delivery methods during the project life cycle (Vahenurm, 2014).

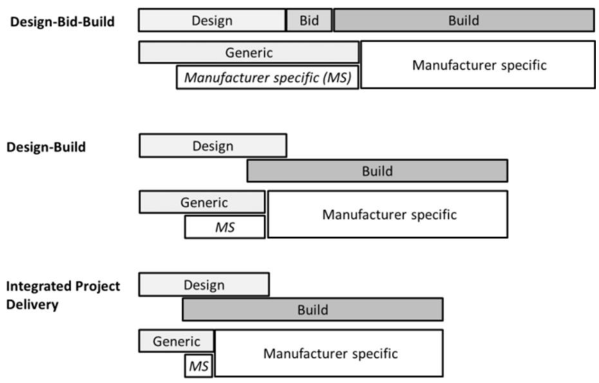

Figure 1: Project delivery types and use of Generic and Manufacturer specific BIM objects (Vahenurm, 2014)

There are several different types of product libraries with BIM objects available and suitable for different phases of the construction projects, depending on the level of specialisation of geometry and information linked to the objects in the library. Some typical examples are:

· CAD/BIM libraries	coming with the design software – generic BIM objects
· Product type libraries	compiled by different associations – standard components in industry segments, e.g. ducts
· Manufacturer's libraries	manufacturer specific products
· Project libraries	project specific, selected for the project
· Company libraries	in-house preferred, selected from old projects

These libraries have very different structures, content and formats and they have also limited support for different levels of detail and information. There is lack of open BIM product information in well-structured and rich information content libraries supporting the whole life cycle of products and buildings.

1.1 Background

Several studies have been carried out regarding product libraries with the focus on accessibility to product information from manufacturers and beneficial ways of interacting with product information (Amor et al., 2004). One of the criterions for comparison of content in the different libraries is the level of definition (LOD) as defined by the American Institute of Architects. For building products, this can be summarised as LOD 200 indicating the approximate size and position of a product or construction type through increasing levels of detail to LOD 400, which is a fully detailed definition of the product/construction type to be installed. LOD 500 is reserved for a verified on-site installation. (Duddy, et al., 2013). The problem is that there are very different interpretations and definitions for these concepts, as well as how and when to use them during the construction process. Amor et al. (2004) state that the following issues are remaining barriers to the uptake and development of online product libraries: ***Products' data representation, Extraction of data from manufacturers, Business models for online catalogues, Contextual impact of project requirements, Mapping between representations, Support for preferences, Life-cycle support.*** Until these barriers are overcome we can expect our access to powerful online identification and incorporation of manufactured product information to be severely constrained (Amor et al., 2004).

1.2 Purpose and Method

This study is focusing on presenting the current state of BIM product libraries supporting the construction industry and the barriers for a wider uptake. The context is information format (proprietary or open), content (generic or manufacturer specific), structure (level of granularity for geometry and information), provider (software vendor, commercial, or in-house), and usage (project phase, contract type).

The research question is: How can a framework for through life support of BIM objects, based on existing open international standards, life cycle phases and a high level building classification framework standard, be a solution to overcome barriers to the uptake and development of online product libraries?

Method: The study was carried out as a review of literature in journals and conferences on BIM product libraries. Also implementations of BIM product libraries in Europe and Australia were reviewed and analysed, as being in the forefront. Planning, implementation and operation of product libraries were in focus. The study started in June 2014. The findings were used as requirements for an object model framework for through life support of BIM objects. They were compared with the life-cycle support for open BIM at the BIM Collaboration platform and experiments carried out at KTH, Royal Institute of Technology (Tarandi, 2015).

2. Definition of used concepts

Product library – "a storage were information about products can be found and accessed." (Stangeland, 2013). As no formal definition exists, this can be a starting point. The content of a Product Library should be products corresponding to BIM objects in the BIM models used in the construction processes. The products have geometry, which can be parametric, and they can have properties with units and values. The classification of objects and properties is vital, and is preferably defined by a dictionary, like buildingSMART data dictionary (bSI, 2015). Today no common guidelines or open standards for BIM object libraries are implemented and used (Palos et al., 2014).

BIM objects - The product objects in a BIM, Building Information Model, are also called BIM objects and they have a geometric representation of physical products and can be high-level assemblies at various levels of detail, including specific products (Eastman, et al., 2011). The granularity of the BIM objects should be matched with the International framework for Construction classification ISO 12006-2:2014 (2014) to fit industry practice for bill of quantities and construction planning.

3. Development of product libraries

Paper catalogues including descriptions, parameters and illustrations were substituted with electronic online product libraries (Amor, Jain & Augenbroe, 2004) when information technology solutions improved. Today, several providers have started to offer online BIM orientated product libraries which include BIM objects with different levels of geometry and information. Some examples are NBS National BIM Library, BIMcomponents, BIMobject, and SmartBIM. More BIM libraries are presented in Table 2. The product libraries that exist today are primarily software specific and directed to various user groups (Palos et al., 2014 p. 59).

There are several ways how to categorise Product Libraries. Succar (2009) states that interchange can occur in three main ways; proprietary (e.g. Revit file – RVT), open-proprietary (e.g. DWF and many XML schemas), and non-proprietary which is open (e.g. IFC and CIS/2). This paper categorises Product Libraries by the following:

1. **Content** – Products (objects) can be (Stangeland, 2013):
   a. Generic
   b. Manufacturer specific
2. **Content's format**
   a. Libraries containing PDF sheets and/or 2D drawings in e.g. PDF, DWG formats
   b. Proprietary Product Libraries – 2D & 3D CAD and BIM software specific formats like DWG, RVT etc. Here also the open – proprietary formats ca be included
   c. Non-proprietary Open Standard Product Libraries – e.g. IFC, bSDD formats
   d. Multiplatform Product Libraries – Proprietary and open formats mixed
3. **Provider**
   a. Software vendors
   b. Associations (e.g. ventilation product manufacturers)
   c. Commercial providers – manufacturers, suppliers, wholesalers
   d. Private AEC companies – have created in-house Product Libraries

The Manufacturer specific products can be designed and produced in alternative ways, and this influence when they have to be ordered and when they can be delivered to the construction site. MTO (made-to-order) components are usually produced as needed due to the short shelf-life and high inventory costs. ETO (engineered-to-order) elements involve more specific design, while the suppliers of MTS (made-to-stock) and MTO components are rarely involved in installation phase as the components are designed for general use. Generally the elements available on BIM platforms are generic and do not describe specific manufacturer's components and do not include product specific information. Product type from a manufacturing and supply chain point of view is also influencing the accessibility of the product information. They are ETO, followed by MTO, and then ATO (assembled-to-order), finally MTS products, as shown in Table 1

(Zeng et al., 2015). It is based on CODP (Customer Order Decoupling Point) classification thinking.

Table 1: Types of product, according to CODP, after Zeng et al. (2015)

CODP	Product Example	Lead Time	Stock
ETO	Power distribution equipment, Preassembled rebar components	long	no
MTO	cast-in-place concrete, prefabricated panels	long/short	no
ATO	doors, windows	short	yes
MTS	consumables such as bricks, bolts	short	yes

Several countries, including UK and Australia, have set requirements or recommended to adopt BIM in the public projects. This has initiated another form of product libraries supported by national institutions. One example of Open standard libraries is IFC Product Libraries that are supported by product information from templates and bSDD (Stangeland, 2013). Table 2 below is an overview of proprietary and multiplatform Product Libraries. Work by Eastman et al. (2011) has been updated.

Table 2: Overview of Proprietary and Multiplatform Product Libraries

	Modelling environment	Format of content	Portal	Links
Proprietary Product Libraries	Graphisoft ArchiCad	ArchiCad	BIMcomponents	https://bimcomponents.com/
	Autodesk Revit	Revit, AutoCad	Autodesk Seek	http://seek.autodesk.com/
			Arcat	http://www.arcat.com/
			RevitCity	http://www.revitcity.com/
			SmartBIM	http://library.smartbim.com/
			MagiCAD	https://portal.magicad.com/
	Nemetschek Vectorworks	Vectorworks	Vectorworks	http://www.vectorworks.net/
	Bentley Systems	Bentley/ AECOsim	MicroStation	http://www.bentley.com/en-US/Products/microstation+product+line/
	Tekla Structures	Tekla	Tekla Warehouse	https://warehouse.tekla.com
Multiplatform Product Libraries		AECOsim, ArchiCad, IFC, Revit, Tekla, Vectorworks	NBS National BIM Library (UK)	http://www.nationalbimlibrary.com/
		ArchiCad, IFC,Revit, SketchUp, etc	BIMobject	http://bimobject.com/

4. Standards

Standardisation is especially important for product libraries, as there often is a change of actors when going from design to supplier specific products in the BIM (Berlo et al., 2015). Palos et al., (2014) state that there is a great need for a product library standard in the construction industry. The purpose of the standard is to determine what products should be contained in the libraries, what properties are required and how libraries are supported by different classification systems (Palos, et al., 2014). Also Nummelin et al. (2011) state that enhanced and standardised libraries would potentially increase sustainability in the construction industry. Three important standards/groups of standards for BIM product libraries are described in the following paragraphs.

4.1 ISO 12006-2

Internationally, the ISO 12006-2:2014 (ISO, 2014) standard is a framework for classification for organising the information about construction works. It defines the granularity of building elements, work results and products to fit the manufacturers' products and their classifications.

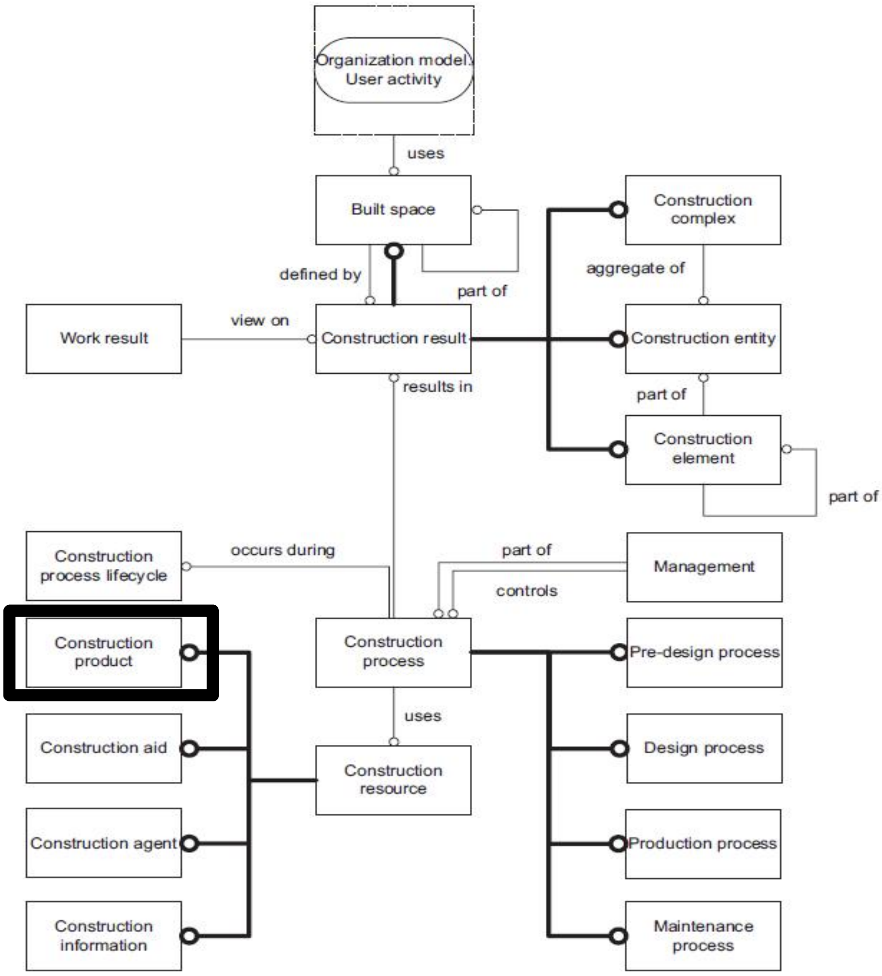

Figure 2: ISO 12006-2:2014 (ISO, 2014) Construction product in relation to Construction resource

The standard is for “Organisation of information about construction works and is implemented in many national classification systems” (ISO, 2014). The Construction product entity is a Construction resource with a relation to the Construction result, which can be a Construction complex (e.g. airport), entity (building) or element (window). In Figure 2 the Construction product is highlighted.

4.2 buildingSMART International open standards

buildingSMART International (bSI) is a worldwide standardisation organisation driving the transformation of the built environment through creation and adoption of open, international standards (bSI, 2015). IFC is a building product data model for building planning, design, construction and management (Eastman, et al., 2011). In addition to IFC and bSDD (IFD), buildingSMART has three other basic methodology standards, Information Delivery Manual (IDM), BIM Collaboration Format (BCF) and Model View Definitions (MVD).

ISO 12006-3:2007 (2007) “Building construction – Organisation of information about construction works – Part 3: Framework for object-oriented information” is known as buildingSMART Data Dictionary (bSDD) and describes the meaning of information that is exchanged.

4.3 PLCS, Product LifeCycle Support

The business objects in PLCS, ISO 10303-239 (ISO, 2012) cover the whole life cycle for products, with the goal to support the maintenance, influence the design, development and production for maintainability and finally influence the requirement improvements for the coming projects.

5. Levels of development, detail and information

While the concept of LOD is gaining popularity as more projects are required to be delivered in BIM, the definition of what LOD levels mean and how they should be used is getting more interest. Moreover, there are different meanings of LOD. This can stand for Level of Development and Level of Detail. One possible view is that Level of Development is better to represent the LOD as it can be thought as a combination of geometry (detail) and non-geometric content (information), while Level of Detail mainly represents the geometry. The need to properly define the concept of LOD is stated by Berlo et al. (2015). Today the industry participants are still asking for different LOD models and everyone has their own idea what the LOD model is. It is not clear what kind of information should be available in a model on a particular level.

“Level of Development is the degree to which the element’s geometry and attached information has been thought through – the degree to which project team members may rely on the information when using the model” (BIMForum, 2013). Berlo et al. (2015) described the Dutch National BIM Levels of Development and the 7 levels of development as having only limited adoption by the industry. In a new research (Berlo & Bomhof, 2014) the result show that the Levels of Development were used, but the names of the phases they represented could not be agreed upon. In the collaboration between multiple partners it should be required to know exactly what the model can be used for, what data in the model is definite, and what confidence level is appropriate for the model? Level of Development (LOD) is a measure how seriously the information presented by the BIM object can be taken (McPhee, 2013). It is not a measure of the amount or accuracy of graphical information, rather the level on trust of the data that can be assigned to a BIM model. It should be clear what information to have in the model to perform a specific task (Berlo et al., 2015).

Level of Detail is a measure of the amount of information provided (quantity). Level of Development cannot exist without Level of Detail. In reality the Level of Detail might be the highest at the beginning of the project while the Level of Development is the lowest. This is in the stage where the design is being sold to the client and the stake-holders. In documentation phase one usually wants to keep Level of Detail low while Level of Development is high (McPhee, 2013).

Level of Information: UK standard PAS 1192-2 (BSI, 2013) “Specification for information management for the capital/delivery phase of construction projects using building information modelling” (BSI, 2013) specifies the requirements for achieving building information modelling (BIM) Level 2, according to UK BIM implementation. PAS 1192-2 defines two components to the level of definition:

- Levels of model detail (LOD), which relates to the graphical content of models.
- Levels of model information (LOI), which relates to the non-graphical content of models.

In this definition the LOI (information) is developed in parallel with the LOD (detail).

6. Life-cycle model

From a life-cycle perspective it is important to have an unbroken information flow. The different phases of the life-cycle for a construction project and the construction itself need to be represented by several unique objects over time. The designed physical element, fulfilling requirements through its function, the product realising the technical solution and finally the product as realized with its serial number (not for all products). This is studied and realized in the BIM Collaboration Hub at KTH (Tarandi, 2011). This requires interoperability through open standards and effective product data management. The presented Plans of Work in Figure 3 are only to be seen as examples of the life cycle stages. Many development projects are ongoing in UK now, and several examples are taken from these like the “resolving of objects at different levels” by Gelder (2012). The following references have been used for the diagram in Figure 3: RIBA Plan of Work 2007 (RIBA, 2008), RIBA Plan of Work 2013 (RIBA, 2013), A report for the Government Construction Client Group (BIM Industry Working Group, 2011) for the Data

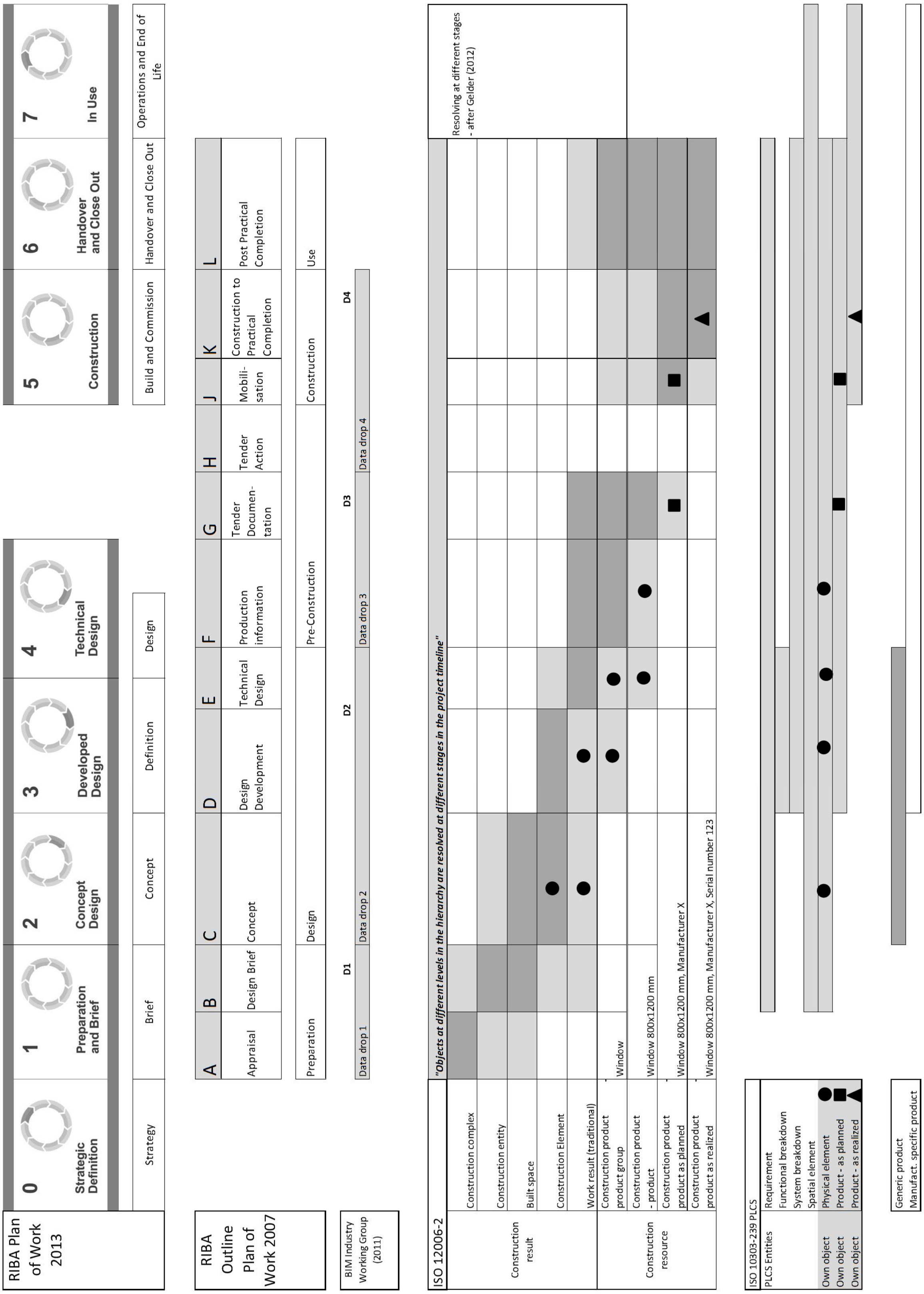

Figure 3: Life cycle framework based on through life support for BIM objects over all the project phases

drops, ISO12006-2 (ISO, 2014), and PLCS ISO 10303-239 (ISO, 2012) for the physical elements, products – as planned and products as realized.

The shaded fields are illustrating the plausible process phases where the different elements in the construction complex from the building (Construction entity) down to the Construction product – as realised - fit. Gelder (2012) explains it as "Objects at different levels in the hierarchy are resolved at different stages in the project timeline". Darker grey means more plausible than the lighter grey. At the bottom the PLCS entities, based on the studies of implementing them in the BIM Collaboration Hub (Tarandi, 2015), are outlined over time to present where BIM objects for different life cycle phases can be managed. The point in time when they – physical element, product and product as realized – are created and used vary depending on contract and project type.

7. Discussion

In the study, the state of and requirements on BIM product libraries for the construction industry gave the answer, there are many alternative developments without open formats being implemented in a consequent way. The granularity standard is fundamental for linking BIM objects from Product libraries to a life cycle supporting BIM model. Many different library types without common metrics for classification of products and properties. Most of the barriers presented by Amor et al. (2004) are still there. Some of them like ***Life-cycle support, Mapping between representations,*** and ***Products' data representation*** can be managed with the life-cycle framework presented in paragraph 6.

Level of Development – geometric and non-geometric information are equally important (Berlo & Bomhof, 2014), but no agreements have been made on international level on how to combine Level of Development and Level of Detail. The information content of the BIM objects which should capture information for different life-cycle phases matching Level of Development both with regards to geometry and properties supporting analysis, simulation and visualisation is not there. The following questions are still open:

- How is transition between different levels of development for BIM object realised?
- What information exists in current libraries?
- How is information delivered to the libraries?

Also these barriers can be eliminated by the life-cycle framework as all these states and definitions can find a place based on granularity, context and life-cycle phase in the framework. The physical element in the design, the product as planned and finally the product as realized on site.

8. Conclusions

The industry should have a clear understanding of what the model should be used for, what data in the model is definite and what confidence level it has in order to have more efficient collaboration between the industry actors. The Level of Development can be seen as the degree to which project team members may rely on the information when using the model. In Level of Development the geometry and non-geometric information are equally important. To make this operative in industry there is, still is, a need for continuing the work on coming to international agreements on how to structure these concepts and also very important – to link it to the life-cycle of the projects. The proposed framework with through life support based on existing open international standards, life cycle phases and the high level building classification framework standard ISO 12006-2 can be one way of managing the BIM objects over the projects, even before the issue of Levels of D has been resolved. The life cycle platform presented is capable to support the unbroken information flow over all the life-cycle phases!

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Promoting Design of Buildings with Low Carbon Footprint Using Environmental Product Declarations

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Abstract

Nowadays, there is an increasing demand for sustainability in construction industry. As significant efforts have been made on reducing operating energy, the share of embodied energy is increasing from the lifecycle perspective. In order to reduce carbon footprint caused by embodied energy, stakeholders should make more optimized material purchase schemes in the design stage. An environmental product declaration (EPD) provides environmental data of a particular product, thus it can serve as an effective tool to assist decision-makers in selecting environmentally friendly products. The aim of this paper is illustrating how EPDs can be used to assist stakeholders in designing buildings with low-carbon footprint. In addition, the concept of carbon footprint index (CFI) is introduced in this paper. CFI can be used as a threshold in a green building rating system for evaluating the cradle to gate embodied energy of a building. A two-story office building with concrete frame structure is used to illustrate the application of EPD in selection of concrete products. The results show that selection of concrete with low carbon footprint can reduce the CFI by 68%.

Keywords: carbon footprint, environmental product declaration, concrete, cradle to gate

1. Introduction

Construction industry is one of the largest consumers of natural materials. According to the Worldwatch Institute, buildings consume three billion tons of raw materials annually, accounting for 40% of the global consumption (Roodman and Lenssen, 1995). In the United States, the situation is even more severe, the Environmental Protection Agency (EPA) reported that the raw material consumption from construction activities contributes to 60% of the national demand (EPA, 2012). Meanwhile, the proportion of energy use in construction industry is higher than other sectors. According to the National Trust for Historic Preservation (NTHP), the energy used in buildings is about 41% of U.S. primary energy consumption, while the industrial and transportation sectors represent 30% and 29%, respectively (NTHP, 2012).

Echoed with the large resources and energy consumption, construction industry imposes serious impacts to the environment due to unwanted discharging, such as waste, greenhouse gas, etc. In the United States, it is estimated that the amount of waste generated from construction related activities reached 170 million metric tons in 2003, which is equal to 1.45 kilogram per capita per day (EPA, 2009). The large amount of construction waste may cause pollution to air, water, soil, and thus further affect human health (Wu et al., 2013). Greenhouse gas (GHG), which is also a main emission of building operations, is regarded as a significant cause of global warming (Buchanan and Honey, 1994). In 2002, the GHG emission from construction industry in the United States is estimated as 131 million tons CO_2 equivalents. Fuel consumption of on- and off-road construction equipment and electricity used for providing power are regarded as the two main emitters (EPA, 2008). From the above presented figures, it can be seen that construction industry is a significant consumer of resources and energy, and produces a substantial amount of wastes and carbon emissions. Thus, there is an urgent necessity to develop strategies to promote sustainability in construction industry by using less natural resources and energy while producing less waste and carbon footprint (Zhang et al., 2014).

In the lifecycle of a building, the consumed energy can be divided into three main categories according to its usage, namely embodied energy, operating energy, and building transportation energy (NTHP, 2012). Building transportation energy refers to the energy used to transport individuals or materials to and from a building, while operating energy is utilized to make building related facilities work. It has been investigated that operating energy is the most significant component among the three categories, accounting for 80-90% of the lifecycle consumption (Liu et al., 2012). So far, building designers have been focusing on the reduction of operating energy in the design stage. However, as technologies have improved energy efficiency of buildings, the proportion of operating energy is decreasing (Islam et al., 2014). As a result, the share of embodied energy is increasing and its reduction is gradually becoming an important aspect in decreasing building energy consumption. Embodied energy is defined as the energy that consumed to construct a building, involving the processes of extraction, processing, manufacture and delivery (Venkatarama Reddy and Jagadish, 2003). A stage that significantly affects the embodied energy of a building is design stage (Shrivastava and Chini, 2012). Therefore, in order to reduce greenhouse gas emissions caused by embodied energy, stakeholders should focus mainly on material selection in the design stage.

Environmental product declaration (EPD) can serve as a useful tool to assist the decision-makers in selecting environmentally friendly materials in the design stage. An EPD is a standardized, third-party verified document that communicates a product's environmental data, which obtained from lifecycle assessment, in accordance with the international standard ISO 14025 (Type III Environmental Declarations) (NRMCA, 2014b). By providing detailed information about the environmental impacts of a product, EPDs can give designers the information they need to minimize embodied carbon footprint of a building. EPD has been implied in other fields for reducing environmental impacts. For instance, Fet et al. (2009) has utilized EPD to provide stakeholders the environmental performance of furniture. However, the application of EPD for selecting environmentally friendly and economically efficient construction materials is not widespread.

The aim of this paper is to illustrate the application of EPD in reducing buildings' embodied carbon footprint at the design stage. A carbon footprint index (CFI) is introduced to facilitate the design determination. The focus in this study is concrete product selection because it is a main material in construction industry and its production process involves an intensive energy demand and CO2 emission. The rest of this paper is organized as follows. Section two gives a general literature review of current studies on carbon footprint reduction in construction and concrete. This is followed by introducing the research method used in this study. Results and discussions are subsequently presented, and conclusions are given at the end of the paper.

2. Literature Review

2.1 Carbon footprint reduction in construction industry

Construction industry contributes significantly to carbon footprint due to the large demand of natural resources and energy. Metz et al. (2007) claimed that the CO_2 generated from construction industry increased at an average rate of 2.7% from 1999 to 2004. To have an insightful understanding of greenhouse gas (GHG) contribution of construction industry, many studies have been conducted to quantify the emissions at both industrial and project levels. At the industrial level, an input-output life cycle assessment, which is based on the whole industrial chain, has been widely implemented (Acquaye and Duffy, 2010). At the project level, a process-based life cycle assessment method is very popular (Wu et al., 2012). In addition to the quantity, the sources of GHG emissions were also investigated. It is found that manufacture and transportation of construction materials, on-site electricity use, and disposal of waste are the main activities that produce GHG emissions during construction process (Hong et al., 2014). Moreover, a number of methodological tools have been developed for investigating carbon emissions in construction projects, such as carbon footprint estimation tool (Melanta et al., 2012), management information system (Barandica et al., 2013), and virtual prototyping technology (Wong et al., 2013).

In addition to the quantification methodologies, a series of technologies have been introduced to reduce carbon footprint in construction industry. For example, Hidalgo et al. (2008) compared a solar absorption system with a conventional vapor-compression machine from the aspects of system performance, economic feasibility, energy saving and environmental impact reduction. The outcome of their comparison supported the utilization of the solar absorption system. In the aspect of heating and cooling, Hacker et al. (2008) conducted a case study and found that the inclusion of thermal mass can reduce building's lifecycle carbon emission by decreasing operational heating and cooling energy. Recently, Zhang et al. (2014) introduced a PV-LED lighting system which produces solar photovoltaic energy in the underground garage to substitute the traditional system. The results proved that the new system can bring benefits in economic effectiveness and CO_2 reduction. A number of green technologies have been introduced to mitigate environmental impact. Johnston et al. (2005) claimed that current available technologies can reduce CO_2 to a large extent by strategic shifts in both energy supply and demand sides. However, most of these technologies focus on reduction of carbon footprint due to operation of the facilities. Researchers from both academia and practice appealed that particular focus should be given to the design stage of facilities (Kim et al., 2013; Zhu et al., 2013).

2.2 Carbon footprint reduction for concrete

Concrete is one of the main materials with high environmental impact in construction industry. It has been widely used in the process of making foundations, structures, infrastructures (e.g., roads, bridges, and dams), etc. (NRMCA, 2008). The consumption of concrete is huge in many countries. For instance, there are approximately 5,500 ready mixed concrete plants in the US, and the value of ready mixed concrete trades is around $30 billion (NRMCA, 2013). Based on the Portland cement sales, it is estimated that the production of ready-mixed concrete in the US is about one billion metric tons per year (EPA, 2013). In China, the concrete consumption is tremendous as well. It is reported that the amount of concrete production in 2007 was two billion cubic meters with an average annual growth rate of larger than 10% (Li et al., 2007).

Concrete is composed mainly of water, aggregate, admixtures, and Portland cement. The proportion of Portland cement in concrete is about 7% to 15% depending on the performance requirements of concrete (NRMCA, 2008). Although concrete has a lower total energy intensity than other generally used construction materials, cement production is a highly energy-intensive process and entails potentially significant air and water pollution (Chini, 2009). In addition, the natural aggregates have finite resources and concern over environmental issues oppose the production of sand and gravel by dredging huge cavities in traditional landscape. Furthermore, the demolition of old concrete pavement and structures produce large quantities of waste that in most cases are landfilled. It has been reported that concrete waste occupied one third of the total wasted materials in the landfills of the US (Zhang, 2012).

Currently, as the concept of sustainable construction has motivated innovative companies, researchers, and industrial coalitions to be more environmentally responsible, potential solutions have been suggested to reduce the carbon footprint produced by concrete. Some highlights of the prevailing technologies and approaches are listed as follows.

- Use of supplementary cementitious materials. The traditional technologies for manufacturing concrete have required unnecessary quantities of cement, thus consuming less cement in production of concrete is the first step for reducing energy consumption and GHG emissions. One solution to achieve this goal is using supplementary cementitious materials (SCMs). SCMs are industrial byproducts which are usually end up in landfills, however, they can be used to substitute a portion of cement in concrete production, such as fly ash, blast furnace slag and silica fume (NRMCA, 2008). The appropriate use of SCMs in concrete production can consume less energy and emit less GHG. In addition, a blend of 50% or more granulated blast furnace slag or fly ash can increase the durability of concrete products compared with using pure Portland cement (Mehta, 2001).

- Use of recycled concrete aggregates. So far, the natural resources of the earth have been exploited to a point where the availability of gravel is scarce in some places. Furthermore, disposal problems have risen because of excessive volume of construction and demolition waste generation (Wu et al., 2014). As a result, there is a need to curtail the production of concrete waste. A possible solution is recycling wasted concrete by crushing it into acceptable sizes and removing impurities such as rebar, PVC pipes, etc. Numerous studies have been conducted utilizing recycled concrete waste to substitute natural raw materials (Chini et al., 2001).

- Design innovation of concrete products. The design of concrete products has been improved continuously, such as design of flat slabs and voided slabs. The recent flat slabs were designed without drops and column capitals, which can withstand greater slab loadings and allow thinner slabs in the design (BCA, 2012). In addition, the deletion of beams allows lower floor-to-floor heights, which contributes significantly in concrete reduction. Especially in cases where there is no requirement for a deep suspended ceiling, flat slab construction can minimize floor-to-floor heights (BCA, 2012). Voided slabs are a form of structural slab system in which voids are introduced to reduce concrete usage, and in turn reduce the dead load of the structural slab (BCA, 2012). This design contributes not only to concrete reduction because of the voids, but also to the reduction in size of the supporting columns and foundation.

- Reuse and deconstruction. The best way to preserve the embodied energy of a concrete structure is adaptive reuse. Adaptive reuse is defined as “to leave the basic structure and fabric of the building intact, and change its use” (Langston et al., 2008). Buildings that employ concrete frame structural systems are well suited for adaptive reuse. Deconstruction or disassembly of the structure can be utilized to divert the maximum amount of the structural components from the waste stream (Chini, 2005). It is regarded that the top priority is placed on the direct reuse of the component in new structures (Chini and Bruening, 2003). This approach has been successfully applied in several countries (CCANZ, 2007).

Through the literature review, it can be found that the concrete industry has been dedicated to reducing the carbon footprint of concrete products. However, the current practice is mainly focusing on the manufacture and recycling of concrete, no attempt has been conducted on reducing carbon footprint in the concrete product selection process. Therefore, this paper is attempting to introduce a tool for reducing carbon footprint by optimized concrete product selection.

2.3 Environmental product declaration for concrete products

To facilitate concrete product selection, EPD is utilized in this study. As introduced in the introduction section, an EPD can provide quantifiable data about the potential environmental impacts of a particular product. The typical procedure for creating an EPD is as follows. Firstly, identify product category rules for describing how to implement life cycle assessment on a particular product. Then, perform the life cycle assessment according to the outlined rules. Finally, input the derived life cycle assessment data into an EPD format and create an EPD for the particular product. Usually, an EPD includes the information about manufacturer, use of the product, and environmental data. Before its publication, a verification must be derived from a third party.

The implementation of EPD has been encouraged in green building rating systems. For example, in the most updated version of Leadership in Energy & Environmental Design (i.e., LEED v4), points can be awarded if a project uses more than 20 products having their EPDs (NRMCA, 2015). As concrete has a wide application in manufacturing construction products (e.g., columns, beams, walls), it is regarded that concrete products with corresponding EPDs can contribute significantly to satisfying this requirement.

In order to help concrete manufacturers meet the new requirements, the National Ready Mixed Concrete Association (NRMCA) of the United States has operated an EPD program for guiding them to develop draft EPDs and conducting corresponding verification. The concrete EPDs verified under this program are all listed on the official website and free for download. An industrial wide EPD which indicates the average environmental characteristics of 48 ready mixed concrete products is provided as well.

3. Methodology

To illustrate the application of EPD in building construction, two scenarios are proposed in this study. The first scenario is designed to explain how to use EPD to make material selection from the environmental perspective. In this scenario, an office building with concrete frame structure is used as an example. This is a two-story building with twenty square reinforced concrete columns (300 mm × 300 mm) located in the grids (4.3 m × 6.1 m). Three concrete slabs which are 100 mm thick are used as floors. The sectional and plan views of this building are presented in Figures 1 and 2.

The second scenario is proposed to introduce the concept of carbon footprint index (CFI) which can be used as an indicator for facilitating carbon footprint reduction at design stage. In this paper, the CFI is defined as the amount of carbon emissions due to the use of concrete to cast a square meter of construction floor area. The calculation scope involves structural and non-structural concrete elements in superstructure, regardless of concrete used in external works and sub-structural works such as basements and foundations. The formula for calculating CFI is shown in Eq. 1.

$$CFI = CV \times CFE / TA \qquad \text{Eq. 1}$$

where CFI ($kgCO_2e/m^2$) is the carbon footprint index, CV is the concrete volume (m^3) that used in building the superstructure, CFE refers to the carbon footprint emission ($kgCO_2e$) in one cubic meter of selected concrete material, TA represents the total floor area (m^2) of the superstructure.

The different values of CFI indicates various levels of carbon footprint. More specifically, the material with a higher CFI produces more carbon footprint than the material with a lower CFI. In the determination process of material selection, the material with the lower CFI is preferred from the perspective of environmental protection. This concept can be introduced into green building rating system (e.g., LEED) to provide thresholds for different categories of buildings.

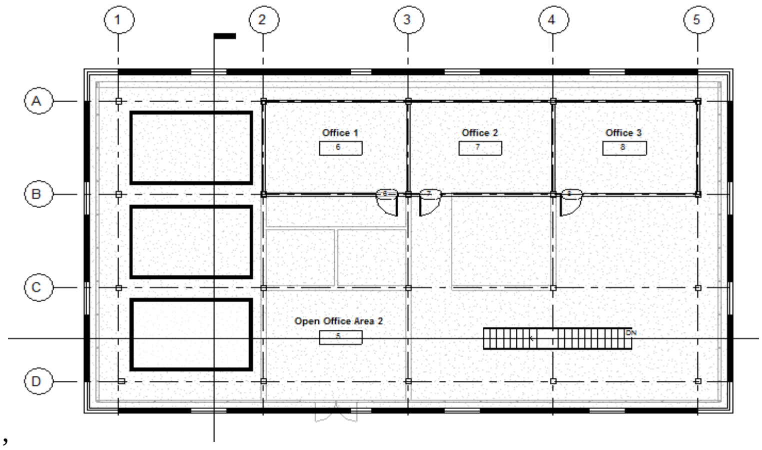

Figure 1 Plan view of the office building

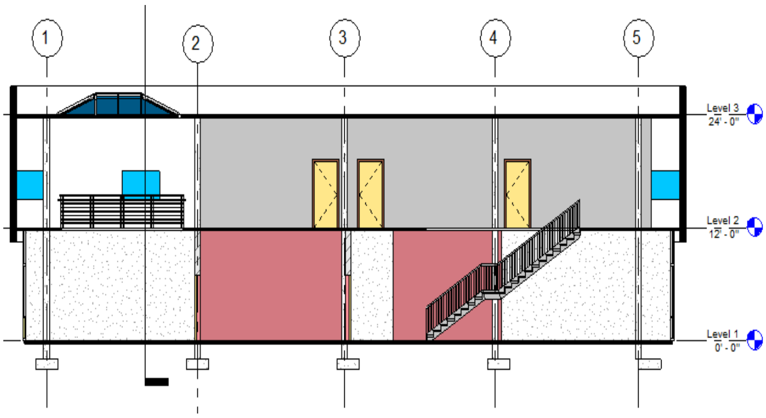

Figure 2: Sectional view of the office building

4. Results and discussions

4.1 EPD application for selecting environmental materials

In terms of the first scenario, the basic information of the office building is shown in Table 1. From Table 1, it can be seen that the concrete strength is various in different floors. Based on the NRMCA member industry-wide EPD for ready mixed concrete (NRMCA, 2014a), the potential concrete products for satisfying different strength requirements and their carbon footprint are abstracted and presented in Table 2.

Table 1 Basic information of the office building

Item	*Floor area (m^2)*	*Concrete volume (m^3)*	*Required concrete strength (MPa)*
Floor 1	*391.9*	*39.19*	*21*
Floor 2	*409.3*	*40.93*	*34.5*
Floor 3	*385.4*	*38.54*	*34.5*
Columns		*14.81*	*28*
Total	*1186.6*	*133.47*	

Table 2 Carbon footprint of potential concrete products

Strength (MPa)	*Range (psi)*	*Potential products*	*Carbon footprint ($kgCO_2e/m^3$)*
21	*3001-4000*	***4000-00-FA/SL***	***416.1***
		4000-20-FA	*357.1*
		4000-40-FA	*291.6*
		4000-30-SL	*316.6*
		4000-50-SL	***250.4***
28	*4001-5000*	***5000-00-FA/SL***	***509.1***
		5000-20-FA	*435.6*
		5000-40-FA	*353.9*
		5000-30-SL	*385.1*
		5000-50-SL	***302.4***
34.5	*5001-6000*	***6000-00-FA/SL***	***536.1***
		6000-20-FA	*458.5*
		6000-40-FA	*372.1*
		6000-30-SL	*405.1*
		6000-50-SL	***317.8***

Note: the name of concrete product is given according to the following rules: the first section of the product name indicates the range of compressive strength in psi, the second section declares the percentage range of supplementary cementitious materials (SCM) used to manufacture the concrete products, and the third section stands for the components of the SCM (FA is short for fly ash, while SL represents slag).

From Table 2, it can be seen that the most environmental-friendly concrete products for different strength levels are 4000-50-SL, 5000-50-SL, and 6000-50-SL. On the contrary, using 4000-00-FA/SL, 5000-00-FA/SL, and 6000-00-FA/SL produces the most carbon footprint.

Tables 3 and 4 show the total carbon dioxide produced using the mix designs without cementitious materials (66,451 $kgCO_2e$) and mixes with 50% slag (39,547 $kgCO_2e$), respectively. Based on the results, it can be found that various schemes of concrete product selection can make a significant difference on carbon emission. While the selected case is just a regular office building with only three floors, the difference can be more significant if it is a high-rise building.

Table 3 Total global warming potential using mix designs without cementitious materials

Member	*Floor Area*	*Material Volume*	*Mix Design*	*Concrete Strength*	*GWP*	*Total GWP*
	m2	*m3*		*MPa*	*Kg Co2e per m3*	*Co2 Eq. Kg*
Floor 1	*391.9*	*39.19*	*4000-00-FA/SL*	*21*	*416.1*	*16,307*
Floor 2	*409.3*	*40.93*	*6000-00-FA/SL*	*34.5*	*536.1*	*21,943*
Floor 3	*385.4*	*38.54*	*6000-00-FA/SL*	*34.5*	*536.1*	*20,661*
Columns		*14.81*	*5000-00-FA/SL*	*28*	*509.1*	*7,540*
Total	*801.2*					*66,451*
Carbon Footprint Index Kg Co2e/m2						*82.9*

Table 4 Total global warming potential using mix designs with 50% slag

Member	*Floor Area*	*Material Volume*	*Mix Design*	*Concrete Strength*	*GWP*	*Total GWP*
	m2	*m3*		*MPa*	*Kg Co2e per m3*	*Co2 Eq. Ton*
Floor 1	*391.9*	*39.19*	*4000-50-SL*	*21*	*250.4*	*9,813*
Floor 2	*409.3*	*40.93*	*6000-50-SL*	*34.5*	*317.8*	*13,008*
Floor 3	*385.4*	*38.54*	*6000-50-SL*	*34.5*	*317.8*	*12,248*
Columns		*14.81*	*5000-50-SL*	*28*	*302.4*	*4,479*
Total	*801.2*					*39,547*
Carbon Footprint Index Kg Co2e/m2						*49.4*

GWP = Global Warming Potential

4.2 EPD application as an indicator for carbon footprint

Equation 1 was used to calculate the carbon footprint index of the building for each case. Tables 3 and 4 show that the carbon footprint index decreased from 82.9 to 49.4 Kg Co2e/m2 when the mix designs without any cementitious materials were replaced by those with 50% slag. Ground granulated blast-furnace slag is a byproduct of steel production and much cheaper than Portland cement. It is highly cementitious in nature, ground to cement fineness, and hydrates like Portland cement. Substitution of ground granulated blast furnace slag for up to 70 percent of the Portland cement in a mix has been used. In addition, Portland cement blends containing 50% or more granulated blast furnace slag can yield much more durable concrete products than the pure Portland cement.

The introduction of CFI can assist designers to measure and benchmark the carbon footprint of building during the design stage to arrive at an optimal design early in the design and construction process. The CFI can also be used as a measure of environmental impact of buildings in building rating systems.

The carbon footprint analysis in an EPD can facilitate manufacturers to understand more about the effects of their products to the environment, while the CFI can assist construction stakeholders in improving the carbon footprint reduction.

5. Conclusion

The construction industry produces a significant amount of carbon footprint. As energy efficiency of buildings has improved, the proportion of embodied carbon footprint with respect to operational energy is increasing. An EPD of a concrete product can tell the customers how much carbon footprint can be generated from the manufacture of this product, thus provide convenient and useful information on materials selection with the aim of reducing embodied carbon footprint. The research findings in this paper reveal that different schemes of materials selection can make significant difference in carbon footprint reduction. Furthermore, the concept of CFI is introduced in this paper, which can be used at the design stage to arrive at an optimal design as well as in a green building rating system for evaluating the carbon footprint reduction performance of a building.

The paper contributes to illustrating the applications of EPD on carbon footprint reduction in construction industry. Further research can be addressed to integrating building information modeling (BIM) with EPD to simulate the effectiveness of different materials selection schemes, establishing CFI thresholds of different materials for green building evaluation.

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Increasing the Market Penetration of Manufactured Green Buildings: A Research Proposal

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Abstract

This conceptual paper provides a desk-top study of secondary sources to outline a robust program of research to increase the market penetration of high quality green buildings produced in advanced manufacturing facilities. The environmental benefits of such buildings are investigated, a theoretical approach to understanding the drivers of best practice is outlined and a field work-method is proposed to understand the dynamic capabilities that support leading manufacturers. An extended sociotechnical systems view of the firm is developed to guide a program of international case studies. This paper makes a theoretical contribution to the understanding of firm performance in an important empirical setting. Future research by the author will involve execution of the described research program. A limitation of the paper is that the effectiveness of the proposed theory and methods is yet to be tested empirically.

Keywords: Sustainability, buildings, off-site, socio-technical systems, Australia

1. Introduction

There is an urgent need to improve the environmental sustainability and the whole-of-life cost of buildings by increasing the market penetration of green buildings produced in advanced manufacturing facilities. This requires new management theory to understand the latent variables underpinning successful facilities internationally. The building sector represents an urgent environmental problem because of its poor performance in energy, carbon, materials, water and waste. It is the single largest contributor to CO_2 emissions among industry sectors (UNEP, 2014) and produces more greenhouse gases than the transport sector (World Business Council for Sustainable Development, 2009). These significant environmental problems can be efficiently and effectively addressed through a shift to advanced manufacture of buildings and their parts, such as modules, bathroom pods and structural insulated panels.

Advanced manufacture results in a higher quality and more sustainable asset compared to buildings constructed on-site through manual processes (Johnsson and Meiling, 2009, Poon et al., 2003, Monahan and Powell, 2011). However, Australian efforts to develop such an industry, although promising, are hampered by a number of obstacles. These include social stigma, sector resistance to radical innovation and lack of design flexibility (Steinhardt et al., 2014). In Australia, it is estimated that less than 5% of new buildings are produced using advanced manufacturing, while in leading countries, such as Japan, the comparable rate is 15% (Steinhardt et al., 2013a). Although these figures indicate that market penetration is currently low, there is overwhelming evidence that such approaches are the direction of the future (CEDA, 2014). This is because of the strong business drivers for green buildings (WGBC, 2013) and the potential for advanced manufacturing to deliver sustainability benefits (Kibert, 2012).

The Australian manufactured building industry has some competitive advantages, but is relatively undeveloped in a global sense (Steinhardt et al., 2013b). The current paper provides a desk-top study of secondary sources to outline a robust program of research to increase the market penetration of such buildings in Australia. The proposed study aims to benchmark current best practice globally, framed by an integrated conceptual framework. This framework is essential to uncovering the latent drivers of excellence in this field. The proposed study addresses the research question ‘How can factory production of buildings be optimised?’

2. Literature Review

The study will address the: conceptual problem of modernizing the STS view of the firm; the empirical problem of reducing the impact of building engineering and operation on climate change; the management problem of the best way to improve building quality; and the policy problem of encouraging efficient building production and expanding export markets.

The focus of this study is residential buildings, like houses and apartments. The vast majority of such buildings in Australia and elsewhere are constructed manually on-site. A small percentage are produced in a factory and transported to site. The factories might produce whole buildings or their parts. Most of these factories are not employing advanced manufacturing techniques;

however this is the approach that leads to the most significant environmental benefits (Noguchi, 2011). The definition of advanced manufacture adopted here follows that of the Committee for Economic Development of Australia (CEDA). CEDA recently produced an Industry Plan that distinguishes between traditional assembly-line manufacturing based on low-cost, high-volume production and advanced manufacturing which is 'about variability, complexity and extensive customisation with high value-add' (CEDA, 2014). Advanced manufacturing directly addresses many of the obstacles to increased market penetration of green buildings by providing (1) flexible and sophisticated designs; and (2) detailed monitoring of whole-of-life outcomes (Noguchi, 2011).

Advanced manufacture of buildings also offers significant efficiency improvements to substantially lift the productivity of construction processes (Kibert, 2012, Manley, 2008), potentially doubling efficiency compared to on-site production (Eastman and Sacks, 2008). The technologies supporting these gains include advanced numerical controlled machinery, robotic assembly, building information models and enterprise resource planning systems. Improved productivity is urgently needed, given that previous attempts to improve the performance of the construction industry have had very limited success (Productivity Commission, 2014). Efficiency improvements are in part reaped through a higher quality product that eliminates re-work (Manley and Miller, 2014, Blismas and Wakefield, 2009). Yet the adoption of advanced manufacture in the building sector has been slower than expected (Middleton, 2014). Recent research suggests that this may be due to inappropriate firm-level management strategies (Brege et al., 2014). The current study builds on those findings by developing a systems approach and employing international comparisons that enable the identification of best practice.

UNEP (2014;16) reports that the building sector is an urgent environmental problem: (1) 30% of energy end-use world-wide takes place within buildings; (2) 10% of the global energy supply is consumed during the manufacture of building materials; (3) 30-40% of CO_2 emissions are generated during the use phase of buildings; (4) 40-50% of the total flow of raw materials globally is used in the manufacture of building products and components; (5) 12% of global water use takes place in buildings; and (6) 40% of solid waste streams in developed countries comes from building engineering and demolition. These issues must be addressed immediately if the ravages of climate change are to be minimised.

Leading international studies show that the average cost premium for a zero-carbon building is 12.5% (WGBC, 2013), yet neither the World Green Building Council, nor the United Nations Environment Program assess how this cost premium might be reduced by extending the use of advanced manufacturing technologies in a factory setting to produce buildings and their parts. For the first time, the current study will compare the cost profiles and environmental outcomes of leading green building manufacturers internationally. By doing so, it will improve the performance of Australian building manufacturers, thus reducing the environmental problems outlined above.

There are persuasive statistics demonstrating the gains to be made if more buildings were produced through advanced manufacture. For example, a recent UK study compared the performance of manufactured homes with those that were constructed on-site. The figures demonstrated a 34% reduction in embodied carbon (Monahan and Powell, 2011). The proposed study will improve (1) the success of climate change mitigation strategies; (2) Australia's standing in the international community; and (3) the international competitiveness of Australia's manufacturers of buildings and their parts.

As a traditional industry, lacking the glamour of research-intensive industries, the building and construction industry has received limited attention from innovation analysts (Gann, 2000, Kibert, 2012). The study addresses this urgent empirical gap by focussing on a significant innovation (advanced manufacturing) that can reduce the environmental impact of buildings and improve efficiency. This empirical gap has occurred because of an acute shortage of rigorous research in this area. Climate change responses are currently focused on high profile polluters such as the coal or transport sectors, yet the building sector is the biggest polluter amongst all industry sectors (UNEP, 2014). The proposed study directly addresses this important issue.

The proposed study addresses the efficiency and effectiveness of the built environment, where the human population lives and where 95% are employed (Newton et al., 2009). This is achieved by encouraging a shift in market preferences away from 'stick-built' buildings constructed on-site, towards the advanced manufacture of buildings and their parts. Advanced manufacture has the twin benefits of improved environmental and productivity outcomes. Although the focus of this study is on environmental outcomes, productivity is also improved through the ability to (1) utilise advanced manufacturing technologies, (2) work through rain, storms and heatwaves, and (3) recycle waste materials more efficiently. Historical data comparing buildings produced on-site, with buildings produced in advanced manufacturing factories, shows higher labour productivity and faster growth in the factory sector. For example, data on curtain wall production in the U.S. between 1992 and 2002 showed a 32% growth in labour productivity in the factory sector, while the comparable figure for on-site production was 8% (Eastman and Sacks, 2008). Data from another study shows that producing a bathroom pod in an advanced manufacturing facility takes one tenth the time of traditional on-site bathroom construction (Singerman, 2013).

The proposed study is likely to reduce the financial burden placed on owners and taxpayers arising from paying too much for buildings. Cost savings will have significant ramifications for Australian society as a whole given that the building and construction industry contributes 8% of GDP and is the 3rd largest industry division across 19 ANSZIC divisions (ABS, 2014). The industry produces the built environment and thus has a significant impact on living standards, the production of other goods and services, and trade. Yet, it is known as a 'serial productivity under-performer' (PWC, 2013). The scale and ubiquity of the industry means that productivity improvements will have much larger multiplier effects compared to nearly all other Australian industries.

3. Conceptual Framework: Validation of Techniques

Conceptually, the problem at the centre of this study can be framed as inadequate diffusion of a radical innovation (advanced building manufacture) given its potential benefits compared to established methods. CI Manley is a global expert in innovation systems and has an intimate knowledge of the evolution of systems approaches to the study of innovation (Manley, 2002, Rose and Manley, 2014). Leading approaches include technological regimes (Nelson and Winter, 1977), technological systems (Carlsson and Stankiewicz, 1991), systems of innovation (Edquist, 1997) and STS (Trist and Bamforth, 1951, Cooper and Foster, 1971). The STS view is selected for development here as it is the most promising for addressing the urgent environmental problems at hand. This is because the STS view explicitly combines the linear end-points of 'technological fix' on one hand, and 'behavioural change' on the other, in framing approaches to sustainability transition problems (Geels, 2012). A STS is a multi-level concept that describes a work system that is typically described as having four components that need to be balanced to maximise performance: (1) goals, (2) actors, (3) technology and (4) structure (Leavitt, 1964). At firm-level, an STS is described here as follows:

1) Goals: work is assigned to actors to achieve the goals of the firm
2) Actors: employees with different beliefs undertake tasks to achieve goals
3) Technology: physical tools are employed by the firm to help actors achieve goals
4) Structure: work is designed to help the actors and technology achieve goals

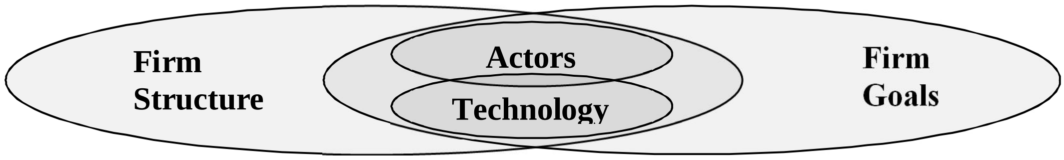

Figure 1: Integrated STS concepts

Figure 1 shows the interconnectedness of STS components. STS theory is more than 60 years old and has been used ubiquitously over the years, yet it is increasingly criticised for being outdated (Eason, 2008), and too focused on information systems (Davis et al., 2014). Key authors are calling for renewal to extend the conceptual basis of the theory and to apply it to new fields (Eason, 2008, Davis et al., 2014). The current study addresses these gaps, building on the integrated concepts encapsulated in Figure 1 by providing theoretical depth and currency for each of them. It challenges the currently limited approaches to understanding STS by developing a highly structured and detailed theory suitable for application to the built environment, based on related management theory, which itself borrows from social psychology theory. The new theory will aid in the understanding of the dynamic capabilities that underpin firm performance (Zollo and Winter, 2002). The application of renewed STS theory to the built environment responds to calls from academics in that field for theoretical approaches that combine technological and social dimensions of change (Schweber and Harty, 2010). The outcome is valid and reliable advice for firms to help them extend market share, based on detailed prescriptions driven by strengthened and streamlined theory.

A taxonomy of dynamic capabilities will be provided by combining the STS literature (Trist and Bamforth, 1951, Cooper and Foster, 1971) with more nuanced management theory, such as planned behaviour (Ajzen et al., 2011), organisational ambidexterity (Patel et al., 2013) and user-producer interaction (Lundvall and Vinding, 2004). While the STS view provides a very useful organising principle for understanding dynamic capabilities and firm performance, its integration with more nuanced approaches, focused on each of the four individual system components, will provide the depth required to direct real-world change. In this way, the learning routines that underpin dynamic capabilities can be better understood and the operational relevance of the STS view will be vastly improved. The new theory developed by this study makes a significant contribution to the emergent field of sustainability transitions that has developed over the past 10-15 years. A recent summary of this field emphasises the critical need for more comparative studies, as will be undertaken here (Markard et al., 2012).

4. Approach and Methodology

The epistemological approach adopted is 'realism' giving rise to modified objectivist findings, through case studies (Healy and Perry, 2000). A deductive approach is proposed, driven by research questions within a rigorous qualitative framework. Based on existing conceptual approaches, an integrated theory is developed to guide the case studies. The proposed study is forecast to take 3 years to complete, as detailed below.

4.1 Stage 1: Theoretical Development: 3 months

Objective: Modernize and improve the operational relevance of the STS view by developing measurable items drawn from related theory for each of the four components.

Method: Development will be based on the procedure pioneered by CI Manley in earlier research funded by the Australian Research Council (LP110200110) (Chen and Manley, 2014). A robust and structured literature search will be undertaken, using directed content analysis (Krippendorff, 2004). CI Manley has extensive experience with this method, leading to many significant journal publications. She will supervise the process of sourcing, classifying and interrogating potentially useful theories, with an RA doing the routine sourcing and classification work, and a Post-doc examining the potential to add value to the predictive power of the initial model. The management literature on topics relevant to the four system components will be reviewed, focussing on highly-cited contributions in leading journals. A two-stage process will be employed, commencing with *general* management literature to establish broad principles and concluding with *engineering* management literature to provide relevant contextualisation. The integrity of the final integrated result will be supported by feedback from a panel of international experts on management theory and firm capabilities sourced from CI Manley's extensive networks.

Contribution: An integrated theory of STS that better facilitates empirical work in the current context.

4.2 Stage 2: Case Study Logistics: 3 months

Objective: To identify and secure interviewee firms and managers for the 15 cases; and establish the flight, accommodation and interview schedules in each of the five countries sampled.

Method: Three leading firms in each of five countries will be studied, including Australia, resulting in 15 cases. The data obtained will cover the four components of the new STS theory. This data will describe the drivers of firm performance. CI Manley's experience suggests that three firms are sufficient to get a good sample of best practice in each country. Each firm will be a leading advanced manufacturer of green buildings, selected on the basis of advice from our foreign collaborators regarding the firms with the largest market share. The foreign countries themselves were selected because they are considered to be progressive in this area, based on earlier pilot research by CI Manley in late 2014 (Steinhardt et al., 2013b). Using contacts established by CI Manley during that study, the schedules will be developed using phone and email communications. This work will be driven by CI Manley, overseen by the Post-doc and actioned by the RA. CI Manley will secure participation; the Post-doc will establish schedules and the RA will make bookings.

Contribution: A register of 15 leading firms globally in the advanced manufacture of buildings.

4.3 Stage 3: Case Study Performance: 12 months

Objective: To efficiently and effectively conduct the case studies to help grow the Australian green building industry.

Method: Case studies are recommended for analysis of messy empirical contexts (Eisenhardt and Graebnew, 2007). This means contexts that are (1) significantly multidimensional, giving rise to a large number of variables; (2) marked by interactive relationships with unclear cause and effect; (3) impacted by situational factors in the surrounding environment; and (4) being examined from a systems' perspective. These conditions apply to the current research, justifying the use of case studies.

Two senior managers from each manufacturing firm will be personally interviewed for one hour by two researchers at the same time; CI Manley and the Post-doc. This dual approach allows for cross-referencing of information provided by the two managers and cross referencing of observations across the two researchers. Personal interview enables unobtrusive observation, augmenting word responses, particularly in relation to non-verbal cues from interviewees, technological infrastructure and factory lay-out. Company reports will also be collected and consulted, including performance audits, employee opinion surveys, training materials and operation manuals. Pilot study manufacturers have indicated a willingness to share such material. The RA will be responsible for transcribing the interview recordings and pulling salient material from company reports. Triangulation across two managers, two senior researchers and three data sources assures robust findings. CI Manley's extensive interview experience suggests that one hour is sufficient time to reach data saturation point, after which no new material is likely to emerge. Academic and industry partners in each foreign country have been secured to help with the case studies.

Many of the case study firms have already been identified and secured including Broad Sustainable Building (China), Sekisui House (Japan), Baufritz (Germany) and BoKlok

(Ikea/Skanska in Sweden). The interviews will be semi-structured involving two phases. In the first phase, the interviewee will be given a short questionnaire to complete, taking about 15 minutes, based on the four system components. In the second phase, open-ended questions about each component will be discussed with the interviewee.

Contribution: 15 'demonstration' case studies, each describing success factors in advanced manufacture of green buildings, driven by integrated theory.

4.4 Stage 4: Cross Case Analysis: 3 months

Objective: To understand the role of context in the different countries and to isolate common success factors.

Method: Directed content analysis will again be employed to review the 30 interview transcripts and associated company documents and researcher notes, with the RA organising and reviewing these research materials to maximise their accessibility. The identification of key variables and initial coding categories will be driven by the novel STS theory developed earlier in the study. NVivo, a qualitative data analysis software package, will provide a rigorous system to assist with coding. The coding will focus on identifying themes within the theory components and will be undertaken independently by CI Manley and the Post-doc, then cross-referenced to produce the final result. This triangulation process will support the validity and reliability of findings. Care will be taken to ensure that coding categories are mutually exclusive, limited in number and clearly aligned with theory components.

Contribution: The first evaluation of pathways to environmental excellence in advanced manufacture of green buildings internationally.

4.5 Stage 5: Theory Refinement: 3 months

Objective: To improve the value of the theory developed in Stage 1

Method: The explanatory power of the theory is reviewed by reflecting on its usefulness in the field. Did some items seem irrelevant? Were new items indicated? Through such analysis, contemporary empirical findings can improve the current state of theory. Analysis will again be undertaken independently by CI Manley and the Post-doc, then cross-checked to produce an interim result, which will be further cross-checked with an expert panel to improve validity and reliability. The final model will be particularly relevant to the study of advanced manufacturers, which is a very valuable research output as these manufacturers are currently being targeted by the Australian government for development through an Industry Growth Centre. During this stage, the RA will be working on industry magazine articles.

Contribution: A refined and contextualised management theory dedicated to an industry sector that is of strategic significance to Australia's future industry growth.

4.6 Stage 6: Knowledge Diffusion Program: 12 months

Objective: To provide advice to industry for improving market penetration of advanced manufactured green buildings and extend the academic knowledge base.

Method: Industry publications will provide research results, together with a set of normative guidelines for firms on how to achieve environmental excellence in their advanced manufacture of buildings. Such guidelines will be validated through feedback from an expert panel of industry practitioners. A Capstone Symposium will also be held for industry stakeholders in the three largest capital cities; Sydney, Melbourne and Brisbane; to share knowledge and map future pathways to greater market penetration. The RA will play a major role in framing industry publications and liaising with industry associations to validate guidelines and ensure appropriate distribution, as well as providing logistical support to the Post-doc, who will organise the Symposia under the direction of CI Manley. This industry phase of the knowledge diffusion program will consume six months. The academic publications will focus on the theoretical and empirical work, and target leading management journals, as well as refereed conferences. The Post-doc will generate the first-drafts of many of these articles. CI Manley will draft some articles herself and provide heavy revision for the others. Initial submission of articles will consume six months. See ‘Communication of Results’.

Contribution: Validated industry guidelines, industry publications, Capstone Symposia, conference papers and journal articles.

5. Conclusions

This conceptual paper was based on a desk-top study of secondary sources to justify and design a proposed program of research. The contributions of the paper comprise (1) an assessment of the environmental benefits of manufactured green buildings, (2) a theoretical approach to understanding the latent drivers of best practice and (3) a field work-method to understand the dynamic capabilities that support leading manufacturers.

The extended sociotechnical systems view of the firm developed here is both useful for the proposed study and has more general applicability as a more nuanced approach to assessing the capability of firms and the strength of their socio-technical systems. The current paper makes a theoretical contribution to the understanding of firm performance in an important empirical setting. Future research by the author will involve execution of the proposed study. A limitation of the paper is that the effectiveness of the proposed theory and methods is yet to be tested empirically.

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Conceptual Framework for CIB W114: Construction Materials Stewardship

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Abstract

Construction Materials Stewardship can be thought of as the range of activities that go into the products and materials used in the infrastructure construction and maintenance process with respect to how they impact society. In particular, Materials Stewardship examines both the material manufacturing process and the raw materials used in addition to the deconstruction or demolition process and the disposal of the waste products. The Construction Materials Stewardship focuses on closing the material loop between the demolition process and the materials manufacturing process or product reuse. By reusing or recycling construction waste products, the quantity of raw materials required for future construction can be reduced in addition to diverting waste away from landfills. The Construction Materials Stewardship mission is interested in (1) drastically reducing the extraction and consumption of new non-renewable construction materials, (2) replacing non-renewable materials with renewable ones whenever possible, (3) achieving equilibrium in the demand and supply of renewable materials, and (4) ultimately restoring the renewable resource base. With this framework in mind, the research is intended to carry out these tasks in ways to maximize positive financial, social and environmental and ecological sustainability effects, impacts and outcomes.

This paper discusses the conceptual framework for the Research Roadmap of The CIB W115 and will address the issues related to construction materials stewardship, their interrelation, and the characteristics of the most relevant systems, processes and technologies.

Keywords: Construction, Materials, Waste, Reuse, Design

1. Introduction

Construction Materials Stewardship can be thought of as the range of activities that go into the products and materials used in the infrastructure construction and maintenance process with respect to how they impact society. In particular, Materials Stewardship examines both the material manufacturing process and the raw materials used in addition to the deconstruction or demolition process and the disposal of the waste products. The Construction Materials Stewardship focuses on closing the material loop between the demolition process and the materials manufacturing process or product reuse. By reusing or recycling construction waste products, the quantity of raw materials required for future construction can be reduced in addition to diverting waste away from landfills.

During the construction process, a significant amount of waste can be generated based on the materials selected due to excess supplies, errors in material selection, or damaged products. Material Stewardship is interested in measures that can be taken to reduce these waste streams and improve the sustainability of the facility based upon product selection. An initial aspect of these studies looks at how existing construction materials can be used more efficiently to reduce waste on the construction site and improve performance. A few examples of this type of improvement can be seen in using techniques such as Lean construction to prefabricate assemblies (Nahmens, 2012) and BIM to evaluate material locations (Wong, 2015). In addition, further research is necessary to look at new technologies that can be applied to material production that would result in improved environmental performance. The design of new products has seen tremendous advancements in technologies that improve the life cycle of the individual materials as well as reduce the pollution emissions of the building. An example of this type of improvement is implementation of nanotechnology in concrete that improves durability and facilitates cleaning of the surfaces (Ortiz et.al, 2009). Additionally, the application of sustainable construction materials in which reused or recycled products are incorporated to create an eco-material with an improved life cycle performance can be significant (Nie and Zuo, 2003). By evaluating the individual construction materials from a sustainable stand point, can result in modifications that can improve the life cycle properties of the materials, increase the useful life of the products, and recognize reductions in waste along with other environmental and economic benefits.

The waste stream generated from the life cycle of infrastructure including building, maintaining, and end of life disposal is often referred to as Construction & Demolition (C&D) waste. Due to the large volume of materials, such as concrete, steel, glass, and masonry, most countries track their recycling rate separately. In the European Union, it is estimated that 850 million tons per year or about 30% of the total waste stream is attributed to C&D waste (Fischer and Werge, 2009). This percentage of the waste stream is consistent with other developed countries in the world as reported in previous W115 publications.

Over time, a building's ownership and/or functionality can transition quite often. If the facility does not have the flexibility to adapt to the new needs, the building may be demolished or left vacant. Either case would not provide the most sustainable use of the facility. By extending the useful life of the facility by planning for the adaptability of new users and occupiers would provide significant economic and environmental benefits. When a building can be initially designed with adaptability in mind, the space and materials would be considered relative to their life cycle and the flexibility that is needed to maximize the building's lifetime while minimizing disturbance to the integrity of the structure. In addition, by designing for adaptive reuse the building owners can more readily adjust the facility at lower costs to account for new technologies. From an environmental perspective, any design for adaptive reuse will demonstrate significant savings in both demolition material being landfilled in addition to the purchase of new structural materials (Saleh & Chini, 2009). Despite the lack of initial designs for building adaptability, a concentrated effort should be made for adjusting existing buildings that have exceeded their current functionality to be altered to permit reuse. The added effort to convert the facility to an adaptable structure will vary depending on the design; but should be considered as a viable option to demolition or the construction of a new facility.

The Construction Materials Stewardship mission is interested in (1) drastically reducing the extraction and consumption of new non-renewable construction materials, (2) replacing non-renewable materials with renewable ones whenever possible, (3) achieving equilibrium in the demand and supply of renewable materials, and (4) ultimately restoring the renewable resource base. With this framework in mind, the research is intended to carry out these tasks in ways to maximize positive financial, social and environmental and ecological sustainability effects, impacts and outcomes.

2. Background

The percentage of Construction and Demolition (C&D) waste that is recycled varies tremendously from country to country. Although a few countries have indicated recycle rates as high as 90%, most countries have less than 50% recycling rates, with several as low as 10%. Recognizing the importance of recycling C&D waste, some national legislative bodies have implemented regulations to encourage more recycling efforts. One of the most stringent new requirements is the EU Waste Framework Directive (European Parliament and Council, 2008) which has established a strategy to handle waste, including a minimum of 70% of C&D waste reuse, recycling, or material recovery by the year 2020 (Hiete, et al, 2012).

C&D waste is generated at four intervals during the life cycle of the facility or structure. First, the site will often require some form of preparation prior to commencing any construction activities. The initial demolition could involve clear and grubbing for an undeveloped site, infrastructure removal for a previously occupied site, or a combination of these methods. Second, during the construction process, excess materials are often discarded as waste. Factors that affect this waste stream include impacts of selected materials and methods, poor workmanship, uneconomical design, and improper material handling. Third, during the operating phase of the building, any renovations or repairs will generate waste from the removal of old material and excess from the new product. Finally, during the building demolition process, all the demolished building materials are often disposed of as waste. Despite attempts to require the recycling of materials during demolition, it is often uneconomical, time consuming, or impractical to sort the waste for efficient recycling. Ideally, if the building is designed for deconstruction at the end of the life cycle, many of the challenges regarding the sorting of the waste to an acceptable quality for reuse or recycling can be dramatically improved.

The following is a summary of the major drivers that can influence designers to design for deconstruction in the initial design process (Hobbs & Adams, 2012):

- **Environmental driver:**
    - Reducing the extraction of new materials;
    - Diverting waste away from landfills
- **Socio-economic driver:**
    - Employment: Jobs may be lost in primary manufacturing, but some will be created in the refurbishment of equipment and in the processing of reclaimed materials;
    - Social benefits: Benefits from reduced loss of land due to materials extraction and landfill sites
- **Political driver:**
    - Government policy on sustainability (minimization of waste, maximization of recycled and reclaimed materials)
- **Risk management:**
    - Legislation, health and safety, fiscal measures encouraging minimization of primary materials extraction and waste generation;
    - Reclassification of materials and waste
- **Economic driver:**
    - Design for deconstruction increases the flexible use and adaptation of property at a minimal future cost;
    - Reducing the whole-life environmental impact of a project and diverting waste away from landfills
- **Ethical Responsibility:**
    - There is a moral responsibility to protect the natural environment and ensure social equality when selecting products for construction.
    - Product selection and waste handling can play a significant role in the ecological and social impacts of a business.

3. Issues

Despite the numerous advantages, the barriers to designing for deconstruction often make it difficult for architects to incorporate material recovery procedures into the initial building design. The following are some of the challenges faced to design for deconstruction (Hobbs & Adams, 2012):

- **Lack of legislation:**
    - At present there are no legal requirements in any country for clients or contractors to consider deconstruction at the design stage or require that waste materials from construction or demolition be sorted for recycling.
- **Human barrier:**

    - Habits: It is easier for people to carry on what they have been doing;
    - Mindset: People tend to prefer new materials to second hand ones.
- **Additional design cost:**
    - Additional time is often required for architects and engineers to include the added features to make the building deconstructable.
- **Procurement and contractual responsibilities:**
    - The design agents may be hesitant to specify products that are not normally used by contractors since they may become liable for the quality of the installation due to their proprietary control of the contractor's choice of products.
    - Likewise, contractors may be hesitant to select products that are not normally recognized by the design agents since they could become liable for any variations from the standard specifications.
- **Technical barrier:**
    - Jointing systems, for example between pre-cast concrete beams, are usually stronger than the actual beam and are very difficult to deconstruct.
- **Economic barrier:**
    - Cost of individual units (tiles, paving slabs etc.) is usually low, so it is more cost effective to buy new ones.
- **Dimensional barrier:**
    - Structural units (beams, columns, etc.) are normally for one-off custom elements with unique dimensions.
- **Physical barriers:**
    - Pre- and post-tensioned beam/ floors, jointing systems, natural ageing of concrete, reinforcement corrosion, presence of coatings.
- **Contamination and aesthetics of components issues:**
    - Contamination with pollutants (petrol, grease, grime)
- **Perception and education:**
    - Perception that composite and strongly bonded elements are more durable and stronger structurally. In reality, a well-designed building that incorporates design for deconstruction elements should pose no increased risk of structural failure.
- **Problem of storage and double-handling of materials:**
    - Transportation between sites and locations can increase reuse costs.
- **Lack of markets for reusable elements or components:**
    - The reusable parts are perceived as being more inferior to newly constructed elements or components in terms of performance and quality.
- **Lack of design codes/ standards/ guidelines:**
    - Without consistent codes that include deconstruction, it is difficult to provide specifications that can be met by a large variety of contractors.
- **Lack of expertise:**
    - To carry out deconstruction and/or supervise the deconstruction process.
- **Lack of project references:**
    - Without good examples to follow that demonstrate the effectiveness of design for deconstruction, it may be difficult for both design agents and contractors to have a reference project to emulate.

An essential element in the evaluation of construction products to reduce waste and minimize the depletion of natural resources is the initial selection of the appropriate materials. In some cases, existing products can be modified or used in alternative methods and thereby improve their performance while minimizing their ecological effect. Additionally, new products should be evaluated to ensure that their manufacture, use, and disposal will not result in further environmental impacts. Life Cycle Analysis tools are one method that can be used to assist in performing these evaluations. By examining the full life cycle of a product it is possible to determine the environmental, social, and economic impact that is expected from the processing, operation, and end of life or recycling. This method of analysis can prove useful in determining which materials are considered sustainable. Construction Materials Stewardship is concerned with the developing methods, strategies, and initiatives to promote the use of more sustainable products.

Churn rate has been used to measure how often a business or building changes its operation. When the old tenant vacates the facility, there can often be a complete demolition of the interior and the installation of new finishes and furnishings. A significant tool in the minimization of material waste is the design for a facility to readily transform and adapt to new tenants and operational requirements. A critical aspect in the success of these transformations is the initial design of the building to facilitate the easy turn over. Additionally, the appropriate materials need to be selected that are durable and can withstand the periodic displacement. By planning in advance to design the building for the eventual churn, significant amounts of construction waste can be reduced.

As communities transition, often there are buildings that outlive their original design and become vacant or abandoned. In many cases, the site will be completely demolished prior to subsequent facilities being constructed. This building demolition results in a tremendous amount of material being landfilled that otherwise could have been reused. The renovation or adaptable reuse of the existing structure would provide a significant improvement from complete demolition and additionally minimize the amount of raw materials needed for new construction. However, changing the functional classification of a building may introduce new regulatory conditions and perhaps require zoning consent (Langstom, 2008). Again, the early planning for the potential adaptable reuse can have significant impacts on the economic, ecological, and social aspects of a building.

4. Stakeholders

With regards to the construction industry, there are two groups of major stakeholders: Internal and external stakeholders (figure 1). The internal stakeholders refers to the groups that have a direct impact on the construction process, while the external stakeholders have more of an impact on the internal stakeholders than they do on the actual infrastructure construction. The internal stakeholders include project owner, clients, project leader, and core team members such as designers, contractors, suppliers, and subcontractors. The external stakeholders include regulators (both local and national), public community groups, financiers, the media, end users, and special interest groups (Chinyio & Olomolaiye, 2010).

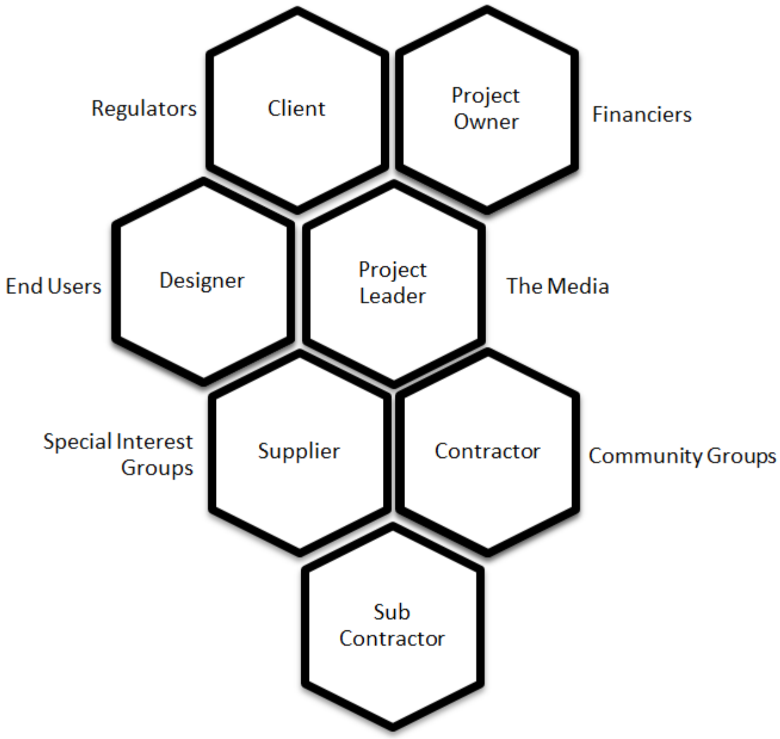

Figure 1: Internal and External Stakeholders

With regards to Construction Materials Stewardship, the following list describes the influences provided by the stakeholders and the perceived barriers for recycling or reuse:

- **Project Owner:**
  - As the primary group or individual responsible for the project, the owner sets the tone and establishes the priorities for the entire construction process. However, the owner may argue that designing for deconstruction or requiring more source sorting recycling programs will increase the cost of the project and not be economically feasible. If only a small portion of the owners are implementing these programs, it may be difficult to sell or lease the more expensive property unless the clients demonstrate a greater need for these requirements or the designers/contractors can perform the material recovery at the same cost.
- **Client:**
  - The group that will lease the spaces or purchase the property. In some cases, the clients may also be the project owners. The group may argue against the materials stewardship principles since they do not want to incur the added costs. Unless, there is government regulations that require that they operate from an environmentally responsible facility they will not have an even playing field from their competition and the added costs for materials stewardship will add an unnecessary expense.
- **Project Leader:**
  - Depending on the contractual situation, the project leader is often the individual responsible for coordinating design and construction efforts with the owner. With regards to materials stewardship, the project leader recognizes the need

for added costs from the design and construction team and thus passes these costs along to the owner. However, if the owner does not desire to pay for these added services, then the project leader normally will not require these services.

- **Designer:**
  - The design team is normally comprised of the architects and engineers responsible for developing the drawings and specifications for the project. They often feel that the limitations of including design for deconstruction are from two other groups. First, is that the material suppliers do not provide enough material options using recycled material that is of equivalent quality to virgin products. Second, the owner may not be interested in paying the added cost to enhance the drawings to the level needed for a structurally sound design that can be readily deconstructed at the end of life. Thirdly they may not want to bear additional responsibilities or risks for being the first movers to adopt design for deconstruction concepts in view of the current lack of project references, design codes/ standards/ guidelines.
- **Contractor:**
  - The contractor is responsible for the physical assembly of the infrastructure in accordance with the design and specifications provided by the architect/engineer. The limitations regarding infusing materials stewardship principles into the construction are directly limited by the design, the regulatory environment, and the market for recycled products. In other words, unless the construction specifications specifically require the recycling operations, the regulating authorities have policies for mandatory recycling, or there is a financially viable market for recycled products, the contractor does not have a strong incentive for capturing the material waste. Another common issue is that obtaining a higher grade of recycled product can be very labor intensive or delays the project; thereby further increasing the construction costs.
- **Suppliers:**
  - The suppliers include all of the material manufacturers that provide the products necessary for the construction. This group has often argued that developing new products using recycled materials can be costly and often there is not an adequate consumer market to justify the expense. Additionally, when the quality of the recycled material is inadequate, it is more difficult to develop better quality products that would be comparable to virgin materials.
- **Subcontractors:**
  - Many of the basic trades that demolish or install the building materials are conducted by subcontractors. The common barrier for subcontractors is due to the uncertainty in performance of new products from recycled material. If the quality is inadequate, the project may require substantial rework and incur significant additional costs.
- **Regulators (both local and national):**
  - This group includes the legislative bodies and government officials that establish the codes and standards along with the tax laws that are applicable for the region. Although it has been demonstrated in many countries how effective legislation can make a significant difference in implementing materials stewardship principles, there is often resistance from industry on excessive legislation in a free market society. Additionally, many of the laws that would

implement the environmentally friendly programs may require higher revenues to administer the policies and this may be politically challenging to acquire.

- **Public Community Groups:**
  - These groups refer to the locally organized citizens organizations that have jurisdiction over the area of the construction project. They can provide a very positive impact on the materials stewardship of the project by specifying that certain demolition and recycling practices be implemented within the community. However, if they see the recycling and reuse practices as unnecessary expenses, then they may also have a negative impact by not encouraging the materials stewardship practices.
- **Financiers:**
  - This group includes the various funding sources that provide the revenue for the project. When sustainable practices can demonstrate a financial benefit for the project, then they are interested in encouraging implementation of the materials stewardship policies. However, if the financial institution is not concerned with the environmental principles then they may not be interested in the extra costs that may be involved in recycling or reuse operations.
- **The Media:**
  - This group includes the various news and public information agencies for a community. In some instances if the owner feels that the media's positive publicity on the material stewardship principles of the project will assist the marketing of the project, there is a greater likeliness that recycling or reuse operations will be implemented. However, depending on the media service, if there is an impression that the materials stewardship principles are adding excessive costs to the project, then it may have a negative impact on publicity.
- **End Users:**
  - The final users of the constructed project are often referred to as the end users. Their impact on material stewardship is often through their willingness to shop or use the appropriate infrastructure. If the recycling or reuse operations created added cost for the users beyond competitive service, it may cause a loss of end users and similarly a decline in revenues for the owner.
- **Special Interest Groups:**
  - Organizations that are interested in promoting various causes and agendas can be referred to as special interest groups. Depending on the environmental preferences of the group, they can have a very positive impact on influencing the implementation of material stewardship principles. Although, there are likewise other groups that are more concerned with fiscal responsibility and reducing costs that may be just as likely to have a negative impact on recycling or reuse practices.

5. Conclusions

The expertise needed to solve these issues includes researchers and policy makers that can collaborate with the stakeholders. The mission of Construction Materials Stewardship is to provide the framework for this collaboration by encouraging the additional research that practitioners need to implement the changes. By working with the policy makers, schemes can be developed to encourage adoption of the procedures that will close the loop of the infrastructure's material life cycle.

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Reinforcement Corrosion Modelling in Renovation Strategy for Concrete Facades

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Abstract

Starting from the 1960s, concrete structures have become prevalent in Finnish construction. This is a result mainly from urbanization and domestic housing policy in Finland which triggered the production of prefabricated concrete buildings. Because of the huge volume of this building stock, its renovation is also challenging in terms of resources. Approximately 11–40 % of the repair costs of prefabricated concrete facades result from corrosion-induced damage.

A subjective methodology is required to compare different repair options technically as well as economically including instant and life cycle costs. Essential information on the durability properties of single buildings and their repair possibilities is gathered in condition assessments but to estimate the residual service life of a concrete structure or to provide strategies for a large number of buildings it is necessary to utilize predictive models. At present, a methodology to assess the residual service life of existing buildings in practice is not available. The propagation of corrosion on concrete facades in Finnish environmental conditions was studied by a series of field and laboratory studies conducted on twelve residential concrete buildings located in different parts of southern Finland. In addition, corrosion rates in concrete facades were evaluated by long term field measurements on concrete facades under natural conditions. The experimental results were contrasted to statistical information on 947 case buildings. This information was used in determining critical parameters in service life modelling.

In the rising trend of renovation in the construction sector, this research will provide information on when to initiate repairs and in what extent. Thereby, the results will enable deciding the order of importance of renovation projects and change from reactive to proactive maintenance. Future applications could include the establishing of alliance type contracts between building owners and renovation specialists covering the long time span upkeep of a large building stock.

Keywords: Concrete facades, service life, modelling, renovation strategies

1. Introduction

Corrosion of reinforcement affects concrete structures basically either by cracking of concrete cover caused by corrosion products or by reduction of effective steel cross-section. The functionality of reinforcement (structural/non-structural) and the corrosion mechanism are decisive for which effect is dominating service life. However, cracking is typically the first sign of corrosion damage visible to the structure's surface. Corrosion is responsible for approximately 11–40 % of the repair costs of prefabricated concrete facades in Finland depending on the surface finishing, and along with insufficient frost resistance, carbonation induced corrosion is the most significant degradation mechanism of concrete buildings in Finnish environment. The damage caused by the both mechanisms accounts for € 3.5 billion in repair need and is increasing. It alone makes 1.8 % of the 2013 GDP of Finland. This is an issue that cannot be solved instantly, but requires a rehabilitation plan over several years.

Private and public buildings built of concrete make up 34 % of the whole building stock in Finland, of which almost 40 % is now 30-50 years old. The majority of the existing concrete facades in Finland have been built in time when service life design practice was not yet established (compared to a common service life requirement today of 50 years). The reinforcement service life is in Finnish guidelines (by50 2012) defined as only corrosion initiation. This means that the target service life should be achieved by carbonation resistance alone. This strategy withholds additional safety since no damage at all has happened yet at the chosen end of service life. In addition in new construction carbonation can be fairly easily accounted for by engineering concrete composition and reinforcement cover depths accordingly. Concerning existing buildings a problem is formed since these properties are already fixed. Also, the initiation phase is in many cases already passed. This makes the assessment of the residual service life of these structures problematic in two ways: (i) the residual service life is, by the definition, zero even though no damage at all has happened, (ii) there is no methods available to evaluate the residual service life.

This research entity focuses on the service life design and maintenance strategies of existing concrete facades in Finland. Service life extension is gained by defining the end of service life in a new way and reliably modelling the corrosion propagation phase. It is a practical issue since many of these concrete buildings have poor quality and ongoing degradation due to freeze-thaw and corrosion. The residual service life of these facades cannot be estimated by carbonation resistance since this phase has already passed. The motivation is to find a way to compare renovation projects and to manage the ever growing renovation needs. The aim is to be able to combine a carbonation model and an active corrosion phase model to form a larger picture of the service life of these structures.

2. Background

2.1 Renovation strategy for concrete facades

Renovation strategy of a built asset is tied to the business/maintenance strategy, financial situation and future prospects of the owner. The renovation project should begin with a project planning phase where the owner sets the requirements (technical, visual, etc.) and the budget for the project. In particular, the owner should define the target service life for the renovation.

The options available for renovation projects can be divided into (SFS-EN 1504-9):

a) do nothing & monitor
b) re-analyse & downgrade in function
c) prevent & reduce further degradation
d) repair & protect
e) replace with new
f) demolish.

The first two options can be used in delaying and budgeting for a larger project in the future. If utilized, these options require comprehensive survey/investigation of the condition of the structure (Lahdensivu et al. 2013). The optimal renovation on the point of view of economy and sustainable use of resources would include options c (prevent & reduce further degradation) and d (repair & protect). In practice, it is however far too common for the owner to only focus on repairing visual damage without analysing properly the need for protective/preventive measures. Cases showing high degree of degradation or obsolescent facilities or technical systems may have to be replaced.

Another way of classifying the repair options is (by41 2007):

a) do nothing
b) preserving renovation
c) altering renovation
d) renewing of the whole structure
e) special methods.

The repair options are followed by the choice of (a set of) renovation principles. The renovation of concrete structures in general can follow several main principles (SFS-EN 1504-9) shown in Table 1. The selection of the renovation principle is often guided by technical, financial, valuation and social aspects.

Table 1:Renovation principles in SFS-EN 1504-9.

Repair principle
1. Protection against ingress
2. Moisture control
3. Concrete restoration
4. Structural strengthening
5. Increasing physical resistance
6. Resistance to chemicals
7. Preserving/restoring passivity
8. Increasing resistivity
9. Cathodic control
10. Cathodic protection
11. Control of anodic areas

2.2 Reinforcement corrosion modelling

A widely accepted description of the corrosion process of steel in concrete withholds the phases of initiation and propagation (Tuutti 1982). The both phases can be analysed as separate entities or combined to form a holistic view of the structure's lifetime for the service life design purposes. The assessment of the residual service life of corroding concrete reinforcement requires detailed information on the corrosion mechanism, initiation, corrosion rate and conditions which are regarded as the end of service life. The diameter and cover depth of the corroding reinforcement as well as the type of products (rust) formed in the corrosion process have been found to have significant impact on the formation of corrosion cracking. These factors are critical in modelling of the residual service life of structures in active corrosion state.

Carbonation of concrete cover is behind the corrosion phenomenon in many outdoor concrete structures, such as facades and balconies. Carbonation of concrete is a chemical reaction between the alkaline hydrates of concrete and carbon dioxide gas, both of which are dissolved in concrete pore water. Because carbonation is mainly controlled by the diffusion of carbon dioxide within concrete, it is commonly modelled using the square root of time relationship, derived from Fick's diffusion law.

Many models have been proposed for depicting carbonation, all of which make use of the square root of time relationship (Parrott 1987). However, empirical measurements have indicated it to overestimate carbonation especially in cases where the concrete is exposed to rain (Tuutti 1982, Huopainen 1997). Therefore, the square root equation should be regarded as an upper limit for carbonation in such cases. The carbonation coefficient k is used to adjust the model to describe the carbonation of different concretes in different environments. (Tuutti 1982).

Another approach has been to incorporate the effect of different environments by modifying the exponent of time (Parrott, 1987). A number of studies e.g. (Thiery et al. 2007, Hyvert et al. 2010) have been concentrated on the reaction kinetics of carbonation by utilizing physical models. The square root equation has also been improved to distinguish between the influences of different individual internal and external factors affecting carbonation (Neves et al. 2012), and to isolate the influences of specific factors (fib 2006) opposed to the one parameter in Eq. (1). A statistical analysis of a carbonation coefficient based on field measurements has been recently presented in Portugal (Monteiro et al. 2012) and in Finland (Lahdensivu 2012).

The main difference between the carbonation model proposed in fib model code (fib 2006) and the one and two parameter models by Tuutti (1982) and Neves et al. (2012) is the requirement for a specific accelerated carbonation test performed in a laboratory environment to determine the carbonation resistance parameter. The latter models, on the other hand, are applicable in practice based on natural carbonation measurements conducted on site.

Corrosion propagation can be modelled by (i) empirical, (ii) numerical or (iii) analytical approaches. (Otieno et al. 2011) Empirical models are sub-divided into three types i.e.: expert Delphic oracle models, fuzzy logic models and models based on electrical resistivity and/or oxygen diffusion resistance of concrete. Empirical models are based on experimentally achieved relationship between corrosion and controlling parameters (e.g. DuraCrete 2000). Three different approaches can be used to develop numerical models: finite element method (FEM), boundary element method (BEM) and resistor networks and transmission line method. Numerical models rely on computational solving of larger entities by dividing them into small elements connected to each other by boundary conditions (FEM, BEM) (e.g. Gulikers and Raupach 2006). Analytical models apply usually thick-walled cylinder approach. Division into cracked inner cylinder and an uncracked outer have also been developed. Analytical models are based on the closed-form solving of mathematical equations derived from the geometry of the problem such as concrete cracking (e.g. Goltermann 1994).

A traditional way of modelling corrosion propagation is by the corrosion rate modified by the diameter of reinforcement and the concrete cover. (Siemes et al. 1985) The corrosion rate itself is related to the wetness and temperature of the structure and is modelled e.g. by the potential electrolytical resistivity of concrete (DuraCrete 2000). A way of finding information on the corrosion propagation phase by statistically calculating backwards the age and initiation time on existing concrete structures subjected to condition assessments has been proposed by Köliö et al. (2014).

3. Research material and methods

The propagation of corrosion on concrete facades in Finnish environmental conditions was studied by a series of field and laboratory studies conducted on twelve residential concrete buildings located in different parts of southern Finland. The studies were conducted in tandem with the normal condition assessment inspections for these buildings. In addition, the extent to which the corrosion rates in concrete facades are affected by the outdoor environment was analysed using long-term (25 months) field measurements from concrete facades under natural weather conditions. These experimental results were compared with statistical information on 947 buildings.

The condition assessment database was used in studying statistically the realized service life of concrete facades in regard of visual damage caused by reinforcement corrosion (Köliö et al. 2014). The age at which visual corrosion damage is generally observed in concrete facades was studied using visual damage ratings given in condition assessments. This damage rating was used together with the age of buildings to study the time it takes for corrosion damage to propagate.

The type and critical amount of corrosion products were studied by electron microscopy and X-ray diffractometry on concrete and reinforcement samples from existing concrete facades on visually damaged locations. This information was utilized in creating a service life limit for concrete facade panels in regard of visual corrosion damage occurrence. Corrosion rate was determined as a combined effect of weather parameters on already carbonated concrete structures exposed to natural outdoor environment. A long term corrosion rate measurement data was combined with weather data from the location of the measurements from the same time period.

These in-depth studies were used to model the probable extension in residual service life given by the active corrosion phase for existing concrete facades. The modelling approach counts among the empirical models with statistical experimental data.

Ways of utilizing the knowledge on the corrosion propagation phase in the renovation strategy were analysed based on acknowledged renovation intervention options or principles (SFS-EN 1504-9; by41 2007). The possible benefits from the propagation phase were analysed in regard of timing, budgeting and prioritizing of renovation projects.

4. Results and discussion

4.1 Reinforcement corrosion modelling

This chapter discusses the service life of concrete facades in Nordic climate including the initiation of corrosion and corrosion propagation until visual corrosion cracking occurs. The discussion is based on studies described in chapter three.

During initiation phase the concrete cover is carbonated as a barrier and finally reaching the steel initiating the actual corrosion process. Until this point, no actual damage has occurred at all. In the propagation phase, as the corrosion proceeds it will eventually induce visual damage to the concrete structure’s surface as cracks or spalls. The rate of this process depends on many things, such as cover depth, diameter of the reinforcing steel as well as temperature and the availability of moisture. A statistical distribution over time was produced for the formation of visual damage after consecutive initiation and propagation phases on concrete facade and balcony structures (Fig. 1). Because the information about the age of the building is linked to the time of condition assessment these examinations do not take into account the fact that visual cracks or damage have, in fact, emerged some time before the assessment date. This time before the condition assessment is in this study unknown. Thus, the visual damage is likely to be formed even earlier than the results indicate, and the results of this study should be treated accordingly.

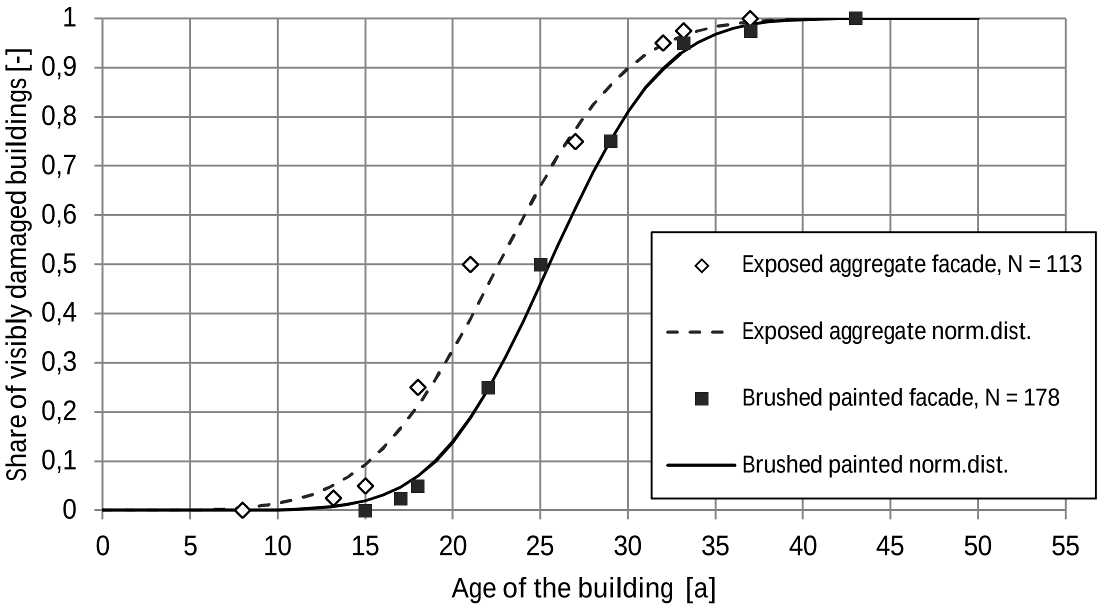

Figure 1: Statistical model for the evolution of corrosion damage after consecutive initiation and propagation phases based on condition assessment data.

The first visual damage had occurred after 15 years from construction in brushed and painted concrete facades and after 8 years in exposed aggregate facades. By median, visual corrosion damage has formed on concrete facades after 21 to 25 years from construction (exposed aggregate and brushed painted respectively). The propagation phase was estimated by extracting from the total age (Fig. 1) a known initiation phase based on carbonation depth measurement data. According to the calculation, the length of the propagation phase is 0.6–1.4 years when adopting a commonly used 5 % safety level. It relates to corrosion of reinforcement with extremely small cover depth or in very capillary concrete. However, this safety level may be too strict compared to empirical knowledge. On average, the length of the propagation phase has been 6–10 years depending on the type of structure.

Concrete structures studied by characterization methods (SEM, EDS, XRD) were on average 38.8 years old. The average time under active corrosion was for the cracked locations 26.0 years. It should also be noted that for all of the samples corrosion has been initiated quite fast (by average 12.6 years) which indicates that both concrete resistance against carbonation has been poor and the environmental conditions favourable to carbonation (somewhere between exposure classes XC3 and XC4). Corrosion products associated with carbonation initiated corrosion on the studied concrete facade panels were mostly hydroxide type of rusts with a unit volume of roughly 3 times the volume of iron. Taking the determined relative volume of the rust layer into account the required corrosion penetration to initiate visually observable cracks in the studied facade panels was by average 67.5 µm (total range of 22.2–119.1 µm) with a corresponding rust thickness of 202.5 µm.

Measured corrosion current densities show high scatter but are in general rather high (Fig. 2). The wind-driven rain amounts on the structures have during the monitoring period been 47 % higher inland than in the coastal region. Inherently, the corrosion rates have been 11–18 % higher inland than in the coastal region. This observation stresses the importance of the micro climate around the building along with the geographical location in regard of degradation rate. Current densities measured as a reference from the bottom surface of a balcony slab (sheltered from rain) were very low. In a regression analysis between corrosion rate and weather parameters all seasons showed high correlation between wind-driven rain and corrosion rate.

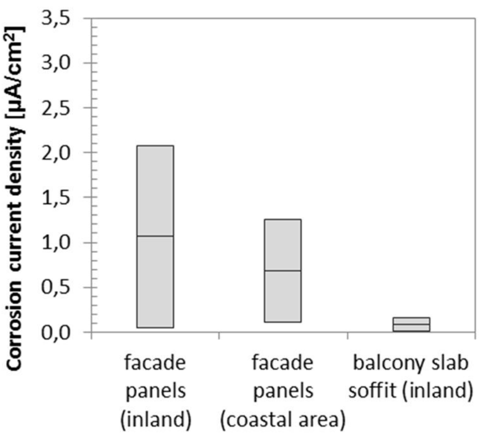

Figure 2: Monthly averaged corrosion current densities recorded in field measurements in inland and in coastal area of Finland.

Corrosion rates during the lifetime of the concrete structures at inland and coastal area locations were estimated using the model with a record of 30-year weather data from 1979–2009. The weather data was available for coastal site from Helsinki-Vantaa airport (distance to site 15 km) and for inland site from Jokioinen observatory (distance to site 79 km). On a long time scale the corrosion rate on concrete facades were relatively steady at the both locations.

The overall average level was 1.2 µA/cm^2 at inland and 1.7 µA/cm^2 at coastal area site. These corrosion rates correspond to a steel loss of 14.6 µm/year and 19.6 µm/year, respectively, derived from the Faraday's law. These corrosion levels can be considered high (Andrade & Alonso 2001) in carbonation initiated outdoor concrete structures. Based on the modelled corrosion rate and the measured critical corrosion penetration, the length of the propagation phase is estimated to be approximately 1.5–8 years in inland and 1–6 years in the coastal area in south facing facades.

4.2 Active corrosion phase in renovation strategy

The studies presented in this paper aim to enhance the knowledge on the corrosion propagation phase in reinforced concrete facades as a part of their service life. The research project confirmed that the propagation phase can provide a considerable extension to the service life of concrete facade panels in Nordic climate. This extension can be from ten to even 30 years. However, it varies considerably due to material, structure and environmental factors.

Table 2: The relationship of initiation and propagation phases in concrete facade panels (average in brackets)

structure surface	share of the initiation phase in the total service life, average in parenthesis (%)	share of the propagation phase in the total service life (%)
brushed painted concrete facade	85–98 (88)	2–15 (12)
exposed aggregate concrete surface	91–99 (94)	1–9 (6)

It appears, from Table 2, that the potential for extending a structure's service life with the propagation phase is in some cases considerable (by average 6–12 %). Although, majority of the service life of concrete is accounted for already in the initiation phase. Therefore, when assessing the total service life of a building, it is critical to ensure the structures have the required resilience to carbonation in terms of concrete composition, concrete quality and cover depths. If the properties of the initiation phase are already fixed (as is the case in existing structures) it seems clear that accurate information about the propagation phase will have to be utilized to extend a structure's service life.

The ability to model or forecast corrosion rates on concrete facades will enhance the capability of realtors to react on upcoming repair needs. This kind of model would be able to predict the residual service life of a certain structure, but it could also be used in creating renovation strategies for a larger building stock by revealing the order of importance or the urgency of single renovation projects. The knowledge on active corrosion phase will enhance the capability of the owner to utilize the delaying options with more confidence. Especially this knowledge will help in pointing out the cases where these options are applicable and where they are not (Table 3). It also illustrates clearly the influence of the delaying of renovation, which will in eventually render lighter repair options not applicable due to increasing degradation.

The occurrence of visual damage is a natural way of judging the service life of these structures since all of the renovation and maintenance decisions are made based on investigations usually commissioned based on these visual signs. This, however, means that lighter remedial actions are not anymore available and repair & protect options have to be considered to some extent. In order to be able to utilize only protective options, the service life should not include propagation phase. The intervention should in this case be taken directly in the end of the initiation phase.

Corrosion induced damage occurred on the studied structures commonly on the lap splicing locations of rebars, in the edges and window openings of the panels and in locations with pronounced moisture load due to poorly functioning flashings and rain water runoff control. If the ratio of concrete cover to reinforcement diameter was small (below 1.5) corrosion related damage had emerged as spalling. If the ratio was well over 1.5 the damage more probably emerged as cracking. Careful design of the above mentioned details will allow longer propagation phases to be taken into account in service life.

Table 3:Renovation options contrasted to different renovation strategies.

Repair option	Early intervention (up to initiation)	Early intervention (up to first visual damage)	Need-based-repair (intrusive)	Maximized service life
a) do nothing & monitor	Available	Available	Not available	Not available
b) re-analyse & downgrade in function	Downgrade not required	Downgrade not required	Available	Not available
c) prevent & reduce further degradation	Available	Available	Not available	Not available
d) repair & protect	Available	Available	Available	Not available
e) replace with new	Not reasonable	Available	Available	Available
f) demolish	Not reasonable	Not reasonable	Available	Available

The available repair options (Table 3) illustrate the importance of early intervention. At this point the available options are many and they are in general fairly light. A need-based renovation strategy already requires some level of intrusive repair. A strategy aiming at maximizing the available service life of the existing structure will lead to heavy renovation, replace or demolition eventually. A conventional limit for the early intervention strategy is the initiation of corrosion. However, it is visualized that this strategy is not compromised even when the service life is extended to the propagation phase. Same set of renovation options will be available until the occurrence of damage as cracking or spalling. This information can be utilized in planning of the renovation of structures, where the initiation phase has already passed. Modelling the length of the propagation phase will allow a time-span of up to 8–10 years for planning and budgeting of the renovation work without compromising the choice of strategy.

5. Conclusions

Renovation strategy of a built asset is tied to the business/maintenance strategy, financial situation and future prospects of the owner. The options and principles available for the renovation of concrete facades are many. However, all of them have specific uses and preferable conditions where they perform best. It should be acknowledged that the decisions of the owner in the timing of the repairs greatly affect which renovation options and principles are applicable. Protective renovation options usually perform best when applied in the initiation phase of degradation whereas delaying intervention will force the use of repair/renew options.

The knowledge on active corrosion phase will enhance the capability of the owner to utilize the delaying options with more confidence. Such a tool could be used also in moving towards a predictive upkeep of realty and the confidence of making long term contracts between realty owners, renovation engineers and contractors.

The research project confirmed that the active corrosion phase can provide a considerable extension to the service life of concrete facade panels in Nordic climate. This extension can be from ten to even 30 years. However, a probable extension is 8–10 years in high environmental stresses. This time period may well provide the necessary latitude for the renovation budget and planning.

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Integrating Building Information Modeling Technology, Facility Management System and Maintenance Cost Database in Predicting Building Life Cycle Maintenance Cost

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Abstract

In building operational phase, facility management problems such as the deferral of critical repair, replacement or renovation of building structure or equipment are often observed in Taiwan due to inadequate annual maintenance funding. Building owners and facility managers are in great need of a method or tool to predict the maintenance costs over the life spans of their facilities in order to allocate adequate maintenance funding to sustain their facilities. To solve this problem, this study adopts and integrates existing technologies such as building information modeling (BIM), facility management system (ArchiBus○,R), and local construction and maintenance cost database (PCCES) to establish the Building Life Cycle Maintenance Cost Prediction method (BLCMCP) to predict annual maintenance costs over building life span based on a set of predefined maintenance plans. It is proposed that (1) BIM software such as REVIT is used to create all the components (each with a CSI's MasterFormat code) of each building subsystem of a building, from which a 'component list' of a building subsystem with quantity takeoff can be generated; (2) Facility management system such as ArchiBus○,R is used to specify the schedules of various maintenance tasks (inspection, repair, renovation, or replacement) for each component of a building subsystem over building life span such as 30 years; (3) local construction and maintenance cost database such as PCCES in Taiwan is used to provide updated construction and maintenance cost data (labor and material costs) for each component of a building sub-system. The annual maintenance cost of a component of a building subsystem in a particular year can be estimated by retrieving the maintenance tasks scheduled from the ArchiBus○,R as well as the unit cost data of each maintenance task from the PCCES according to its MasterFormat code. The 'elevator' subsystem of the Taiwan Building Technology Center (TBTC) building located on the NTUST university campus is used as a case to demonstrate how the established BLCMCP method can be used to estimate the annual maintenance costs of this subsystem and its components over a 25-year life span.

Keywords: MasterFormat code, maintenance schedule, construction and maintenance cost database

1. Introduction

1.1 The Problems

The structure and various building control equipment of a building have their design service lives, and they are expected to degrade or breakdown sometime during the building life span. Facility management plays an important role in operating and maintaining building components and keeping them in reliable conditions. Nevertheless, facility management problems such as the deferral of critical repair, replacement or renovation of building structure or equipment are often observed due to inadequate annual maintenance funding. Building owners and facility managers are in great need of a method or tool to predict the maintenance costs over the life spans of their facilities in early operational phase in order to allocate adequate maintenance funding to sustain their facilities.

1.2 Potential Technologies as the Solution

To solve this problem, this research argues that existing potential technologies such as building information modeling (BIM), facility management systems, and local maintenance cost database can be adopted and integrated to establish a building life cycle maintenance cost prediction tool.

Building Information Modeling (BIM) has recently attained widespread attention in the architectural, engineering and construction (AEC) industry worldwide. Many researches have been dedicated to demonstrate the applications of BIM's responsive quantity takeoff capability in cost estimation in building design and construction phases (Eastman et al., 2008; Meadati and Nelabhotla, 2011; Lu et al., 2016; Popov et al., 2006; Smith, 2014). This study argues that the same capability is potentially applicable to maintenance cost prediction during operational phase as well by producing quantity takeoff for those building elements to be maintained.

Facility management systems or computerized maintenance management system have been used to plan and manage maintenance tasks during building operational phase. To predict building life cycle maintenance cost in early operational phase, it's critical that cost estimations are based on a set of pre-planned maintenance tasks to be conducted on various building subsystems and their components over a certain life span, which can be effectively assisted and scheduled by facility management systems.

To further estimate the cost of each maintenance task, it is necessary to acquire the unit costs of the labor, material, or equipment involved in that task. Local construction and maintenance cost databases, such as RS Means cost data (Plotner, 2013), have been established in many regions or countries, and can provide cost data required for maintenance cost estimation purpose.

1.3 Research objectives

This research intends to develop a building life cycle maintenance cost prediction method to be used in early operational phase. To be more specific, the objectives of this research are:

1. To establish a Building Life Cycle Maintenance Cost Prediction method (BLCMCP) that integrates BIM, ArchiBus®, facility management system and a local construction cost database (PCCES) to predict the annual maintenance costs of a building over its life span given a set of maintenance plans specified in early operational phase;
2. To demonstrate how the developed BLCMCP framework can be applied in the Taiwan Building Technology Center (TBTC) Building on NTUST university campus to predict the life cycle maintenance costs of its elevator subsystem.

2. Literature review

Compared to the construction cost estimation methods devised for new building construction, relatively few researches have been dedicated to developing effective building life cycle cost estimation methods. In their book *Life Cycle Costing for Facilities*, Dell'Isola and Kirk (2003) not only present the methods for economic analysis (ROI, etc.) and life cycle cost analysis (NPV, etc.), but also suggest a framework for estimating life cycle costs, in which decomposing a whole building into several levels of hierarchical elements and adopting MASTERFORMAT or UNITFORMAT that link to cost databanks appear to be the key concepts. Stanford (2010) proposes effective building maintenance as a way to protect capital assets. He not only addresses the importance of budgeting for various types of maintenance taking place during building life span, but also presents budgeting methods adopting the ideas of decomposing a building into four levels of elements as well as remaining design service life for maintenance cost estimation. Kim et al. (2010) employed similar decomposition structure to develop a life cycle cost estimate system for structures of light rail transit infrastructure. The notions underlying the life cycle cost estimation methods proposed above are to decompose a building into several levels of components and then to estimate the life cycle costs for all components individually, which represent great amount of work if done manually.

BIM seems a reasonable technique to be adopted for life cycle cost estimation, considering its capabilities in structuring building components and automatic quantity takeoff. In fact, numerous studies have proposed the 5D concept and applied BIM in building cost estimation to be used during design and construction phase (Cheung et al., 2012; Lu et al., 2016; Popov et al., 2010; Smith, 2014). In these applications, BIM involves more than just 3D modeling and is also commonly defined in further dimensions such as 4D (time) and 5D (cost). 4D links information and data in the 3D object model with project programming and scheduling data and facilitates the simulation analysis of construction activities. 5D integrates all of this information with cost data such as quantities, schedules and prices.

Literature review conducted by this study reveals that little research has been done in applying BIM in predicting long term building life cycle costs. Whyte and Scott (2010) employed statistics and probability, fuzzy set logic, artificial neural networks and objected orientated analysis to develop a life-cycle-cost system in order to assist design decisions, which require advanced techniques to implement. This study argues that the 5D BIM concept, although mainly applied in new building construction cost estimation, linking the 3D BIM model, quantities, schedules, and prices is still a feasible approach to be explored in life cycle cost prediction.

3. The Building Life Cycle Maintenance Cost Prediction (BLCMCP) Methodology

3.1 BIM Model and the MasterFormat Code

This study proposes that building information modeling (BIM) technology be used to organize a building in the following ways for the purpose of life cycle maintenance cost prediction:

1. Each building is decomposed into ten building subsystems: structure, enclosure, interior, HVAC, electrical, telecommunication, fire safety, water/plumbing, conveying, and landscape sub-systems (Table 1).
2. Each building subsystem is decomposed into two levels of elements. A subsystem is first categorized into several major 'assemblies' (level one element), which is then further decomposed into several 'components' (level two element). BIM software such as REVIT can then be used to establish the BIM models for all the 'components' of each subsystem (Table 1). For each 'component' of a subsystem, the maintenance schedules or frequencies of various types of maintenance task can be further specified by facility management software.
3. For each component of a building subsystem, a CSI's MasterFormat code is assigned (Table 1). The MasterFormat code of a component is an unique number or 'key' used to link to and retrieve its maintenance cost data stored in a local maintenance cost database.

Once the BIM models of all subsystems of a building is established, the 'bill of quantity' of all components of ten subsystems can be generated automatically. The 'quantity' of each component is an important parameter for estimating its long term maintenance cost.

3.2 Facility Management System for Long Term Maintenance Tasks Planning

Over the life span of a building, various maintenance tasks (planned or unplanned) are often conducted on individual subsystems and their components to sustain their performance and achieve their service lives. To predict the long term maintenance costs of a building, it is imperative to plan ahead (in early operational phase) for the planned maintenance tasks to be conducted on each component of each subsystem at different time during a certain building life span. The planned maintenance tasks typically conducted are preventive maintenance (inspection/ testing, repair) as well as planned renovation and replacement (Stanford, 2010). The labor (man-hour) and material (or equipment) involved in a particular maintenance task on a component can be assessed, based on which the maintenance cost can be further estimated.

Given the decomposition-structure of a building described in the previous section (3.1), this study suggests that facility management systems (such as ArchiBus®) be used to plan and specify the frequencies (or the schedules) of each type of planned maintenance task (inspection, repair, renovation, and replacement) to be conducted annually for each component of a subsystem over building life span such as 30 years (Frequency columns in Table 1).

Table 1: *Data to be specified by BIM model, FM system and local maintenance cost database for building life cycle maintenance cost estimation.*

Building Subsystems	Level 1 Assembly	Level 2 Component	Master Format / PCCES code	Spec. info	Quantity	A. Inspection			B. Repair			C. Renovation			D. Replacement		
						Freq-uency	Man-day Material	LUC MUC	Freq-uency	Man-day Material	LUC MUC	Freq-uency	Man-day Material	LUC MUC	Freq-uency	Man-day Material	LUC MUC
1. Structure	S1 Foundation	S1-1 Structural concrete	03 31 13														
		S1-2 Concrete Reinforcing	03 20 00														
		S1-3.....															
	S2 Column	S2-1 Structural steel for bldg	05 12 23														
		S2-2 Steel Joist Framing	05 21 13														
		S2-3.....															
	S3 Beam	S3-1 Structural concrete	03 31 13														
		S3-2 Concrete Reinforcing	03 20 00														
		S3-3.....															
	.....																
2. Enclosure	E1 Roof	E1-1 Mortar-based ceramic tile	09 32 13														
		E1-2 Tooled concrete finishing	03 35 29														
		E1-3 Built-Up asphalt waterproof	07 12 13														
		.....															
	E2 Exterior wall	E2-1 Masonry stone cladding	04 42 13														
		E2-2 Grooved concr. surf. finsh.	03 35 26														
		E2-3 Heavywght arch. concrete	03 33 13														
		.....															
	.....	.....															
3. Interior	I1 Ceiling	I1-1 Acoustic panel ceiling	09 51 13														
		I1-2.....															
	I2 Flooring	I2-1 Wood block flooring	09 64 16														
		I2-2.....															
	I3 Wall	I3-1 Curtain Wall	08 44 00														
		I3-2 Sheet Metal Wall Cladding	07 64 00														
		I3-3 Faced Panels	07 44 00														
		.....															
	.....	.....															
4. HVAC	H1 Central cooling equipment	H1-1 Centrif. refrig. compressor	23 61 13														
		H1-2.....															
	H2 HVAC air distribution	H2-1 Metal Ducts	23 31 13														
		H2-2.....															
	.....	.....															
5. Power / Electrical	P1 Electrical distribution	P1-1 Dry-type, transformers	26 12 16														
		P1-2.....															
	P2 Lighting	P2-1 Interior lighting fixtures,	26 51 13														
		P2-2.....															
	.....	.....															
6. Telecommunication	T1Communications	T1-1 Communications Cabling	33 82 13														
	T2Wireless	T2-1 Transmitters and Receivers	33 83 16														
	.....	.....															
7. Fire safety	F1 Fire Pumps	F1-1 Centrifugal Fire Pumps	21 31 00														
	F2 Fire-Suppression	F2-1 Fire-Suppression Water	21 41 00														
	.....	.....															
8. Water / Plumbing	W1 Plumbing Piping	W1-1 Facility Water Distribution	22 11 00														
	W2 Plumbing Equipment	W2-1 Water Filtration Equipment	22 32 00							1							
	.....	.....															
9. Conveying	C1Guideways/Railways	C1-1 Rail Tracks	34 11 00														
	C2 Traction Power	C2-1 Traction Power Distribution	34 21 00														
	.....	.....															
10. Landscape	L1 Paving	L1-1 Rigid Paving	32 13 00														
	L2 Planting	L2-1 Turf and Grasses	32 92 00														
	.....	.....															

Note: PCCES = Public Construction Cost Estimation System (Taiwan construction cost database); LUC = labor unit cost (NTD/man-day); MUC = material unit cost (NTD/unit)

3.3 Local Construction Cost Database for Providing Updated Maintenance Cost Data

The unit cost data of the labor and material (or equipment) involved in a particular maintenance task performed on a particular component of a subsystem are required for the estimation of this maintenance cost. In many regions or countries, local building related cost data (in hardcopy or online) have been investigated and updated periodically. For example, the Gordian Group Inc. offers RS Means facilities maintenance cost data in the US, which are organized by using the Construction Specifications Institute's MasterFormat (Plotner, 2013). In Taiwan, the Public Construction Cost Estimation System (PCCES) is a cost estimation system developed by the government to be used by the contractors to prepare the construction cost estimation of a building project. The PCCES contains an updated construction and maintenance cost database (labor, material and equipment unit cost data) for various components of building subsystems which are given with individual MasterFormat codes.

This study suggest that the unit cost data of labor and material (or equipment) involved in four types of maintenance tasks (inspection, repair, renovation, replacement) performed on components of all subsystems be retrieved from the local construction or maintenance cost database in order to further estimate the maintenance cost of all subsystems year by year over a certain building life span (labor cost and material unit cost columns in Table 1).

3.4 Building Life Cycle Maintenance Cost Estimation Model

3.4.1 Total Building Life Cycle Maintenance Cost

To predict the total building life cycle maintenance cost over a certain life span of a building, this study proposes that the total costs of planned maintenance conducted on all ten subsystems and their components are estimated year by year, as indicated in Eq-1.

$$BLCMC_n = \sum_{i=1}^{n}(STRUCTURE_i + ENCLOSURE_i + INTERIOR_i + HVAC_i + POWER_i + TELECOM_i + FIRE_i + PLUMB_i + CONVEY_i + LANDSCAPE_i) \quad \text{(Eq-1)}$$

where:

$BLCMC_n$ = total long term maintenance cost over a n-year building life span
$STRUCUTRE_i$ = total maintenance cost of structure subsystem in year-i
$ENCLOSURE_i$ = total maintenance cost of enclosure subsystem in year-i
$INTERIOR_i$ = total maintenance cost of interior subsystem in year-i
HVACi = total maintenance cost of HVAC subsystem in year-i
$POWER_i$ = total maintenance cost of power/electrical subsystem in year-i
$TELECOM_i$ = total maintenance cost of telecommunication subsystem in year-i
$FIRE_i$ = total maintenance cost of fire safety subsystem in year-i
$PLUMB_i$ = total maintenance cost of plumbing subsystem in year-i
$CONVEY_i$ = total maintenance cost of conveying subsystem in year-i
$LANDSCAPE_i$ = total maintenance cost of landscape subsystem in year-i

3.4.2 Annual Maintenance Cost of a Subsystem and its Components

To predict the annual total maintenance cost of a subsystem and its components in a particular year, this study proposes that the total costs of four major types of planned maintenance (inspection, repair, renovation and replacement) conducted on the subsystem and its components in that year are estimated. For example, to predict the total annual maintenance cost of HVAC subsystem in year-i ($HVAC_i$), the total costs of inspection, repair, renovation and replacement tasks conducted on all HVAC components in year-i can be estimated individually and added up, as indicated in Eq-2.

$$HVAC_i = H\text{-}inspect_i + H\text{-}repair_i + H\text{-}renovate_i + H\text{-}replace_i \qquad \text{(Eq-2)}$$

where:

$HVAC_i$ = total cost of four types of maintenance on all HVAC components in year-i
$H\text{-}inspect_i$ = total cost of all <u>inspection</u> tasks conducted on all HVAC components in year-i
$H\text{-}repair_i$ = total cost of all <u>repair</u> tasks conducted on all HVAC components in year-i
$H\text{-}renovate_i$ = total cost of all <u>renovation</u> tasks conducted on all HVAC components in year-i
$H\text{-}replace_i$ = total cost of all <u>replacement</u> tasks conducted on all HVAC components in year-i

3.4.3 Annual Maintenance Cost of a Particular Component of a Subsystem

To predict the annual total cost of four types of planned maintenance tasks conducted on a particular component of a subsystem in a particular year, this study proposes that the monthly costs of each type of planned maintenance conducted on that component in that year are estimated and added up, as shown in Eq-3.

$$HVAC_{k\text{-}i} = \sum_{j=1}^{12}(H_k\text{-}inspect_{i\text{-}j}) + \sum_{j=1}^{12}(H_k\text{-}repair_i) + \sum_{j=1}^{12}(H_k\text{-}renovate_i) + \sum_{j=1}^{12}(H_k\text{-}replace_i) \qquad \text{(Eq-3)}$$

where:

j ranges from 1 to 12, representing 12 months;
k represents the k^{th} component of the HVAC subsystem.

To further estimate the annual 'inspection' cost conducted on the k^{th} component of HVAC subsystem ($H_k\text{-}inspect_{i\text{-}j}$), the frequency of inspection and the labor and material required in year-i planned earlier can be retrieved from the FM system, and then the labor and material unit costs can be retrieved from local construction cost database, whose multiplications yield the monthly inspection costs and thus annual inspection cost. Similarly, annual 'repair', 'renovation' and 'replacement' costs for the k^{th} component of HVAC subsystem can be estimated.

By adding up the annual total maintenance costs of all components of HVAC subsystem in year-i, $HVAC_i$ can be estimated. Similarly, the annual total maintenance costs of all other sub-systems can be estimated. Likewise, the annual total maintenance cost of a ‘whole building’ can be estimated year by year, and finally the total building life cycle maintenance cost.

4. Demonstration Case

4.1 The Subject - TBTC

The Taiwan Building Technology Center (TBTC) building is a relatively new but small building (in operation since 2011.1) located on the NTUST university campus (Figure 1). TBTC is a steel structure with a curved facade assembled from triangular punched aluminium panels, and a seven-story facility (plus B1) with a total floor area of 1,400m^2. It's mainly a research building with functional uses of research lab, conference room, and office. Its 'elevator' subsystem is used as a case to demonstrate how the established BLCMCP method can be used to estimate the annual maintenance costs of this subsystem and its components over a 25-year life span.

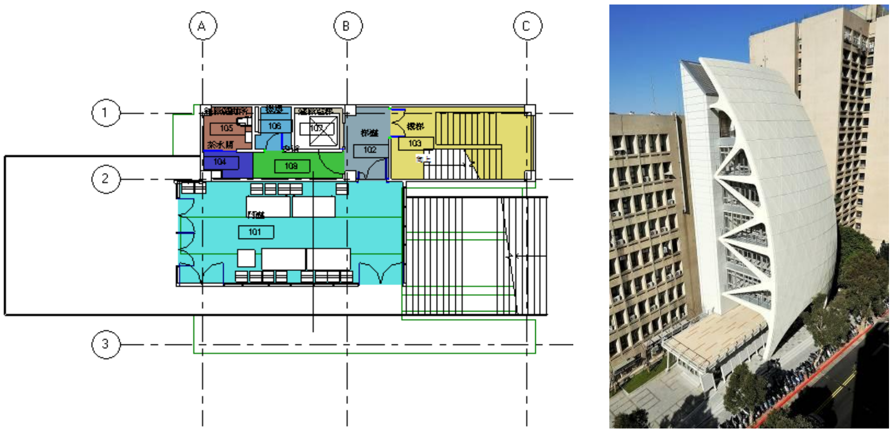

Figure 1: First floor plan and exterior view of TBTC.

4.2 The BIM Model of TBTC

Autodesk's REVIT® was used to build the BIM model for TBTC (Figure 2). BIM models were built for each of the ten subsystems with two levels of elements according to the decomposition structure specified in Section 3.1. Each component of a particular subsystem is given a MasterFormat code. The exemplary 'elevator' subsystem consists of four assemblies (machine, car, control and hoistway) and 18 components (Figure 2, Table 2).

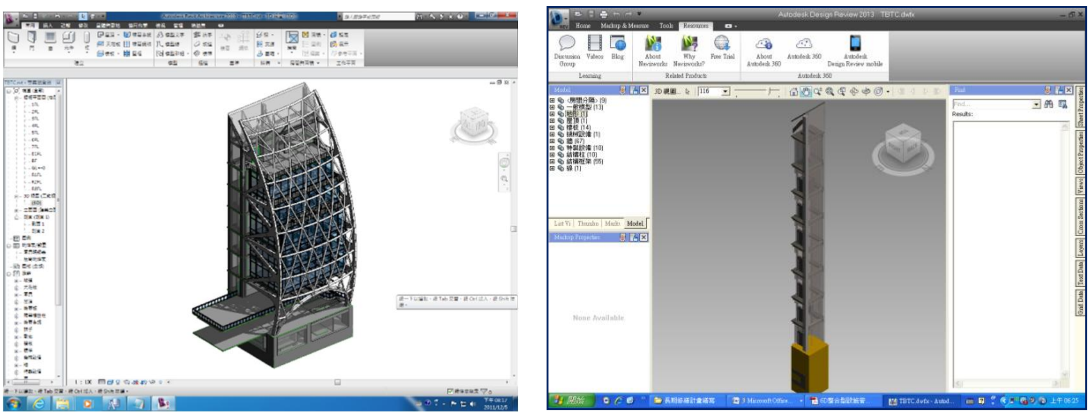

Figure 2: The established BIM models of a certain floor and the elevator subsystem of TBTC.

4.3 ArchiBus○,R for Maintenance Planning

Facility management software ArchiBus○,R was used to establish the maintenance plans of all the components of the ten subsystems of TBTC over a 25-year life span. In the case of TBTC's elevator subsystem, the schedules or frequencies of four types of maintenance tasks to be conducted on each of the 18 components were planned year by year. Table 2 shows conceptually the maintenance schedules of all 18 components planned for 2026 (to be 16 years old). It's noteworthy that five components are scheduled to be replaced in January, 2026 (Ds in Jan. column in Table 2). Besides, the labor and material required for each type of maintenance tasks are specified by ArchiBus○,R, as indicated by the MD and Mat. columns in Table 3.

Table 1: The maintenance schedules of all components of elevator subsystem planned for 2026.

Level 1 Assembly	*Level 2 Component*	*Master Format / PCCES code*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
C1 Elevator Machine	*C1-1Prim. veloc. transducer*	*14210T*	D	A	B	A	A	B	A	A	B	A	A	B
	C1-2 Traveling cable	*14210E*	A	A	B	A	A	B	A	A	B	A	A	B
	C1-3 Counterweight	*14210X*	D			A	B	A	B	A	B	A	B	A
C2 Car	*C2-1 Elevator car*	*14210V*		A		A		A		A		A		A
	C2-2 Door drive	*14210R*	D			A	A	B	A	A	A	A	A	B
	C2-3Take gate	*14210J*	A	A	A	A	A	B	A	A	A	A	A	C
	C2-4 Guider rail fixing brckt	*14210M*	B	A	A	C	A	A	C	A	A	C	A	A
	C2-5 Elevator rail	*14210U*	A	A	A	A	A	A	A	A	A	A	A	C
	C2-6 Car safety System	*14210N*				A	A	B	A	A	B	A	A	B
	C2-7 Slide guide & oil	*14211w*	A	A		A	A		A	B		A	A	
C3 Control	*C3-1 Control system*	*14210c*	A	A	B	A	A	B	A	A	B	A	A	B
	C3-2 Operator panel	*14210L*		A			A			A			A	
	C3-3 Control cable & wiring	*14210E*			A		A	B		A		A	B	
C4 Hoistway	*C4-1 Roller guides*	*14210F*	D			A	A	B	A	A	B	A	A	B
	C4-2 Side guide rail	*142100*	D			A	A	B	A	A	B	A	A	B
	C4-3 Tension pulley	*14210G*	B			A	A	B	A	A	B	A	A	B
	C4-4 Car buffer	*14210P*	A	A	A	A	A	B	A	A	A	A	A	B
	C4-5 Counterweight buffer	*14210b*				A	A	A	A	A	A	A	A	A

Note: A = inspection; B = repair; C = renovation; D = replacement.

4.4 PCCES: The Maintenance Cost Database

The Public Construction Cost Estimation System (PCCES) is a local construction cost estimation system and construction cost database in Taiwan. For each component of all ten subsystems of TBTC, the labor and material unit cost data for each type of maintenance task were retrieved from PCCES according to the MasterFormat code of the component. Table 3 shows conceptually the labor and material unit cost data for each type of maintenance task retrieved from PCCES for all 18 components of the elevator subsystem.

4.5 The Building Life Cycle Maintenance Cost Prediction for TBTC

For the elevator subsystem of TBTC, the annual total cost of each type of maintenance tasks conducted on a certain component (say 'inspection') were calculated as: $CONVEY_{k-15}$ = quantity * $INSPECT_{freq}$ * ($INSPECT_{labor}$ * $INSPECT_{lab\text{-}unit\ cost}$ + $INSPECT_{material}$* $INSPECT_{mat\text{-}unit\ cost}$). Three other types of maintenance tasks conducted on this component were calculated similarly. Table 4 shows the monthly maintenance costs for all components of the elevator subsystem in 2026 (inflation rate not considered in this study for simplicity reason). In most of the months in 2026, periodical inspection and repair are to be conducted, resulting in 1441~2936 NTD monthly maintenance costs; whereas five components are scheduled to be replaced in January, resulting in 238,224 NTD replacement cost. The annual total maintenance cost for elevator subsystem in 2026 is estimated to be 263,574 NTD. Figure 3 exhibits the annual and accumulated maintenance costs of TBTC's elevator subsystem over its 25-year building life span. Most of annual maintenance costs of the elevator subsystem range from 20,000~30,000 NTD and the accumulated maintenance cost over 25 years is estimated to be 1,362,415 NTD.

Similarly, the annual total maintenance costs of nine other subsystems of TBTC over 25-year life span can be estimated and added up to generate the building life cycle maintenance cost at the whole building level for TBTC.

Table 2: The labor and material required for each type of maintenance task are specified by ArchiBus and their unit cost data retrieved from PCCES for all elevator subsystem components.

Level 1 Assembly	Level 2 Component	Master Format / PCCES code	A. Inspection				B. Repair				C. Renovation				D. Replacement			
			MD	LUC	Mat	MUC	MD	LUC	Mat	MUC	MD	LUC	Mat	MUC	MD	LUC	Mat	MUC
C1 Elevator Machine	C1-1Prim. veloc. transducer	14210T	0.013	2500	1	10	0.125	2500	0.25	4000	0.188	2500	0.2	2000	0.500	2500	1	70000
	C1-2 Traveling cable	14210E	0.038	2500	1	5	0.375	2500	0.25	800	0.188	2500	0.2	800	0.188	2500	1	80000
	C1-3 Counterweight	14210X	0.013	2500	1	5	0.250	2500	0.07	1200	0.125	2500	0.2	1200	0.125	2500	1	19000
C2 Car	C2-1 Elevator car	14210V	0.044	1800	1	15	0.025	1800	0.05	1200	0.125	1800	0.1	1200	0.250	1800	1	150000
	C2-2 Door drive	14210R	0.125	1800	1	10	0.025	1800	0.15	400	0.025	1800	0.1	400	0.063	1800	1	38000
	C2-3Take gate	14210J	0.063	1800	1	15	0.025	1800	0.02	3600	0.031	1800	0.02	3600	0.250	1800	1	56000
	C2-4 Guider rail fixing brckt	14210M	0.125	1800	1	5	0.025	1800	0.07	1600	0.063	1800	0.1	1600	0.188	1800	1	46000
	C2-5 Elevator rail	14210U	0.063	1800	1	5	0.100	1800	0.07	3000	0.063	1800	0.1	3000	0.188	1800	1	24000
	C2-6 Car safety System	14210N	0.063	1800	1	5	0.025	1800	0.25	600	0.125	1800	0.2	600	0.125	1800	1	35000
	C2-7 Slide guide & oil	14211w	0.094	1800	1	5	0.025	1800	0.07	1500	0.031	1800	0.1	1500	0.125	1800	1	36000
C3 Control	C3-1 Control system	14210c	0.125	2500	1	15	0.313	2500	0.25	400	0.125	2500	0.2	400	0.188	2500	1	55000
	C3-2 Operator panel	14210L	0.031	1800	1	10	0.106	1800	2	240	0.031	1800	2	240	0.188	1800	1	120
	C3-3 Control cable & wiring	14210E	0.013	2500	1	5	0.188	2500	3	170	0.125	2500	2	170	0.250	2500	1	85
C4 Hoistway	C4-1 Roller guides	14210F	0.025	1800	1	5	0.025	1800	0.25	500	0.063	1800	0.2	500	0.125	1800	1	50000
	C4-2 Side guide rail	142100	0.063	1800	1	5	0.025	1800	0.25	600	0.125	1800	0.2	600	0.125	1800	1	35000
	C4-3 Tension pulley	14210G	0.025	2500	1	5	0.250	2500	0.07	4800	0.125	2500	0.1	4800	0.250	2500	1	68000
	C4-4 Car buffer	14210P	0.031	1,800	1	20	0.031	1,800	0.02	50000	0.031	1,800	0.02	50000	0.063	1800	1	25000
	C4-5 Counterweight buffer	14210b	0.050	1800	1	5	0.025	1,800	0.02	16000	0.025	1800	0.02	16000	0.063	1800	1	35000

Note: MD = man-day; LUC = labor unit cost (NTD/MD); Mat = material; MUC = material unit cost (NTD/unit).

Table 3: Monthly maintenance costs (in NTD) in 2026 for all elevator subsystem components.

Level 1 Assembly	Level 2 Component	Master Format / PCCES code	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
C1 Elevator Machine	C1-1Prim. veloc. transducer	14210T	82469	41	366	41	41	366	41	41	366	41	41	366
	C1-2 Traveling cable	14210E	99	99	358	99	99	358	99	99	358	99	99	358
	C1-3 Counterweight	14210X	37225			36	330	36	330	36	330	36	330	36
C2 Car	C2-1 Elevator car	14210V		79		79		45		79		79		45
	C2-2 Door drive	14210R	69625			235	235	20	235	235	235	235	235	20
	C2-3Take gate	14210J	113	113	113	113	113	50	113	113	113	113	113	41
	C2-4 Guider rail fixing brckt	14210M	198	230	230	198	230	230	198	230	230	198	230	230
	C2-5 Elevator rail	14210U	118	118	118	118	118	118	118	118	118	118	118	193
	C2-6 Car safety System	14210N				174	174	174	174	65	174	174	174	65
	C2-7 Slide guide & oil	14211w	1513	313		313	313		313	313		313	313	
C3 Control	C3-1 Control system	14210c	328	328	348	328	328	348	328	328	348	328	328	348
	C3-2 Operator panel	14210L		66			66			66			66	
	C3-3 Control cable & wiring	14210E			36		36	246		36		36	246	
C4 Hoistway	C4-1 Roller guides	14210F	20113			50	50	75	50	50	75	50	50	75
	C4-2 Side guide rail	142100	25913			118	118	80	118	118	80	118	118	80
	C4-3 Tension pulley	14210G	458			68	68	366	68	68	366	68	68	366
	C4-4 Car buffer	14210P	56	56	56	56	56	66	56	56	56	56	56	510
	C4-5 Counterweight buffer	14210b				90	90	90	90	90	90	90	90	90
.....		Total	238224	1441	1624	2113	2462	2667	2327	2139	2936	2149	2672	2822
		Annual Total	263574											

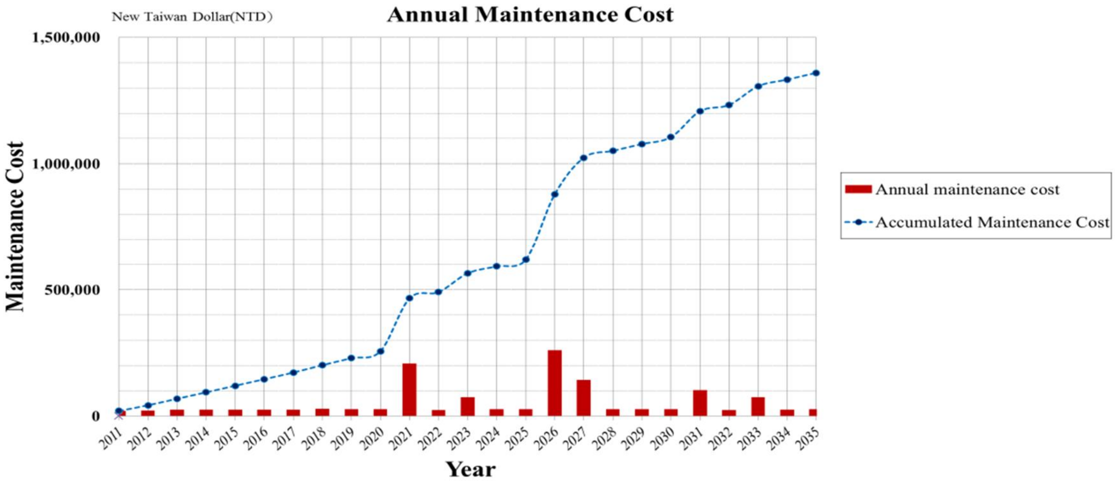

Figure 3: Annual and accumulated maintenance costs of TBTC's elevator subsystem over its 25-year building life span.

5. Conclusions

Building owners and facility managers need a method or tool to predict the maintenance costs over the life spans of their facilities in early operational phase to allocate adequate maintenance funding to sustain their facilities. Responding to this need, this study adopts and integrates existing technologies such as building information modeling (BIM), facility management system (ArchiBus○,R), and local construction and maintenance cost database (PCCES) to establish the Building Life Cycle Maintenance Cost Prediction method (BLCMCP) to predict annual maintenance costs over building life span according to a set of maintenance plans specified in early operational phase. The 'elevator' subsystem of the Taiwan Building Technology Center (TBTC) building located on the NTUST university campus is used as a case to demonstrate how the established BLCMCP method can be used to estimate the annual maintenance costs of this subsystem and its components over a 25-year life span.

This research focuses more on elaborating the concepts and the framework of the developed Building Life Cycle Maintenance Cost Prediction method (BLCMCP). The life cycle maintenance cost estimation for the exemplary elevator subsystem of TBTC was done manually in Excel. Further research effort is required to make the BLCMCP a working tool in predicting building life cycle costs. For example, building utility cost and custodial cost should be included as the major items of life cycle costs as well as the prediction methods should be researched. In addition, inflation rate should be considered when making long term cost estimations. Finally, software engineering effort is required to provide a functional system architecture, database, and user interface that integrate BIM model, FM system, and local construction and maintenance cost database so that life cycle cost estimation can be performed automatically.

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The Utilization of BMS in BIM for Facility Management

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Abstract

The emergence of BIM in the construction industry has come with promises of improving efficiency in project delivery and asset management. BIM concerns the digitization of the building project by depending on information technology capabilities already achieved in various professional domains associated with different stages of the building life cycle. While the utilisation of BIM in the various professional domains and project stages is increasing, research suggests that the building operation and management stage is being left behind. Exploring BIM applications that encompass the building operation are therefore important to improve efficiency during use and coordination with other stages in the project life cycle. As such a framework for utilizing feedback loops on building energy consumption to inform and improve design and facility management in a BIM environment is proposed. In this paper, the authors present the prototype from the implementation of the framework which is interfaced with a BIM-enabled tool. The paper concludes that the framework is useful in contributing to bridging existing gaps between the design, construction and operation phases of a building's life-cycle.

Keywords: BIM, data acquisition, facility management, energy consumption

1. Introduction

A considerable amount of research has been conducted on digitizing the various aspects of a typical building project since the advent of building information modelling (BIM). Most of these efforts leverage on the BIM/computer-aided capabilities already achieved in the various professional domains associated with the different stages of the building life cycle. The overall aim is to provide consistent digital information that can be reused by stakeholders throughout the building life cycle (Eastman et al., 2008; Arayici et al., 2012). It is predicted that BIM will help to drastically reduce errors, fast-track project delivery time and save implementation costs, as well as assisting with asset management. Benefits in the latter sphere can only be accrued if feedback loops can be established so that the information in a BIM is used to inform future design of similar buildings and facilities management. This paper illustrates how such feedback loops can be established by incorporating building management system (BMS) data into BIM to inform the designer and the facility manager.

Section 2 provides a background on the role of data acquisition in facility management integration with BIM .The challenges associated with the utilization of acquired data from building management system are presented in Section 3. The proposed framework is discussed in Section 4 before presenting a test-case of the prototype from the framework implementation in Section 5. Section 6 concludes the paper.

1.1 Research Problem

The existing multi-disciplinary nature of the construction industry offers advantages entrenched in the division of labour. However, it presents challenges such as the lack of interoperability between IT tools used by different professionals resulting in barriers to seamless information exchange. One aspect that is common in these different domains is design specifications, where materials are specified for production/construction according to anticipated performance mainly based on laboratory tests in order to meet the relevant standards. In this context, the design stage offers the best opportunity to influence cost and sustainability through design specification (Ding, 2008; Kohler and Moffatt, 2003). However, professional domains have not sufficiently explored even this clear opportunity (Wang et al., 2013; Oti and Tizani, 2015). Concerning the area of facility management (FM), BIM deficiencies are partly due to the fact that projects are being delivered with little or no considerations for FM integration unless a Client specifically requires this to be done. FM is particularly peculiar as it covers the building operation stage when the performances of all facilities in the building are tested against the building as designed. In addition, the efficient management and integration of resources in the form of people, places, processes and technology are panaceas to ensuring optimum functionality of the built environment. Thus, the facility manager is confronted with location of the property/project, type of facility vis-à-vis users, quantity of workspace and associated requirements, quality and performance of workspace, and the impacts of content layout and space allocation on work performance (Tay and Ooi, 2001). The advent of BIM promises to greatly lighten up the seeming complexities inherent in the tasks assigned to the facility manager as well as other professionals. Despite this potential, the results from a recent survey (Becerik-Gerber et al., 2011) in the USA suggests that the operation and management stage appears to be the least explored, compared to design and construction, in adopting BIM applications to execute requisite project tasks. By implication, the process of leveraging on BIM to close up the feedback loop of learning from best practice examples inherent in the project life cycle stages is equally at the lowest ebb. As the scope of

BIM application gradually expands, there is therefore the need to learn from performance histories of projects via feedback loops to the appropriate stages in the project life cycle.

1.2 Research methodology

Review of literature has been carried out to establish research gaps and further employed to ascertain appropriate methodologies for achieving the aim of this research. The review covered aspects relating the modelling of building energy consumption histories from building energy management systems and areas such as BIM enabling systems, building design and construction and facility management. This helped in identifying research gaps associated with modelling building performance feedback to BIM and possible process options for such communication. The Rapid Application Development (RAD) information modelling approach (Maner, 1997) was used to develop and implement a framework for utilizing performance histories in BIM and facility management. The RAD methodology employs cycles of re-specify, re-design and re-evaluate on the prototype system from its conception to when it achieves a high degree of fidelity and completeness. The prototyping process is therefore characterized by increased speed of development and experiences of series of births rather than deadlines. It informed the implementation of the prototype which entailed the interfacing of a BIM-enabled tool with object oriented representation of information in a contemporary computer programming language.

2. Data acquisition in FM and integration with BIM

There exist potential areas for BIM application in facility management where feedback can be useful. Some areas already identified by Becerik-Gerber et al (2011) include locating building components, facilitating real-time data access, visualization and marketing, considering ease of maintenance, creating and updating digital assets, space management, planning and feasibility studies for noncapital construction, emergency management, controlling and monitoring energy, and personnel training and development. While the modalities of BIM implementation may differ in all these areas, what will perhaps be common to all is the process of harnessing feedback from the model to inform and improve asset performance. This process will require more than just engaging the facility manager in the design stage as suggested in Wang et al (2013). It will require careful planning, mapping and integration of the facility management operations into the BIM approach, including the operations data acquisition, analysis and management strategy. This research stems from this premise. Its aim is to present a framework focused on the integration of energy performance data as an option in BIM implementation.

Energy consumption in the building operation stage is higher than other life cycle stages (Clarke et al., 2008). Obviously, one of the reasons behind such high energy consumption is the cumulative consumption over the long building life-cycle, usually in decades. It is therefore important that efforts are directed towards keeping energy consumption at a very low level during the operation of the building. This requires active participation of facilities management personnel in decision making regarding regular building operation and maintenance tasks. As such facility management personnel need to be better informed about the performance of building systems. A means for enhancing informed decision making and effective management of facilities is through context sensing and data capture from applications or entities in the building (Taneja et al., 2010). Context sensing operations may cover the monitoring of information on the environmental state, behaviour and situation of an application or a device (Dey, 2001).

The use of building energy consumption data to improve the design and operation of buildings is an active area of research. This process has been commonly called building energy management system (BEMS) or simply building management system (BMS). It is concerned with the active control of energy-dependent systems in the operation phase of the building (Doukas et al., 2007). The technological advances in BIM offer opportunities to integrate BMS data. This area needs to be fully explored. The existing gaps in linking BMS data to BIM has been noted for contributing to the inconsistencies in graphical energy data generated from manual input of repetitive energy management system data (Becerik-Gerber et al., 2011). It is therefore necessary to integrate data acquisition systems into BIM to facilitate real-time monitoring and automated control of building facilities.

2.1 Approaches to the integration of BMS data to BIM

A key goal of this paper is to facilitate the understanding of how BMS data can be analysed to inform design iterations taking advantage of technological trends of using BIM. This encompasses identifying how to provide feedback loops from the building in-use to successive design iterations of proposed building projects. The integration of facility management with BIM that particularly relates to the aim of this paper has two basic approaches to linking BMS data to BIM. The approaches include (1) BIM – Energy Analysis Tool – BMS link and (2) BIM – Energy Consumption Viewer Plugin link.

- **BIM – Energy Analysis Tool – BMS Link**

In this approach (Figure 1), it is envisaged that BMS data can be sent to Energy Analysis tools to carry out requisite analysis before feeding the outputs to building models in a BIM-enabled tool. This approach can take advantage of database management systems, open file formats and common data environments. The linking of DAT to Onuma Planning Systems (Ozturk et al., 2012) falls into this approach. It is also possible to have the Energy Analysis Tool in a single module with BIM tool or integrated with BMS data collection. For example Autodesk Project Dasher, as a visualization tool, can overlay BMS data on 3D BIM for the monitoring of historical and real-time analysis of building performance data (Attar et al., 2010; Khan and Hornbæk, 2011). In a BIM environment, meaningful visualisation of energy consumption profiles becomes possible which can aid the quick understanding of non-experts including occupants and so may influence their behaviours.

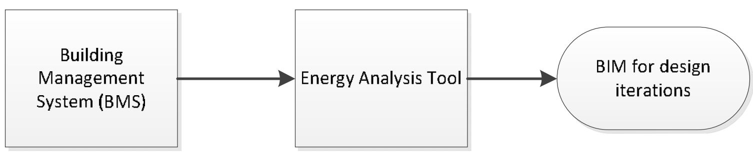

Figure 1: BIM - Energy Analysis Tool Link

- **BIM – Energy Consumption Viewer Plugin Link**

Here, a BIM tool is bolted with an external application such as Energy Consumption Plugin to enable the viewing of energy consumption profiles of buildings (Figure 2). A plugin is an external application which can be continuously improved in sophistication through computer programming. Refined BMS data is uploaded into the plugin linked to a BIM-enabled tool through associated application programming interface (API). Depending on the sophistication of the plugin, aspects of consumption data analysis could also be carried in the plugin environment. The result is addition of a new external tool to the BIM environment that can be called up for the visual presentation of historical energy performance to ease understanding of non-experts such as building occupants. For our research, this approach offers us a flexible way to input refined BMS data into the prototype system for display in a BIM environment that is beneficial to standardized building designs.

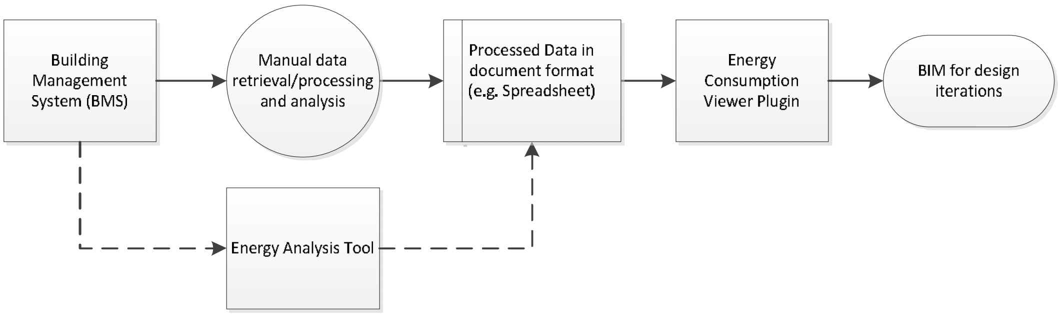

Figure 2: BIM - Energy Viewer Plugin Link

3. Challenges in the use of BMS data

The technological advances made in the development of building data acquisition systems are well acknowledged (Taneja et al., 2010; Becerik-Gerber et al., 2011; Ozturk et al., 2012). However, there have been challenges in utilizing such data to meaningfully inform and improve subsequent project design and delivery. The Big Data syndrome is also associated with the streaming of data from such acquisition systems (Olsson et al., 2015). More often than not, data collected from acquisition systems grow very large in size and is too unstructured to put to immediate beneficial use without some form of structuring and analysis. Thus, the technological advances in BIM offer opportunities to overcome a number of these challenges by integrating BMS data and learning from energy performance data as feedback to various building life cycle stages.

One obvious objective of measuring building energy consumption such as through BMS is to ascertain how the building performs in use. It also helps in determining what the user needs to pay for the services provided. Besides the collective responsibility to reduce environmental pollution, “the polluter pays” approach (Owen, 2006; Bürger et al., 2008) has been a major driver compelling energy consumers to explore avenues to reduce their quotas of pollution arising from energy use. The monitoring and acquisition of energy consumption over a period provide opportunities for strategising various means to achieving reductions in costs that accrue from energy bills. This is especially important as energy is used for a wide range of activity categories including air conditioning and heating, heating and pumping of water, lighting, powering of ICT, and the plethora of personal electronic devices etc. Ascertaining the various proportions of consumption attributed to these categories could be beneficial. BIM-BMS linkage may prove useful for the facility manager in achieving desired energy consumption reductions. Such linkage will provide opportunity for harnessing feedback from the model to inform and improve asset performance and vice versa. It will entail careful planning, mapping and integration of the facility management operations into the BIM approach. This includes the use of BMS to improve the design and operation of buildings concerned with the active control of energy-dependent systems (Doukas et al., 2007). Research suggest that the existing gaps in linking BMS data to BIM are contributory to the inconsistencies in graphical energy data generated from manual data input of repetitive energy management systems (Becerik-Gerber et al., 2011).

4. Proposed framework for utilizing data from BMS in BIM

Figure 3 summarises the overall research context. It shows the proposed schematic framework of the BIM implementation process to improve building design. As illustrated in the figure, existing drawings, textual information and specification are reproduced as BIM generic systems which can be combined with various site models. These combinations can then be further tailored as site – specific building information models for building construction and operation purposes. These processes produce progressive as-designed BIM, as-built BIM and the live BIM which are used for actual building construction operations and the building operation. They also serve as channels to supply feedback information as a learning process to Model Preparation stage for the development of the generic building design model. Also highlighted in Figure 3 is the aspect of BIM - BMS data interaction for which the BIM - Energy Viewer Plugin Link proposed. This achieves the requirement of users (designers) being able to graphically visualize and compare energy consumption histories of completed buildings in BIM environments. Also such system should allow appreciable degree of flexibility in configuring the input of data from BMS. Lastly, the linkage system should leverage on automating the process of entering BMS data into the system.

5. Case illustration of framework implementation

The framework of data acquisition utilization in BIM is implemented using a prototype as a demonstration of proof concept. The technicality involved in developing the prototype is briefly explained in this section including a scenario of using the prototype in a real- life project.

5.1 Description of prototype for data acquisition utilization in BIM

The approach adopted in developing the prototype for data acquisition utilization in BIM is the BIM – Energy Consumption Viewer Plugin Link. The BIM platform used in developing the prototype for data acquisition utilization is Revit 2014. The prototype can be configured to work in Revit 2015 or new versions to come. The implementation of the prototype system was carried out in C# using .NET and linked to the BIM enabled software (Revit 2015). The prototype plugin can be accessed via the external tools link in Revit 2014 IDE. It functions as an extension of plugin application of the earlier research work on the sustainability appraisal of structural steel framed building (Oti and Tizani, 2015).

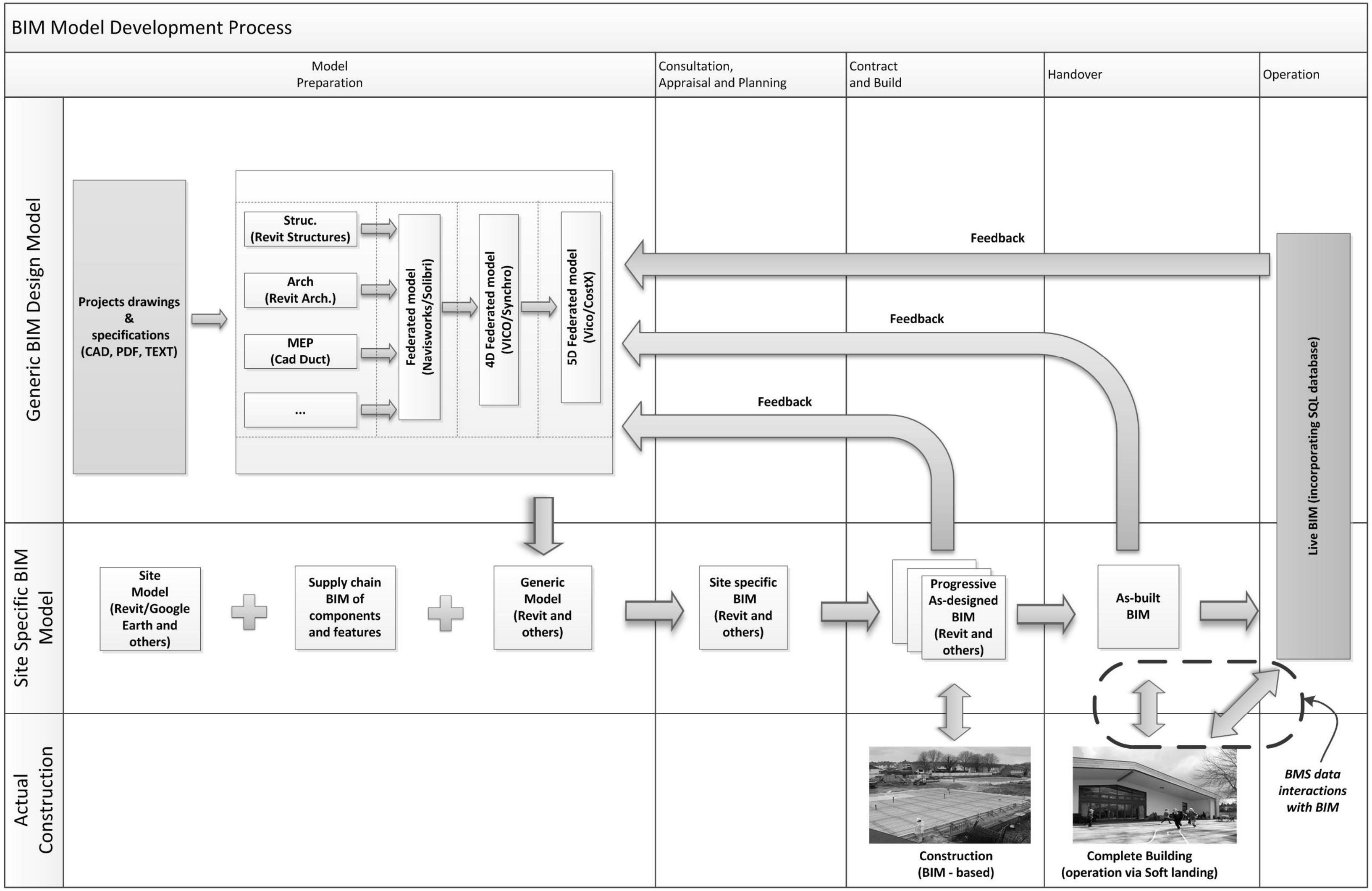

Figure 3: Framework for using BIM to improve the project delivery process

The prototype has been developed through the iterative testing of system components following the RAD approach. It leverages on the characteristic increased speed of development and progressive system refinement to achieve early usability. The flowchart illustrating the actions and processes captured in the prototype system is given by Figure 4. The programme is called through the Energy Use History option of the sustainability Estimation Programme from a BIM enabled environment. On the selection of the project (by name) to examine, the type of information to further explore can then be specified. This offers the option of comparing Design benchmarks and Actual Consumption records or examining various energy consumption categories. These information records are extracted by the system from spreadsheets saved in the various project names and containing pre-defined data. The consumption categories can be examined for a single project or a combination of projects. The intention of such combination is to compare and contrast trends of the same consumption categories of different projects. The system then displays corresponding output charts; from this point, reports can be produced. The user can switch back and forth different projects and consumption categories or quit the programme.

The prototype accesses design data and processed BMS (energy consumption) data saved in MS Excel file formats and expresses abstracted information on energy consumption in terms of ‘Design’ and ‘Actual’ for buildings. These values are compared at various levels of granularity to investigate wastes and encourage the use of appropriate measures to reduce consumption levels and save costs. At the moment, the input data into the plugin need to be provided in Excel file format which requires manual processing of the BMS data. However, there is a possibility that this function of processing BMS data and saving in Excel Format can be done by an appropriate Energy Analysis Tools if available.

5.2 Test case of using the prototype

Three projects have been used to illustrate the testing of the prototype. The data from one (Oakfield Project) of the projects have been obtained from a collaborative research project platform on low impact school procurement. The data from the other two projects were generated as a variant of the Oakfield project in order to demonstrate the operation of the prototype. The Oakfield Project is a primary school building in the UK completed and opened for use in October 2012 with a data acquisition system in place and running. Energy consumption levels have been collected and processed in spreadsheets serving as ready input for the prototype. The relevant information were extracted from the spreadsheet and recorded in formats for easy abstraction by the prototype. Since the prototype can be called in a BIM-enabled environment, the operation history of consumption levels and design benchmarks of buildings can be compared.

Figures 5 and 6 show alternative chart views of the design and actual energy consumption figures of the Oakfield project from November 2012 to February 2014. Similar charts can be obtained for the other listed projects. Thus, project information need to be entered in prescribed Excel format and loaded into the prototype to appear in the list of Project and Analysis listBox. The advantage of these charts to designers is that they will help to provide opportunity for quick review of design and performance benchmarks for more critical examination and analysis where required. For example, the designers' attention may be drawn to the Heating, Hot water and ICT sub-consumption category for further investigation if the respective charts reveal some unexpected outputs. The plug-in neither extracts data from nor feeds data/information to BIM objects but serves as a visualisation tool for historiacal building energy performance as a starting point. Further, the prototype can compare information on energy costs for design and actual consumption of projects. This can be done for any of the listed projects and also compared on project basis. These charts and the underlying data can be viewed and printed for hard copy recording.

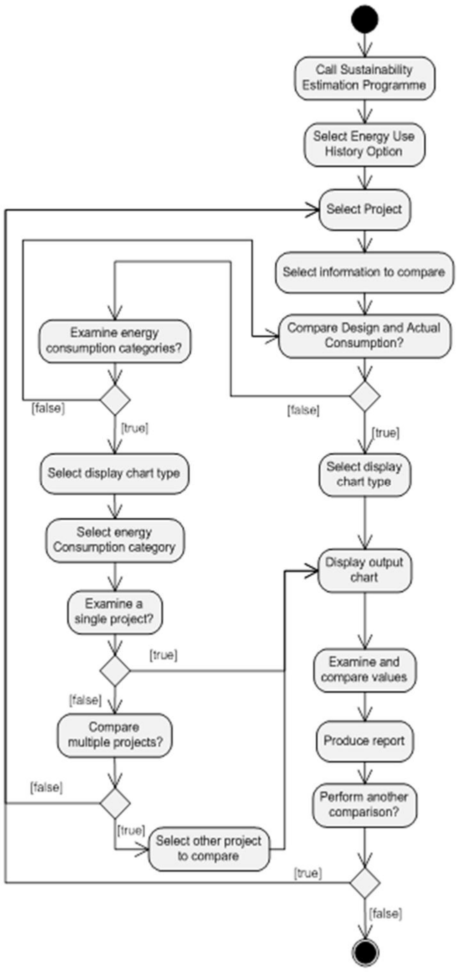

Figure 4: Prototype implementation flowchart

6. Conclusion

One aspect of concern in the emerging BIM applications is how to influence overall project costs and improve sustainable construction practices right from the planning and design stages. This requires the integration of existing work stages and processes into BIM. The incorporation of FM issues into BIM have seen the least patronage even though it is one of the key stages where all the outputs of the concerted efforts of planning, design and construction of the building is put to test by use. There is the existing gap of how outcomes from such tests are fed back to the planning, design and construction processes to contribute to improving the overall project delivery.

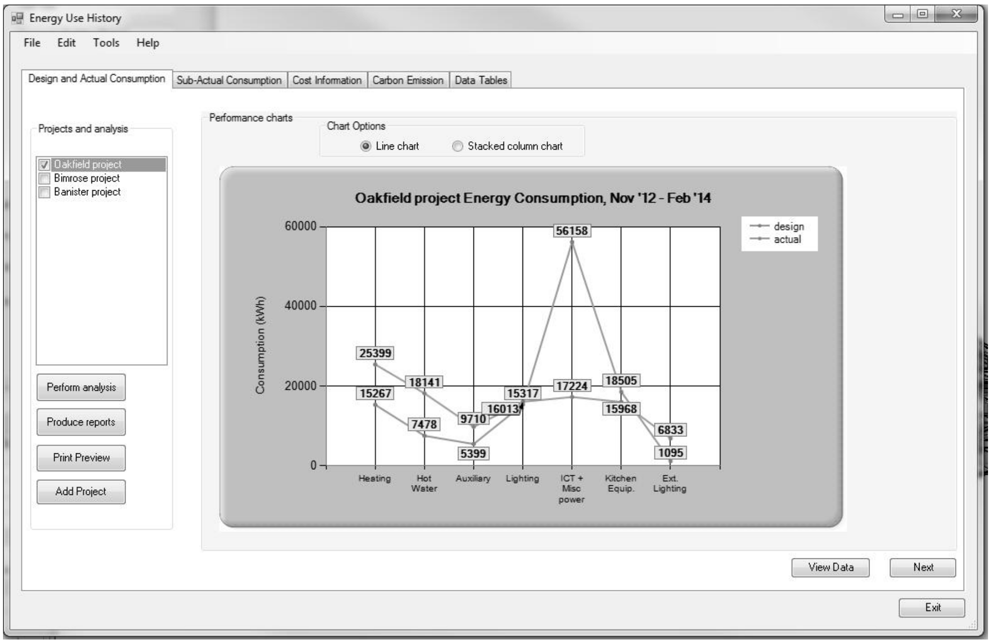

Figure 5: Comparison of Oakfield project design and actual (line chart)

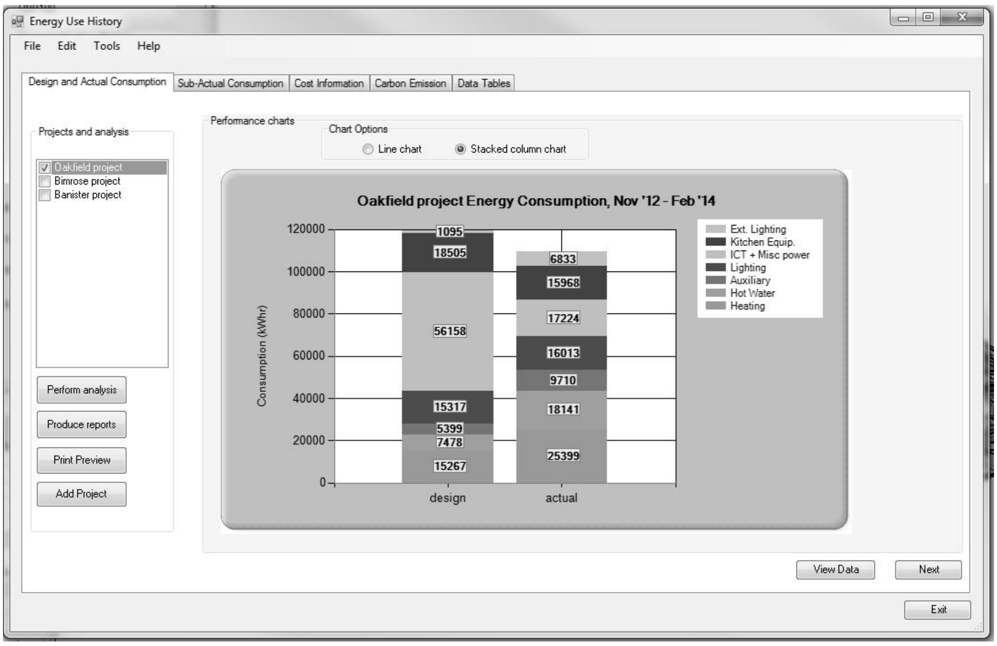

Figure 6: Oakfield project design and actual stacked column comparison

We therefore proposed a BIM-BMS data linkage plugin as feedback to enable designers learn from building energy performance histories. Thus, current energy analysis and design tools utilize conceptual design information such as volumetric and spatial data. These tools are lacking in achieving the aim of establishing requisite feedback of performance histories to BIM. Thus, it is difficult to input raw or refined BMS data in these tools for the purposes of analysis and linking such data back to a building information model. The reason are that (i) large volume of data will usually be involved, (ii) the process of entering data into such tools lack flexibility and (iii) facility management tools do not carry out energy design and analysis at the early project phases but have the capability of capturing and reporting data generated in the field or during building operation. In this paper we detailed the approach to meeting the requirement of utilizing sensing and automated data acquisition technologies (BMS data) in building information models (BIM). Also, we identified available approaches for integrating BMS data to BIM and described the adopted approach of using plugins. The work described a framework that utilizes feedback loops on building energy consumption to inform and improve design and facility management to explore adequate building digitization. The demonstrated approach including the process flow chart and information representations utilized in this work are useful in bridging existing gaps of harnessing historical data from the building operation phase to assist in building information modelling and design.

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The Role of Live Energy Modeling in the Integrated Design Process

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Abstract

The integrated design (ID) process has received numerous endorsements across many disciplines as an effective way to design and build more sustainably. Countless reports, papers, journal articles and lectures have demonstrated the many benefits inherent to the ID process; however, rarely do these accolades provide concrete numbers. Energy modeling is becoming common practice, especially for buildings seeking green certifications or improved performance. However, energy modeling is often done too late in the process, after nearly all design decisions have been made. As a result, the process of modeling after design negates the possible benefits and does little to improve the energy performance of the building. Energy modeling professionals have the capacity to provide concrete predicted energy use numbers throughout the design process that can lead to informed design decisions.

This research outlines how to effectively utilize the ID process in order to build a more sustainable building. Additionally, it looks at the role of live energy modeling during the ID process and identifies the benefits of providing design teams with predicated energy use information early in the design process.

The purpose of this research is to identify the benefits of interactive live energy modeling during the ID process over the use of energy modeling simply to show code compliance. The research consists of a comparative analysis using case studies, data analysis and expert interviews with energy modeling professionals. This research demonstrates how the use of live energy modeling within the context of an ID charrette can reduce the predicted energy use of new schools.

Keywords: Integrated Design, Live Energy Modeling, Energy Conservation Measures, ID Charrette, Case Study

1. Introduction

In his book *Sustainable Energy – Without the Hot Air* author David MacKay outlines the need for 'numbers, not adjectives' when it comes to our conversations about energy efficiency. He writes,

> *"In public debates, people just say 'Nuclear is a money pit' or 'we have a* huge *amount of wave and wind.' The trouble with this sort of language is that it's not sufficient to know that something is huge: we need to know how the one 'huge' compares with another 'huge,' namely our huge energy consumption. To make this comparison, we need numbers, not adjectives* (MacKay 2009, p.3).

We often look for the 'silver bullet' or 'low hanging fruit' that will dramatically improve the energy performance of our buildings. But in order for us to come up with effective solutions, we need numbers on which to base our decisions and not mere adjectives. Energy modeling is one tool that provides designers with numbers to demonstrate building performance though it can be utilized in many different ways.

The purpose of this research is to identify the benefits of interactive live energy modeling during the integrated design (ID) process, over the use of energy modeling simply to show code compliance. The research consists of a comparative analysis using case studies, data analysis and expert interviews with energy modeling professionals. The quantitative methods include case studies and data analysis, while the qualitative methods include expert interviews with energy modeling professionals. This research demonstrates how the use of live energy modeling within the context of an ID charrette can reduce the predicted energy use of new schools.

Additionally, this research establishes a road map for future design teams looking to effectively design and build more sustainable K-12 schools. This research focuses on schools in particular because they are often owner-occupied and directly concerned with operating costs. By focusing on schools that have utilized energy modeling during the early design stages, specifically during ID charrettes, and comparing the predicted energy use results and various modeling inputs with schools that did not participate in charrettes, this research will show the tangible benefits of live energy modeling.

2. Integrated Design and Live Energy Modeling

In order to gain a better understanding of the relationship between integrated design and live energy modeling, below an overview of the ID process is outlined along with how it benefits the design process.

2.1 Overview of the Integrative Design Process

The design and construction industry has long struggled with being efficient, collaborative and cost effective (Latham1997; Gallaher et al. 2004). These drawbacks have made it challenging to produce high performance buildings that meet the needs of the occupants and the environment. Over the years, a number of approaches have been developed to address these drawbacks such as "Building Information Modeling" or "Integrated Project Delivery," yet these approaches still lack the holistic methods inherent in an ID process (Owen et al. 2010).

In 2001, the British Columbia Green Building Roundtable, comprised of public sector and non-profit organizations in the province of British Columbia, Canada, came together to develop a "Roadmap for the Integrated Design Process." This roundtable led to a number of publications and reports designed to advance green building principles and practices across the sector. One of the early roundtable reports established a working definition of the ID Process, which is described as:

> *[a] method for realizing high performance buildings that contribute to sustainable communities. It is a collaborative process that focuses on the design, construction, operation and occupancy of a building over its complete life-cycle. The ID Process is designed to allow the client and other stakeholders to develop and realize clearly defined and challenging functional, environmental and economic goals and objectives. The ID Process requires a multi-disciplinary design team that includes or acquires the skills required to address all design issues following the objectives. The ID Process proceeds from whole building system strategies, working through increasing levels of specificity, to realize more optimally integrated solutions (BC Green Building Roundtable, 2007).*
>
> Excerpt from "The Integrated Design Process: Report on a National Workshop" held in Toronto in October, 2001.

We are still designing buildings the way we have for decades, but the ID process offers a more sustainable building by design as evident from the definition above. In order to have a clearer understanding of what the ID process is, it is important to recognize how it differs from conventional design. Table 1 outlines the primary difference between a conventional design process and an integrated design process. The simplest way to understand the difference is to think of conventional design as ***linear*** and integrated design as ***iterative***.

Table 1: Integrated Design Process vs. Conventional Design Process

Integrated Design Process	**Conventional Design Process**
Inclusive	Involves team members only when necessary
Front-Loaded	Less time and energy early on
Decisions made by team	More decisions made by fewer people
Iterative	Linear
Whole-system Thinking	Systems considered in isolation
Allows for full optimization	Constrained optimization
Seeks synergies	Few opportunity for synergies
Full life-cycle costing	Emphasis on up-front costs
Process continues post-occupancy	Process ends with construction completion

There is nothing exceptionally revolutionary about the ID process, rather it benefits from a holistic and principled approach that can lead to a better built building. By combining a set of attitudes, principles and strategies, the ID process can result in more sustainable buildings (BC Green Building Roundtable 2007). These attitudes and principles set the tone for the project and allow for the creation of measurable goals.

3. Types of Modeling Processes

For this research, two types of modeling processes were identified and formalized based on the first author's professional experience and familiarity in Canadian K-12 energy modeling requirements. These modeling processes are *compliance modeling* and *integrated design*. Together they form the energy modeling processes that establish a framework for the selection and analysis of case studies. In mapping out the two processes, key factors contributing to the design processes and energy performance outcomes emerged and allowed for comparisons and conclusions to be drawn.

3.1 Compliance Modeling Process

The first process identified is a *compliance modeling* process. For the purpose of this research, the compliance modeling process is defined as: energy modeling completed using Issued for Construction (IFC) drawings and specifications with the modeling team having had no input during the design stages of the

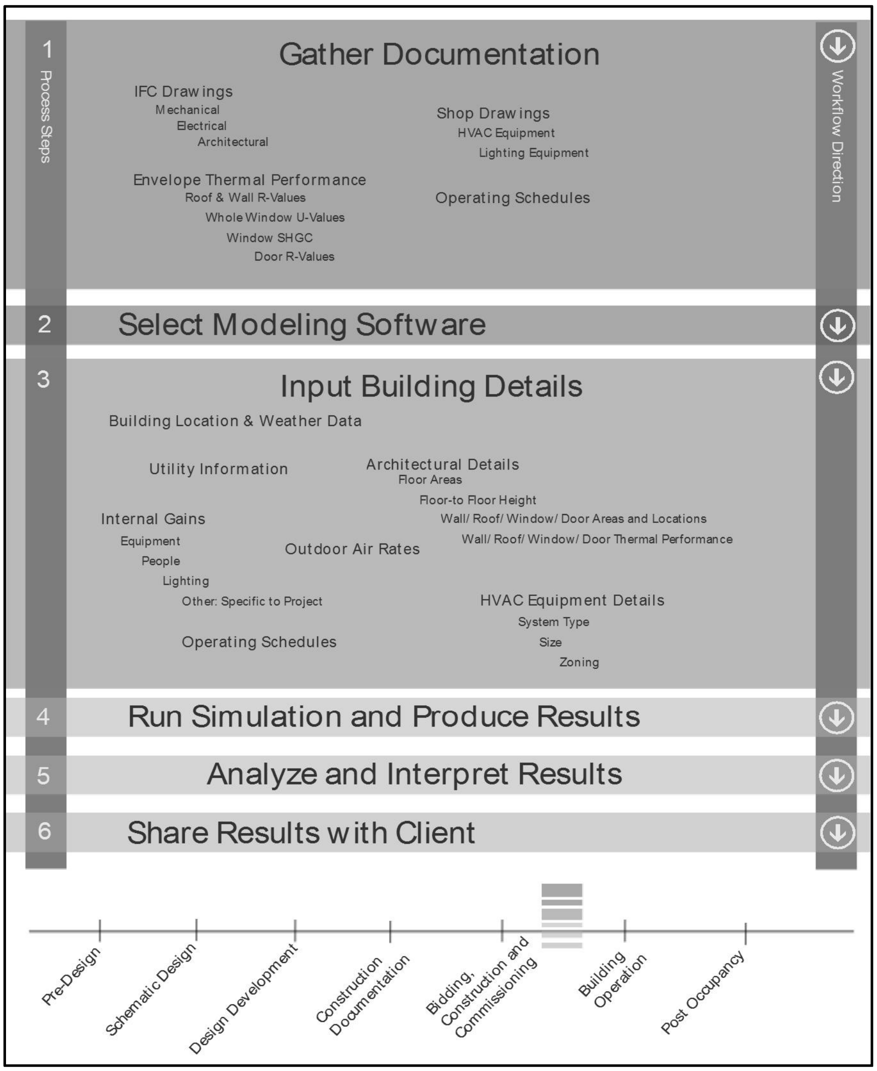

Figure 1: Compliance Modeling Process

project. During the compliance modeling process, an energy model that includes predicated energy use and energy cost numbers is produced; the results are often used to indicate if the building complies with specific requirements such as building code, LEED, or other industry standards. The steps of the process are visually represented in Figure 1 below.

3.2 ID Charrette Modeling Process

The second process was modeled using an *integrated design (ID) charrette modeling* process. For the purpose of this research, an ID charrette modeling process is defined as: energy modeling that takes place live during an ID charrette where design team members are present and are provided with energy use results based on the discussion and suggestions made during the actual charrette. During an ID charrette modeling process, an energy model that includes predicated energy use and a number of discussed Energy Conservation Measures (ECMs) is produced; the results are often used to indicate if the building achieves established energy performance goals. The steps of the process are listed below and a visual representation can be found in Figure 2.

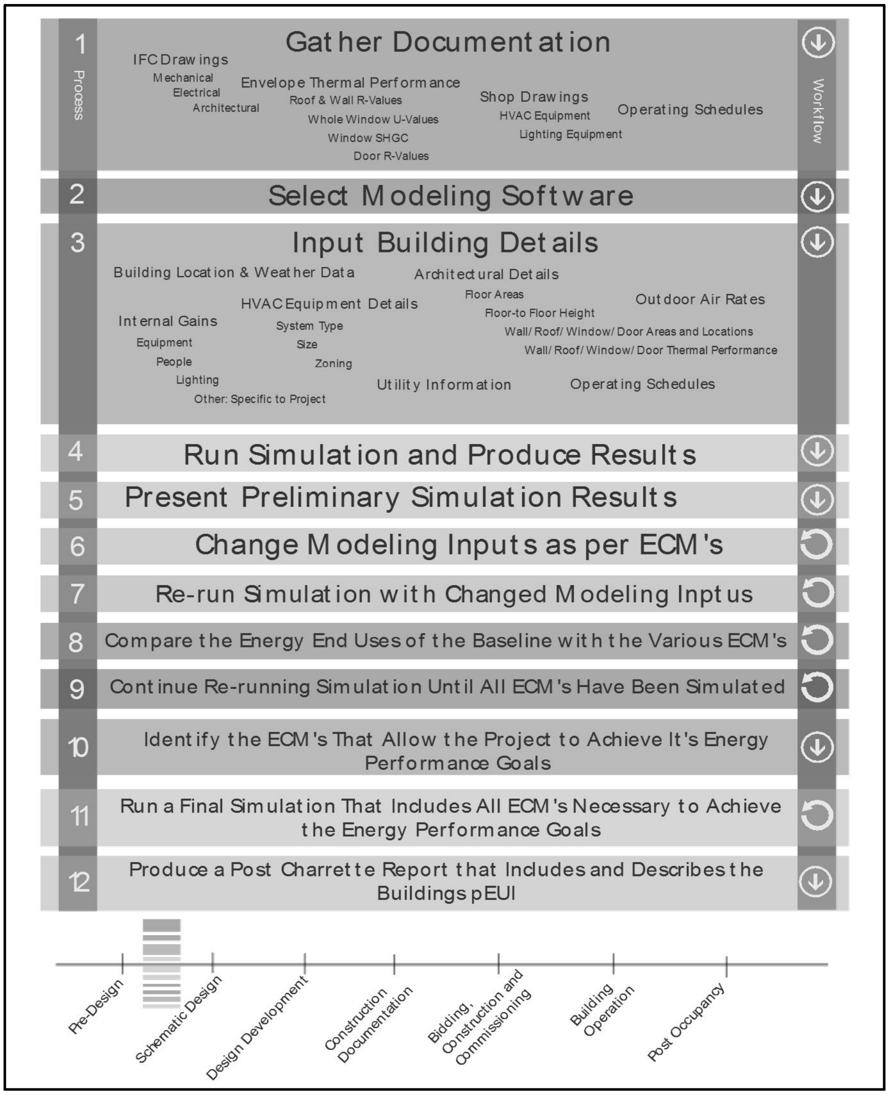

Figure 2: ID Charrette Modeling Process

4. Case Studies Analysis

Buildings utilizing the ID process should use energy simulation early and often. This provides the design team with the necessary information and adequate time to make informed energy related design decisions. The purpose of this research is to demonstrate how the use of live energy modeling can lead to predicted energy savings in new K-12 schools. As such, the following six case studies were analyzed in order to identify the different variables that lead to improved energy performance. All six schools are located in Eastern Ontario, Canada and are publically funded. All Ontario publically funded schools are subject to the same funding formula used to determine the schools operating budget and construction budgets for new builds. Since all six schools are proposed new builds, they are subject to the same funding formula, which in turn means no school within the data set has a budgetary advantage. Schools A1, A2 and A3 serve as the compliance modeling data set, while schools B1, B2 and B3 serve as the ID Charrette modeling data set. The model inputs and energy performance results can be seen in Table 2.

4.1 Case Study Results

Drawing causation conclusions based on an analysis of the case study results is very difficult. The modeling results (energy end use and performance) for each school are the result of a single simulation, as isolating the impact of a single variable (model input) is nearly impossible because there is no point of reference. However, comparing the modeling results of each school helps identify trends, which are further explained through the expert interviews. A more accurate picture emerges only when the quantitative data (modeling inputs) is examined next to the qualitative data (interview findings).

The analysis of the case studies revealed that the ID charrette modeling schools use 58% less energy than the compliance modeling schools, on average. Additionally, the ID charrette schools have an average Predicted Energy Use Intensity (pEUI) that is 11.1 ekWh/ft2/yr less than compliance modeled schools. A deeper analysis of the modeling inputs helps identify what impacts these predicted energy savings, but it does not tell the whole story. No individual variable or modeling input alone can be linked to the significant reduction in predicted energy use, however, averaging each input and comparing them between the two data sets tells a different story.

In nearly every case, the average input variables for the ID charrette modeling schools are better than the compliance modeling schools; however, in a few cases the reverse is true. Focusing only on the averages for each input is deceiving since the averages are not generalized; it is important to drill down on some of the outliers in order to better understand how these two data sets compare. For example, the compliance modeling schools average glazing U-value is 0.36 verses 0.38 for the ID charrette schools; the poorer glazing performance for the ID charrette modeling schools is directly due to the fact that school B1 has a U-value of 0.44 and pushes the average down to 0.38. Looking a bit closer at all the inputs for school B1 shows that the design is not particularly high performing. The primary energy savings measure for school B1 is its outside air rate of 0.16 cfm/ft^2, which is significantly less then all of the other schools. School B1 has a much lower outside air rate partially because it was a discussion topic during the ID charrette and the design team was able to test assumptions and develop a design that specifically addressed the schools needs. Comparing the average values for each input is important, however, understanding the differences and strengths of the two modeling processes is equally important.

Table 2: Case Study Model Inputs and Results

Project Details	A1	A2	A3	B1	B2	B3
Location	Kingston	Cornwall	Ottawa	Ottawa	Ottawa	Ottawa
Climate Zone	6A	6	6A	6A	6A	6A
Modelling Software	IES-VE 2014	IES-VE 2014	EE4	eQuest	eQuest	eQuest
Weather file	CAN_ON_Ottawa.CWEC	CAN_ON_Ottawa.CWEC	CWEC\Ottawa.bin	CWEC\Ottawa.bin	CWEC\Ottawa.bin	CWEC\Ottawa.bin
Total Building Area (ft^2)	56,474	50,600	44,014	58,477	36,201	48,074
Number of Storeys	1	1	1	2	2	1
General Building Characteristics						
Insulation Values						
Roof (average weighted R-value)	R-30	R-30	R-25	R-37	R-37	R-47
Walls (average weighted R-value)	R-20	R-23	R-18.5	R-17	R-27	R-20
Windows						
Window-to-Wall Ratio	16%	9%	13%	19%	12%	5%
Frame type	Aluminum	Aluminum	Aluminum	N/A	N/A	N/A
Glazing type	Double Pane - Air filled	Double Pane - Air filled	Double Pane - Air filled	N/A	N/A	N/A
Glazing U-value	0.36	0.36	0.35	0.44	0.33	0.36
Glazing SHGC	0.40	0.40	0.30	0.40	0.42	0.54
Lighting Power Density (W/ft2)	1.17	1.24	0.86	0.89	0.66	0.61
Misc. Equipment (W/ft2)	0.90	0.86	0.46	0.28	0.32	0.30
Outdoor Air Rate (CFM/ft2)	0.63	0.31	0.29	0.16	0.32	0.29
Operating Schedule						
Weekdays	7am-6pm	7am-5pm	7am-10pm	8am-4pm +	7am-6pm	8am-4pm +
Weekends	Closed	10am-1pm Sat	Closed	Closed	Closed	Closed
Holidays	Closed	Closed	Closed	Closed	Closed	Closed
System Set Points						
Heating (degrees F)	70	70	70	72	72	72
Cooling (degree F)	75	75	74	75	75	75
Mechanical Equipment						
Heating Plant	HE gas-fired boilers	HE gas-fired boilers	gas-fired boilers	Condensing HW Boiler	Condensing HW Boiler	gas-fired boilers
Heating Plant Efficiency	91%	91%	80%	91%	93%	85%
Cooling Plant	DX office, CW Vent	Chilled Water	DX Cooling	DX Cooling	Chilled Water	DX Cooling
Ventilation Heat Recovery	60%	60%	60%	60%	88%	75%
Energy End Use						
Lighting (kWh/year)	187,235	177,537	123,617	135,342	88,989	62,090
Space Heating (ekWh/year)	475,173	569,027	558,593	224,702	87,959	200,881
Space Cooling (kWh/year)	85,188	50,788	27,461	11,076	28,151	9,793
Pumps (kWh/year)	3,266	4,171	7,473	3,956	10,642	2,740
Heat Rejection (kWh/year)	21,167	10,298	0	0	0	0
Fans (kWh/year)	80,188	65,736	168,252	125,920	60,329	68,112
Misc. Equipment (kWh/year)	140,123	122,182	82,294	43,380	41,242	34,421
Energy Performance						
Annual Electrical Use (kWh/year)	517,167	430,711	409,097	319,674	229,353	177,156
Annual Nat Gas Use(ekWh/year)	475,173	569,027	558,593	224,702	87,959	200,881
Total Energy Use (ekWh/year)	992,340	999,738	967,690	544,376	317,312	378,037
EUI ($kWh/ft^2.yr$)	17.6	19.8	22.0	9.3	8.8	7.9

5. Expert Interviews

The primary goal of the interviews was to identify how live modeling is done in practice and link the benefits of this process with possible energy savings. Interview participants were selected based on their level of experience with live energy modeling within the context of ID charrettes. Five interviews were completed with professional energy modelers from across Canada. Two of the interviewees were from Ottawa, Ontario (in Eastern Ontario), two from the greater Toronto, Ontario area, and one from Vancouver, British Columbia. Additionally, two of the interviewees had direct experience with the models for the three ID charrette modeling case studies. Despite there being countless professional energy modelers around the world, the selected experts represent a group of modelers who have spearheaded the use of live modeling for the purpose of identifying energy savings within a Canadian context. Each interview participant was asked the same series of questions especially designed to get a better understanding of the live energy modeling process.

The interviews were broken down into four main sections in order to outline the process of live energy modeling. The first section focused on background experience and knowledge; this series of questions was used to collect information about the knowledge areas needed to be successful at energy modeling as a profession. The second section focused on charrette preparation; this series of questions addressed the groundwork leading up to a live energy modeling session within an ID charrette. The third section looked charrette activity; these questions focused on what the live modeling expert was doing during the actual charrette. The fourth section focused on post-charrette activity and lessons learned; these questions addressed what the modeling experts did after the charrette and how the knowledge acquired during the charrette works its way back into the practice.

5.1 Background Experience and Knowledge

The first series of interview questions focused on the background experience of the interview participants and identified the necessary knowledge areas to effectively run live modeling within an ID charrette. Each interviewee was a professional modeler or energy efficiency expert that had between 4 to 30 years' experience. In addition, they collectively have administered more than 200 ID charrettes that incorporated live energy modeling with projects dating back more than 10 years. It is clear that the interviewees are highly experienced professionals working to find innovative ways to use energy modeling to improve performance.

Each participant was asked the question: 'What skills or knowledge areas do you believe to be essential to successfully run a live energy modeling session?', and several themes emerged. First, some key areas of understanding were identified that included thermodynamics, building science, and relevant energy codes. It was also identified that modelers should be familiar with current state-or-the-art building technologies and be highly experience with the selected software used in the charrette.

Finally, interviewees were asked what software they use and what about that software makes it ideal for live modeling. The most common software was eQuest, which uses the DOE 2.2 engine, while another group of charrettes utilized DOE 2.1e. It was indicated that these software programs were used primarily because of their ability to complete simulations quickly, but also because they are well-supported and fairly simple to use. During a live energy modeling session, simulation run time is critical since the entire discussion hinges on the speed at which results can be produced. Although being able to produce simulation results quickly does not directly impact the performance of the building, it allows the ID charrette to run more smoothly, which in turn improves the quality of the charrette.

5.2 Charrette Preparation

Like most complete processes, a key element of a smooth charrette is preparation. Each interviewee was asked what information do they required for charrette preparation, as well as how much time do they spend preparing and what assumptions are made at the onset. There was little variation about what information is required in preparation. Generally, every modeling expert required a complete set of preliminary mechanical, electrical and architectural drawings as well as a complete set of preliminary shop drawings or specifications. Or as one modeler said, "any information available concerning the building program, design information (which varies depending on how advanced the design is), and intended use of the facility," is requested for preparations.

A lot of information is still missing when the team begins preparing for an early stages ID charrette. To get a better understanding of what information is still missing at this stage, the modelers were asked 'What assumptions need to be made in order to move the project forward while remaining accurate?' Because projects can vary so dramatically, no consistent list of assumption beyond using standard ASHRAE 90.1 defaults whenever information is missing was identified through the interview process.

Finally, the amount of preparation time varied between 20-60 hours within the 2-week period leading up to the charrette. Several modelers identified that part of the preparation included either scripting or pre-running a number of generic ECMs in order to make the actual live modeling sessions run smoother. There is a lot of pressure on the modeler during the actual live modeling session, so good preparation is key.

5.3 Charrette Activity

By the time the actual charrette is underway, the modeler's role is fairly focused. When asked what they do during the actual charrette, each modeler described a fairly similar process. It begins with participating in the team discussion with a greater emphasis on listening; this way they are fully aware of the charrette goals and innovative ideas being discussed. They also each described how, working in tandem with the charrette facilitator, they start to run each ECM discussed by the team while the facilitator keeps the conversation focused and moving. As they begin to get results, the modelers provide the energy use changes of each discussed ECM to the group so that the process can continue forward. At times, certain ECMs require additional input from the team; this is where other experts can support the modeler. Several modelers described scenarios where fenestration experts or envelope experts were able to provide more accurate thermal performance numbers rather than relying on software defaults for example. As a result, more team members were involved and the charrette model calculations were more accurate while also offering an opportunity for collective learning.

Several of the modelers described charrette processes that involved cost consultants. In the first section of this research, the importance of including a cost consultant was addressed. It was identified that the financial information that cost consultants are able to provide leads to greater buy-in from the team members and also connects the energy performance goals with the project budget. Although there is clear value in ID charrettes as a whole, it is important that cost consultants are always involved.

Finally, each modeler identified the need for taking notes on the various ECMs discussed. This aided in the development of the report after the charrette and ensured the spirit of the conversation was incorporated into the model as well as the report. Additionally, each modeler described a charrette process that involved multiple team members, this generally included a facilitator and note taker in addition to the dedicated modeler.

5.4 Post Charrette Activity and Lessons Learned

The lessons learned and post charrette activities part of the interviews provided the most insight in the process, as each of the modeler had a lot to share. There was a wide range of lessons learned, yet there was still quite a bit of consistency between responses. Every modeler identified that live modeling sessions are stressful and that good preparation is key. Because live modeling requires expert knowledge of the modeling software and engineering principles, it was identified that experienced modelers should always be involved. However, several modelers identified that live modeling sessions is a great way for a less experienced modelers to learn. Actively participating in the charrette process is a great way for inexperienced modelers get a better understanding of how to successfully run an ID charrette with live modeling.

Another lesson learned was the need to run the ID charrette as early in the process as possible; a best practice identified earlier in the ID charrette process section. A charrette runs smoother earlier in the process for several reasons, as identified in the interviews. First, during an early charrette fewer decisions have been solidified and the design team members are more willing to consider changes. In turn this leads to more innovation and willingness to participate from all of those attending the charrette since there is less need to defend certain decisions.

Keeping the model as simple as possible was another lesson learned. As one practitioner put it, ‘we should aim to make our models accurate rather than precise.’ The more complicated the model is, the longer the simulation run times will take; when performing energy simulation live, speed is almost as important as accuracy. For example, a recent project the first author was working on required collaboration with the mechanical designer to provide deeper analysis. The project was still in the schematic design phase, however, the model received from the design team already had every room defined, all 346 rooms. As a result the model took roughly 1 hour to simulate on a fairly robust computer. In an ID charrette, this run time would ruin the entire process. Had the model been created with larger thermal blocks rather than every room, the simulation time would have been much quicker. Keeping a model simple and selecting software capable of quick simulations is key to a successful charrette.

5.5 Key Interview Findings

Running a live modeling session is not an easy task, however, if done correctly it can yield superior energy performance and improve the design process and outcomes. The expert interviews led to a number of key findings that allow for a successful live modeling session. The key findings are:

- Schedule the modeling session as early in the design process as possible.
- Ensure that all of the necessary documentation has been collected in order to prepare. This includes a complete set of preliminary mechanical, electrical and architectural drawings as well as a complete set of preliminary shop drawings or specifications.
- State assumptions and ask design team to confirm inputs and ensure assumptions are correct.
- Allow for enough preparation time, somewhere between 20-60 hours. During that time, try to run likely ECM's so that the modeling session runs smoother allowing for certain trends to be identified early.
- Select software capable of running simulations quickly.
- Do not over complicate the model.
- Take lots of notes.
- Ensure a cost consultant is present.
- Invite other experts to the session, i.e. fenestration, building envelope, landscape, lighting, etc.
- Have a dedicated session facilitator, someone other than the modeler, so that things continue to move forward.

6. Conclusion

An improved process almost always leads to an improved outcome, and as this research indicates the same is true for the ID charrette modeling process over the compliance modeling process. ID charrette modeling schools have significantly less predicted energy use than compliance modeling schools, as indicated by a 58% predicted energy use reduction. This research clearly indicates that participating in live energy modeling during the ID process can lead to significant predicted energy use reduction for new K-12 schools in Ontario, Canada. Live energy modeling provides design teams with concrete number necessary to make informed design decisions and allows for participation in the process by all design team members. It should be noted that this research is limited in its generalizability due to a small sample size of six schools located in Eastern Ontario.

An area for further research is the variation of predicted energy use versus actual energy use. Based on the findings, concluding that live modeling during an ID charrette results in a better performing occupied building is inaccurate. Predicted energy use is based on simulation results and actual energy use is based on metered data and it is important that distinction be made when interpreting the results of this study. Additional research needs to be completed in order to state the effect of live modeling during ID charrettes on actual energy use. Are larger sample size across a verity of geographic locations would allow the research to be more generalizable. Once all of the schools in this study are fully constructed and occupied, an analysis of the actual metered energy use of each school could be analyzed in order for additional conclusions to be made.

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Investment Value of Long-Term Building Adaptability

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Abstract

Physical adaptability of buildings has a major role in creating competitiveness for property investors as well as creating a sustainable built environment. Current real estate investment analysis methods do not value investments into long-term adaptability because the discounting effect gives less weight to cash flows further in the future. This paper attempts to apply a newly developed investment theory for justifying the investor value of long-term adaptability. The theory, which combines of real options valuation, investment analysis and building component lifecycle design, proposes that physical asset characteristics can create valuable real options (i.e. building adaptability) for the real estate investor. This paper applies this theory into a real life property development case and evaluates the value of real options for the investor. The results try to explain in economic terms why investors should invest into long-term adaptability. The study found that the value of real options ranges from 0,0 % to 221,4 % compared to the initial investment cost of the building component. The extra investment costs for creating these real options ranges from 0,0 % to 5,0 %. The real option values exceed the costs in most of the cases. As can be seen from the results, it is important to recognize valuable options from the ones that do not provide value in the long-term. More research and discussion regarding the practical usability of the results is needed, as the topic is quite complex.

Keywords: Building adaptability, real options, investment analysis, technical lifecycle, economical lifecycle

1. Introduction

Average lease lengths have decreased rapidly and in major markets are now under 5 years (IPD, 2014; Titman and Twite, 2013). The shortened interval for lease break points requires more active management from the property owner. Since tenant requirements are changing rapidly, the buildings have to be adaptable into different scenarios of best use in the future. Physical adaptability of buildings has a major role in creating competitiveness for property investors as well as creating a sustainable built environment. However, current real estate investment analysis methods do not value investments into long-term adaptability.

Real estate investment analysis is mainly done with discounted cash flow (DCF) valuation method (KTI and IPD, 2012; Shapiro, Mackmin and Sams, 2013) where predicted net rental cash flows are discounted to the present value. The discount rate effect gives less weight to cash flows further in the future. Many authors, such as Hayes and Garvin (1982) and Myers (1984), have noted that the use of DCF results in short sighted decision-making because short-term cash flows can make up the best part of the investment value. In the property sector, this short sightedness is especially problematic as buildings are constructed for lifecycles of 50+ years and initial design plays a key role on how the buildings can be used in different market conditions.

Many of the opportunities in active real estate management are constrained by the physical asset characteristics (PACs) of real estate investments, which are in turn determined in design processes. Vimpari and Junnila (2015) define PACs as *"the limitations and opportunities that the physical attributes of buildings impose on assets' economically best use... In other words, PACs express the extent in which the real estate manager has to operate during the lifecycle of a building investment."* They also noted *"it appears that PACs do not have a large role in property analysis as they are mainly assessed through their negative effect on rent and on capital expenditures that is not as a source of value creation, per se."* Vimpari and Junnila (2015) developed a theory for valuing building lifecycle investments that can justify the investor value of long-term adaptability. The theory, which combines of real options valuation, investment analysis and building component lifecycle design, proposes that PACs can create valuable real options for the real estate investor. Real options are originally defined as *"opportunities to purchase real assets on possibly favourable terms"* (Myers, 1977). In the context of this paper, real options enable that the PACs can adapt into new use when the best use of the building requires it, in economically favourable terms.

This paper applies this theory into a real life investment case and evaluates the value of real options for the investor. The results try to explain in economical terms why investors should invest into long-term adaptability. The study found that the value of real options ranges from 0,0 % to 221,4 % and the extra investments into adaptability ranges from marginal to a maximum of 5,0 %. This paper aims to discuss the reliability and practical usability of the numerical findings.

The paper is organized as follows. The next section describes the relationship between economical and technical lifecycle as well as presents the Vimpari and Junnila (2015) framework. The following section presents an applied case study of the framework. Then discussion and conclusions are provided.

2. Aligning economical and technical lifecycles of buildings

Arge (2005) found that short-term owners, such as developers, invest less into long-term adaptability because the extra investment may be hard to justify in the transactions. On the contrary, long-term owners, such as owner-occupiers, invested more into adaptability. This is an interesting observation because construction literature argues that the cost of adding adaptability into PACs is only marginal. Slaughter (2001) analysed 48 commercial renovation projects and found that interaction between building systems (i.e. structure, enclosure, services and interior finish)*"strongly influenced the building's adaptability, and that the structural and exterior enclosure systems, as well as the services and interior finish, should be designed with respect to anticipated changes."* The study found out that different design strategies that increase the adaptability often requires only, on average, 2 % extra investments into initial construction costs.

These small extra investments can have an important impact on the building's economical lifecycle. To understand the economical value of adaptability, the connection between the market demand of project (economical lifecycle) and the actual lifecycle of the building components (technical lifecycle) needs to be examined. In principle, sustainable use of built environment resources would expect that both the economical and technical lifecycles are as close as possible. Often this is not the case because the economical lifecycle changes faster than the technical lifecycle, which results into inefficient occupancy rates or premature demolition.

The importance of aligning economical and technical lifecycles is explained through technical lifecycle measurement. A building component (i.e. PAC) has an expected technical lifecycle based on the design requirements for the project. Building components can be divided into two categories, fixed and movable, with an expected average technical lifecycle. The fixed category includes components, such as heating (technical lifecycle of 40 years), ventilation (40), sewage and water (40), air conditioning (40), electricity (50), structures (200), windows (35), façade (40), roof (40), balconies (40) and fixed devices and systems (40). The movable category includes components, such as surfaces of walls (12), roofs and floors (12), fittings (40), partitioning walls and doors (40). These lifecycles are used as a basis for building design as well as for calculating the future renovation costs.

However, since the economical lifecycle of the first best use can be much shorter, the technical lifecycle cannot be exploited fully if there is no adaptability, i.e. investments into technical value is lost because the PAC cannot adapt into the new economical demand. This effect of this is more dramatical in the building components that have longer lifecycles, such as HVAC, electricity and building structures. The lost or gained value with adaptability is pointed out numerically in the Vimpari and Junnila (2015) framework presented in Figure 1. The NPVs in the framework *"represent the amount that is lost or gained due to the length of the lifecycle that is, if the lifecycle lasts only* n_{min} *years,* NPV_{min} *is lost because the PAC has to be replaced* n_{stan}-n_{min} *years earlier compared to the standard lifecycle. On the other hand, if the lifecycle lasts* n_{max} *years,* NPV_{max} *is gained for the opposite reasons. Therefore, if the PAC reinvestment has to be made early, the X cannot be invested elsewhere with the hurdle rate and it is lost because the PAC does not produce any profits, per se. The higher the hurdle rate, the higher the amount lost/gained and vice versa."*

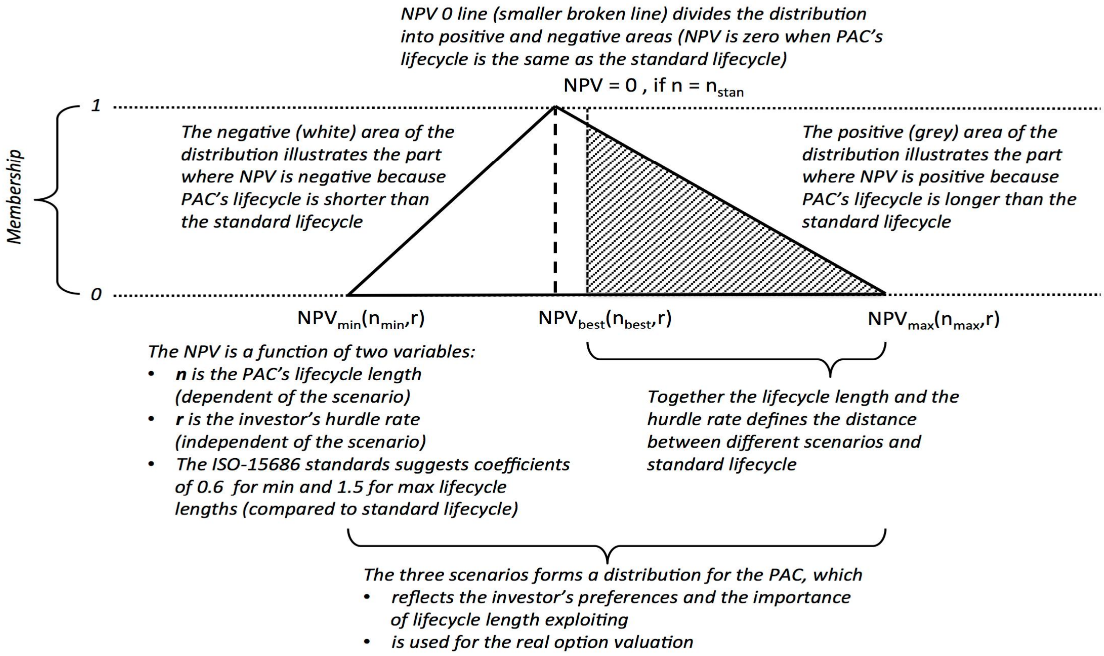

Figure 1: Conceptual framework for valuing lifecycle investments (Vimpari and Junnila, 2015)

The framework is used to form a single distribution of the PAC's lifecycle. A distribution is used because the technical lifecycle defines the limits for the economical lifecycle, i.e. at best the economical lifecycle has the same distribution as technical lifecycle. At worst, a short economical lifecycle transforms the distribution in a way that the positive area has a much smaller proportion (this is illustrated in Figure 2) because there is no adaptability. The framework uses a triangular distribution because it is much easier to use in practice, as there is often limited information to form a probability distribution in property context. The framework suggests that the ISO-15686 standards can be used to define the minimum and maximum lifecycle lengths to form the triangular distribution. The standards suggest that a coefficient of 0.6 can be used for the minimum lifecycle and the 1.5 for the maximum lifecycle, compared to the standard expected lifecycle. For example, a façade has a standard expected lifecycle of 40 years, but the coefficients suggest that the range for the lifecycle is from a minimum of 24 years to a maximum of 60 years. In practice, wear and tear, different conditions, etc. can have an effect on the length of the lifecycle.

The technical lifecycle distribution (which gives the upper boundaries for the economical lifecycle) is rather straightforward to measure, but defining the economic lifecycle is not as straightforward. However, it is more important because it dictates how efficiently the technical lifecycle can be exploited. The economical lifecycle distribution is affected by uncertainty in space demand during the technical lifecycle. Figure 2 presents the relationship of time and demand uncertainty.

Figure 2: Relationship of time and demand uncertainty

The figure presents what kind of uncertainty can incur to the property owner during the technical lifecycle of the building. The longer the expected same use of the building, the smaller the amount of uncertainty is during the technical lifecycle. For example, a very long lease agreement reduces the uncertainty dramatically and thus reduces the need for adaptability investments, from the property owner's perspective.

If the PACs cannot adapt to the uncertainties, the economic lifecycles for the PACs will be shorter than the technical lifecycles. The value of adaptability comes from the fact that the economic lifecycle is aligned with the technical lifecycles. Therefore, to value adaptability we need to define the technical lifecycle and economical lifecycle. If these are not aligned, we need to identify real options (adaptability investments) for aligning the lifecycles. Then the options are valuated with the framework and the values are compared to the cost of the extra investments. This is attempted in the following case study.

3. Case Study

AINOA is a 4-story shopping centre development in Tapiola, Espoo, Finland. It is part of a larger urban development project that transforms the old centre of Tapiola into new use. A lot of older buildings from the 1970's and 80's are demolished, as they cannot be used anymore. Additionally, a new metro line will connect the area to the metro grid of Helsinki Metropolitan Area (HMA). The shopping centre will be ready in 2017.

The investor in AINOA is LähiTapiola that is one of the largest institutional investors in Finland. LähiTapiola plans to own the centre for a long holding period and thus can be considered as an owner who is interested in the long-term lifecycle performance of the building. Even though the building has better construction quality than average and is in a great location, there is uncertainty regarding the economical lifecycles of rentable space within the centre. The main tenant is renting majority of the premises. In addition to the main tenant, there are a few large and several smaller retail spaces in each floor. While the main tenant is a very reputable tenant, the owner cannot expect that it will occupy the premises indefinitely.

In order to value the adaptability strategies for different PACs, technical and economical lifecycles are defined. Let us assume that the best-guess estimate for the building's technical lifecycle is 40 years (in Finland, the average life of shopping centres before demolition has been 39 years according to Huuhka and Lahdensivu, 2014). Based on the ISO standards, the minimum technical lifecycle would be 24 years and maximum 60 years. The minimum lifecycle can feel very short but the triangular distribution gives only a very small weight to it - see Vimpari and Junnila (2015) for more details. For the economical lifecycles, let as use the following lengths presented in Table 1.

Table 1: Economical lifecycle distributions

Tenant	Min	Best	Max
Main tenant	10	25	60
Large tenants	5	10	60

The economic uncertainty can have the largest effect to the main tenant and the larger tenants. The smaller retail spaces are so small that it is unnecessary to include them into the analysis. The table presents the economic lifecycles for the tenant categories. The maximum lifecycles are based on the maximum technical lifecycles, i.e. in the most optimistic scenario the economic demand is in line with technical lifecycle. The minimum lifecycles are based on hypothetical first lease agreements (the owner does not want to disclose the real lengths). The best-guess lifecycles are the most likely scenario for how long the tenant will remain in the building. Figure 3 illustrates the economical distributions the large and main tenants with and without adaptability.

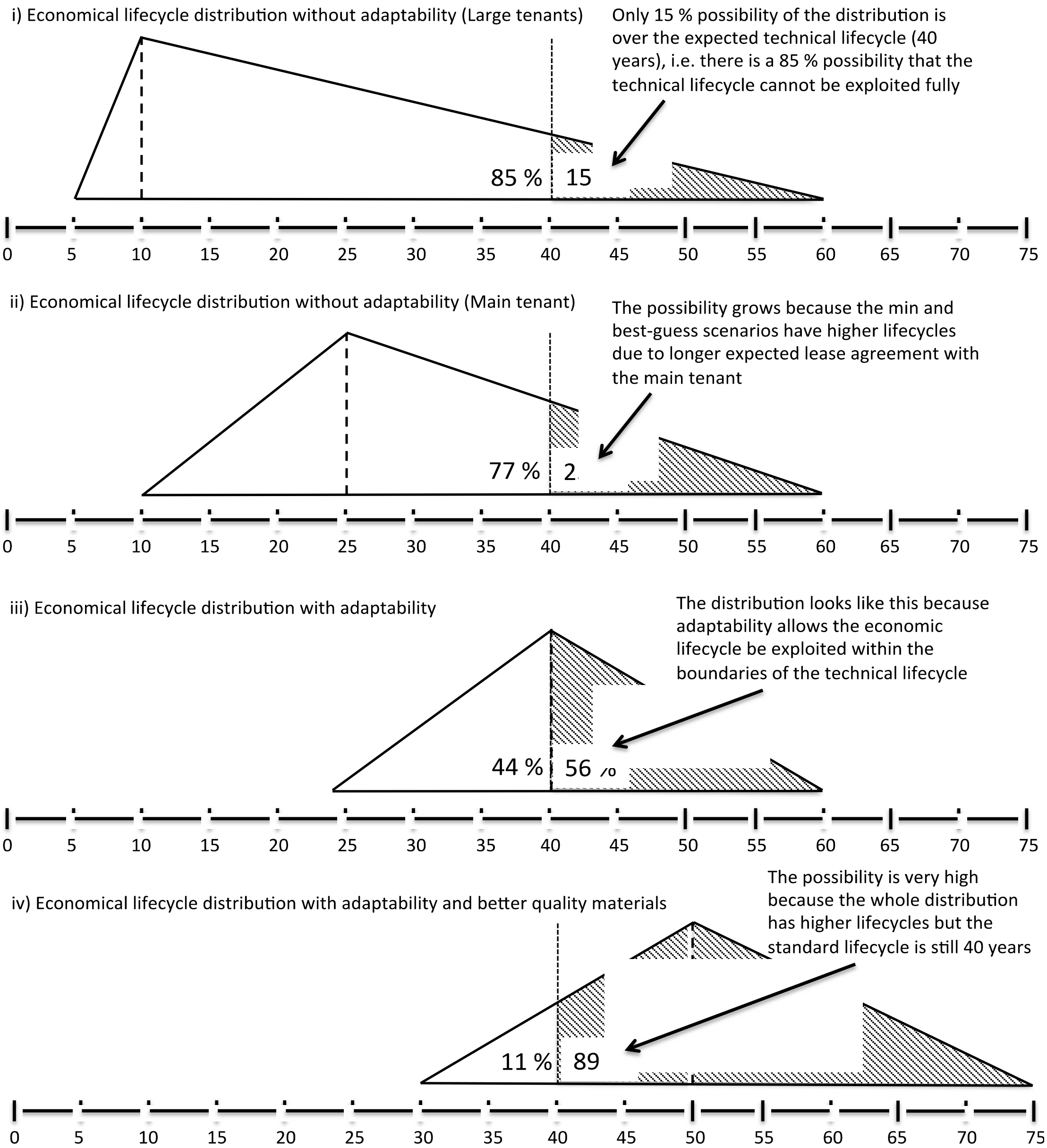

Figure 3: Economical distributions with or without adaptability

The figure presents four different economical lifecycle distributions. The first two illustrate how uncertainty affects the economic distribution and the chance of exploiting the whole technical lifecycle. The third distribution illustrates how adaptability changes the possibility of exploiting the lifecycle. The fourth adds the effect of better materials into the distribution, i.e. better materials raises the expected technical lifecycle for the PAC, which reduces the possibility that the PAC has to be replaced early.

The grey area in the distributions represents the proportion of the area that exceeds the average expected lifecycle of 40 years. This is the area where extra optional value is created when the lifecycle lasts longer than expected. The option value, is calculated from the grey area, see Vimpari and Junnila (2015) for details. The option value increases as the proportion of the positive area increases because the expected lifecycle for the technical lifecycle is higher. This means that more clever design with potential extra investments is needed to increase the adaptability. In essence, if the main tenant would leave and the space would have to be divided into much smaller areas, it would not be possible efficiently without the real options. Without the adaptabilities the areas would have to be divided inefficiently which could results into loss in rentable space, etc.

Using the formulas in the Vimpari and Junnila (2015) framework, the real option values for the distributions are as follows: i) 0,2 %, ii) 0,5 %, iii) 3,3 % and iv) 18,3 %. These numbers are the value of adaptability compared to the initial investment. For example, in distribution iv), a maximum of 18,3 % can be invested into adaptability and better materials.

To find out what kind of adaptability is needed to change the distributions, the building design solutions had to be assessed. Different designers (Electricity, Architecture/Structure and HVAC) were interviewed in order to find out what kind of adaptability has been constructed into the building. The following real options were identified. In the parenthesis is presented the best-guess technical lifecycle based on common expectations in Finland - the min and max lifecycles for the option valuation are estimated using the ISO-coefficients as the framework suggests.

- Electricity:
  - E1: Higher capacity for the main electricity connection (50 years)
  - E2: Higher capacity in the cabling (50 years)
  - E3: Higher capacity for the main electricity unit (25 years)
- Architecture/Structure:
  - A1: Openings for escalators/staircases in middle floors (100 years)
  - A2: Storey heights allow all types of use (100 years)

A3: Distance between pillars very long (100 years)

A4: Façade not load-bearing and allows for window openings (100 years)

· HVAC:

H1: Higher capacity in the ventilation units (25 years)

H2: Ventilation ducts allow higher airflows (40 years)

H3: Higher capacity for district cooling can be installed easily (40 years)

These real options changes the i) and ii) distributions to iii) and iv) distributions. The extra costs and option values are presented in Table 2. In the option valuation is assumed that the standard lifecycle is 40 years. Therefore, the option value is based on the area that is over 40 years. The area weighted option value is the value of adaptability. The further over 40 years the area is, the higher the option value.

Table 2: Option values and extra investment costs

Real option	Extra investment costs	Option value	Option value (better materials)
E1	Max 5,0 %	18,1 %	46,2 %
E2	Max 5,0 %	18,1 %	46,2 %
E3	Max 5,0 %	0,0 %	0,0 %
A1	Marginal	180,1 %	221,4 %
A2	Max 5,0 %	180,1 %	221,4 %
A3	Max 5,0 %	180,1 %	221,4 %
A4	Marginal	3,3 %	13,7 %
H1	1,3 – 1,7 %	0,0 %	0,0 %
H2	1,3 – 1,7 %	3,3 %	13,7 %
H3	1,3 – 1,7 %	3,3 %	13,7 %

The results in Table 2 suggest that the option values are higher than the extra investments costs in all cases except E3 and H1. This means that the extra investments are worth the investments because the potential upside from the options is higher. Raw estimates were used for the extra investments because the designers had not systematically identified and calculated the extra investment costs. In the better materials is assumed that they increase the best-guess lifecycle by 20 %. This chosen to demonstrate how the value of adaptability increases because of better materials chosen.

The extra investments in Electricity allow using the same cabling and main electricity unit with higher loads that is if the space efficiency increases or tenants with higher electricity requirements occupies the premises. The electricity designer had a raw estimate that these investments have a maximum extra investment cost of 5,0 %.

The extra investments in Architecture/Structure allow using the same structures if the layouts have to be converted into new use. Additionally, the structures can be used in different type of use as the storey heights are higher and facades allows for windows openings. Based on a raw estimate, the extra investments costs ranges from marginal to maximum of 5,0 %. The option values are very high because the technical lifecycles of building structures are very long.

The extra investments in HVAC allow using the same ventilation units and ducts if the space efficiency increases or a tenant with higher cooling requirements occupies the premises the same component can be used. The designer had a raw estimate that these extra investments are only 1,3 % to 1,7 %.

4. Discussion

When interpreting the results, it should be remembered that the numbers are best approximations based on the expected lifecycles. Nevertheless, the magnitudes of the results seem somewhat intuitive, as the value of adaptability should correlate with the length of the lifecycle. For example, the very high option values for the building structures seems logical if they allow using the same structures for different types of uses over a lifespan of 100 years. Naturally, when talking about lifespan lengths of this magnitude it raises questions about how relevant it is to prepare for a period that far in the future. However, if the extra investments into a very small part (e.g. pillars and ceiling height) of the total building investment ranges from a marginal to a maximum of 5,0 % of extra costs, and as a results it raises the possibility that the whole structures can be used much more efficiently, the investments is likely worth it. The option value tries to approximate the monetary value of the extra investment, even though they are merely an approximate. The option value of e.g. 180,1% would suggest that this is the maximum amount that could be invested into adaptability – intuitively it does not make any sense. On the other hand, as the extra investments point out, the real costs are very small. It should be acknowledged that some of these options could be added later but it would result into much higher investments costs as well as longer periods of vacancy during the construction activities. This is why the author thinks that the value of these options should be looked from the lifecycle perspective rather than the rental perspective.

If we look at the results of E3 and H1 where the option values are zero. The results does not make sense because it suggest that the main electricity unit and the HVAC unit does not need any adaptability because their expected lifecycles are only 25 which is shorter than 40 years that was chosen for the standard lifecycle in the valuation. The results would make sense if there would be no economical uncertainty during the 25 years but there is as the lease agreements can have a minimum length of only few years.

The challenge with the framework seems to be on how to choose correct the standard (n_{stan}) lifecycle length for different PACs and for the whole building. Actually, the results would suggest that the property owner should take an active role of choosing the expected lifecycle from the business perspective, rather than basing it on the technical quality (lifecycle) of the product. Then the value (grey area) that exceeds this expected business lifecycle would be optional and the property owner would seek for design solutions that maximize this optional value. Thus, the property owner would have to take a stand on the actual business lifecycle of product (with technical implication) rather than take them as a given from the developer, which is the case at the moment. This would result into better alignment of the economical and technical lifecycles.

5. Conclusions

This paper attempted to use the Vimpari and Junnila (2015) framework in practice by applying it into a real life investment case. The study founds that the value of real options ranges from 0,0 % to 221,4 % compared to the initial investment cost of the building component. The extra investment costs for creating these real options ranges from 0,0 % to 5,0 %. The real option values exceed the costs in most of the cases. As can be seen from the results, it is important to recognize valuable options from the ones that do not provide value in the long-term. More research and discussion regarding the practical usability of the results is needed, as the topic is quite complex. The value of the options depends on what kind of lifecycles is inputted into the framework. Defining these lifecycles is somewhat confusing because both economical and technical lifecycles have to be considered.

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Integrated Urban Water Management, the Green Economy and Institutional Eco-Innovations

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Abstract

This paper aims to pinpoint the global megatrends related to urban water management, and to make recommendations for urgently needed institutional innovations. This paper and the subsequent analyses are based on the literature study. Almost 700 million people lack access to safe drinking water, 2.4 billion lack access to improved sanitation services, and 600,000 children under five die every year as a result of lack of access to improved water services. While these estimates identify the extent of the problem, the number of people threatened by poor management of constructed systems is much greater.

The world's population is increasingly urban, and cities cannot be sustainable without ensuring reliable access to improved water services. Urban settlements are the main source of point-source pollution. In many fast-growing cities in developing countries, wastewater infrastructure is non-existent, inadequate or obsolete. Water storage, treatment and distribution systems are poorly maintained, and water losses due to leakage and theft, often exceed 40-60% of the total water distribution. Water infrastructure is rapidly aging and facing massive rehabilitation. By 2016 the capital expenditure on water infrastructure is estimated to increase 1.5 times from USD 90 billion in 2010 to USD 131 billion. It's estimated that the urban infrastructure of the world's cities over the next 20 years will require USD 41 trillion, including USD 22.6 trillion on water and sanitation.

To achieve the Sustainable Development Goal 6 *"Ensure access to water and sanitation for all"* by 2030, specific enabling conditions will be required. Therefore, the typology and concepts of the green economy, along with the principles, approaches and processes of the Integrated Urban Water Management, and the institutional innovations should be considered and applied.

Keywords: Integrated Urban Water Management, the green economy, institutional eco-innovations, efficiency improvements, strategic asset management

1. Introduction

Water is arguably more fundamental than any other resource – to life itself, supporting a huge array of ecosystem services – and to every economy and society. Water contributes directly and indirectly to virtually all other ecosystem services but the area of water supply and sanitation also comprises an economic sector in itself. Water supply and sanitation can thus be considered as a driver with its own dynamics of pricing, infrastructure and governance (UNEP 2012, 15-16, 19).

According to the United States Environmental Protection Agency (EPA), the sustainable water infrastructure (the collection and distribution systems, treatment plants and other infrastructure that collects, treats and delivers water-related services) and the sustainable water sector systems (all aspects of effective operations and maintenance practices of the utilities and systems that provide water-related services) are necessary to safeguard the sustainable environmental and economic development of all the communities (Figure 1, EPA 2012).

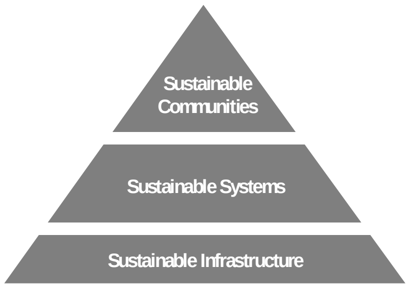

Figure 1: Sustainable communities are based on sustainable drinking water, wastewater and stormwater infrastructure and on sustainable systems' operations and maintenance (EPA 2012).

In 2015, however, 663 million people still lack improved drinking water sources and 2.4 billion people still lack improved sanitation facilities (UNICEF and World Health Organization 2015, 4-5). Deaths from water-related diseases are inadequately monitored and reported. A wide range of estimates is available in the literature, ranging from 2 million to 12 million deaths per year. The best estimates analysed by Gleick (2002, 4) appear to fall between 2 and 5 million deaths per year.

While these estimates identify the order-of-magnitude of the problem, the numbers of people threatened by poor management of constructed systems is much greater (Biswas 2013). Billions lack access to safe water that is reliably and continuously delivered in sufficient quantities (WHO 2014, iv). Of critical importance is the fact that access to an "improved" water source does not necessarily mean access to "safe" water fit for human consumption. As a result, for example, half of Africa's hospital beds are filled with people suffering from a water-related disease (OECD 2012b cited by OECD 2013a, 38-40).

A UN-Water Global Analysis and Assessment of Sanitation and Drinking-Water (GLAAS) 2014 Report provides a global update on the policy frameworks, institutional arrangements, human resource base, and international and national finance streams in support of sanitation and drinking-water. Ten key findings emerge from the GLAAS 2014 Report as follows (WHO 2014, ix-xi):

1. Governments show strong support for universal access to drinking water and sanitation.
2. Political aspirations, nonetheless, are impeded by weak capacity at country level to set targets, formulate plans, undertake implementation and conduct meaningful reviews.
3. Critical gaps in monitoring impede decision-making and progress for the poorest.
4. Neglect for WASH (water, sanitation and hygiene) in schools and in healthcare facilities undermines country's capacity to prevent and respond to disease outbreaks.
5. National financing for WASH is insufficient.
6. International aid for WASH has increased and regional targeting has improved.
7. Lack of human resources constrains the sector.
8. Sanitation in rural areas: high needs, yet low expenditures.
9. Weak monitoring of the critical 'H' factor – hygiene promotion.
10. Efforts are being made to reach the poor, but few at scale.

A UNESCO report states that a shortage of engineers in developing countries is hampering development. For example, to meet the target of the Millennium Development Goal (MDG) to safe drinking water and basic sanitation, the report gives an estimate that some 2.5 million new engineers and technicians would be needed in sub-Saharan Africa alone (Marjoram 2010, 3).

According to the United Nations Department for Economic and Social Affairs 3.9 billion people, or 54% of the global population, lived in cities in 2014, and by 2050, two-thirds of the global population will be living in cities (UNDESA 2014, 2). Major growth will take place in developing countries, particularly in urban areas that already have an aging, inadequate or even non-existent sewage infrastructure, unable to keep up with rising populations. It is estimated that the urban infrastructure of the world's cities over the next 20 years will require USD 41 trillion for investments in urban infrastructure, including USD 22.6 trillion on water and sanitation (UNEP 2011a, 44).

The increase in the number of people without access to water and sanitation in urban areas is directly related to the rapid growth of slum populations in the developing world and the inability (or unwillingness) of local and national governments to provide adequate water and sanitation facilities in these communities (UN-Water 2015, 3). Globally, more than 80% of wastewater resulting from human activities is discharged into rivers or seas without any pollution removal (UN 2015). The financial, environmental and social costs are projected to increase dramatically unless wastewater management receives urgent attention. Under-dimensioned and aging wastewater infrastructure is already overwhelmed, and with the predicted population increases and changes in the climate the situation is only going to get worse. Without better infrastructure and management, several millions of people will continue to die each year and there will be further losses in biodiversity and ecosystem resilience, undermining prosperity and efforts towards a more sustainable future (Corcoran, Nellemann, Baker, Bos, Osborn and Savelli 2010, 9-11).

Water storage, treatment and distribution systems are often poorly maintained. Moreover, in many countries of the developing world, water losses due to technical leakage and water theft often exceed 40-60% of the total water distribution (UN-Water 2012b, 4-5). Underpricing of water has contributed to the situation across Africa, where on average 35% of water supply infrastructure assets needs rehabilitation (Foster and Briceño-Garmendia 2009, 73). In the OECD countries the water services infrastructure is also aging and decaying, and needs rehabilitation or replacement. The estimated investment gap and the state of water infrastructure in some OECD countries and in sub-Saharan Africa (SSA) are shown in Table 1.

Table 1: Estimated investment gap of water services (water and sanitation) infrastructure in some OECD countries and in sub-Saharan Africa (compiled by the authors in 2014-16).

Country/ Region	*Population*	*State of water services infrastructure (scale)*	*Estimated current funding gap (EUR)*	*Estimated funding gap per population (EUR/hd)*
Canada[1]	*35,182,000*[a]	*Good (Very good-very poor)*	*34,755,000,000*[**]	*988*
Norway[2]	*5,213,985*[b]	*Water networks 3 (5-1)* *Sewers 2 (5-1)*	*22,329,000,000*[**]	*4,280*
Finland	*5,426,000*[c]	*7 (10-4)*[3]	*4,803,000,000*[4]	*890*
USA	*320,051,000*[c]	*D (A-E)*[5]	*406,426,000,000*[6*]	*1,270*
SSA	*973,400,000*[d]	*6 (10-4)*[7]	*219,012,000,000*[8**]	*225*

Note: Currency enchange rates on 3 March 2014[*] and on 3 March 2016[**]; Population figures: http://www.statcan.gc.ca/daily-quotidien/150617/dq150617c-eng.htm[a]; https://www.ssb.no/en/befolkning/statistikker/folkemengde[b]; United Nations, Department of Economic and Social Affairs, Population Division (2013). World Population Prospects: The 2012 Revision, Highlights and Advance Tables. Working Paper No. ESA/P/WP.228[c]; http://data.worldbank.org/region/SSA[d].

[1]Canadian Construction Association, Canadian Public Works Association, and Canadian Society for Civil Engineering and Federation of Canadian Municipalities (2016) *Informing the Future: The Canadian Infrastructure Report Card.* 163 p.

[2]Rådgivende Ingeniørers Forening (2015) (Original in Norwegian) *State of the Nation 2015.* 93 p.

[3]ROTI (2013) *State of the Built Environment – Finland.* RIL (Finnish Association of Civil Engineers), Finland.

[4]Ministry of Agriculture and Forestry (2008) (Original in Finnish) *The Current Condition of the Drinking Water Networks and the Rehabilitation Requirements.*

[5]ASCE (2013a) *American Society of Civil Engineers 2013 Report Card for America's Infrastructure.*

[6]ASCE (2013b) *Failure to Act: The Impact of Current Investment Trend on America's Economic Future.*

[7]The estimate by the authors in 2014.

[8]Ghosh Banerjee S and Elvira Morella E (eds) (2011) *Africa's Water and Sanitation Infrastructure: Access, Affordability, and Alternatives.* The International Bank for Reconstruction and Development/The World Bank, Washington. 401 p.

The study question is ultimately, how the access to the water services can be increased and how the functioning of the built systems and facilities can be sustained through their planned lifetime. Therefore, in the following chapters we briefly introduce the typology and concepts of the green economy, along with the principles of the Integrated Urban Water Management and the institutional eco-innovations, which are – based on our findings – the keys in solving the above problems.

2. Integrated Urban Water Management

Integrated Urban Water Management (IUWM) is nested within the broader notion of Integrated Water Resources Management (IWRM). Given that cities are significant elements of their catchments, IUWM needs to be linked to IWRM plans and management processes in the broader basin context to allow the alignment of the urban water sector with others beyond the urban boundaries (Bahri 2011, 3). IUWM principles are the following (GWP 2013, 2-3): Encompass alternative water sources; Match water quality with water use; Integrate water storage, distribution, treatment, recycling, and disposal; Protect, conserve and exploit water resources at their source; Account for non-urban users; Recognise and seek to align formal and informal institutions and practices; Recognise relationships among water, land use, and energy; Pursue efficiency, equity and sustainability; and Encourage participation by all stakeholders.

It is essential that we develop a framework for green growth and water security that incorporates the integrated approach and addresses water within wider socio-economic goals (GWP 2012, 13). Figure 2 illustrates the coordinating structure that will ensure communication between departments, levels of government, local communities, and stakeholders (GWP 2013, 3, modified from Tucci 2010).

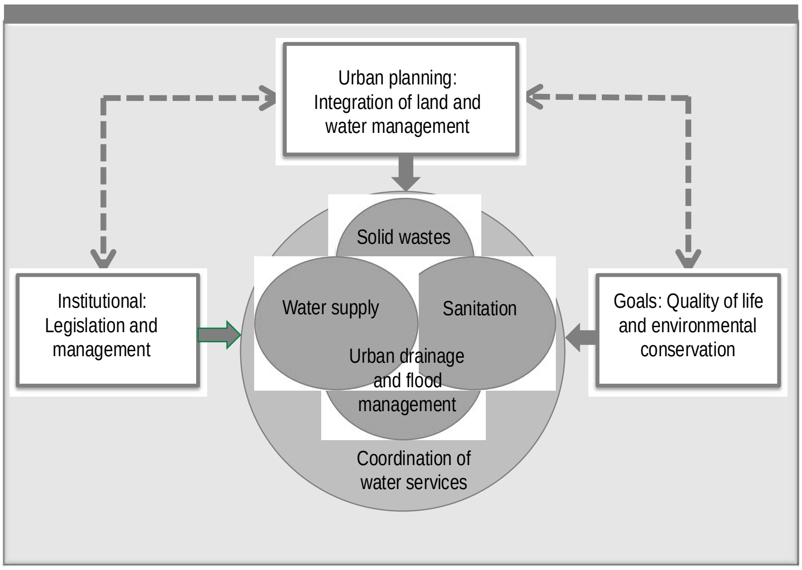

Figure 2: Integrated Urban Water Management (GWP 2013).

Urban planners can help governments overcome fragmented public policy and decision-making by linking planning with other policy sectors like infrastructure, and adopting collaborative approaches that involve all stakeholders in determining priorities, actions, and responsibilities (Figure 3, GWP 2013, 3, modified from Tucci 2010).

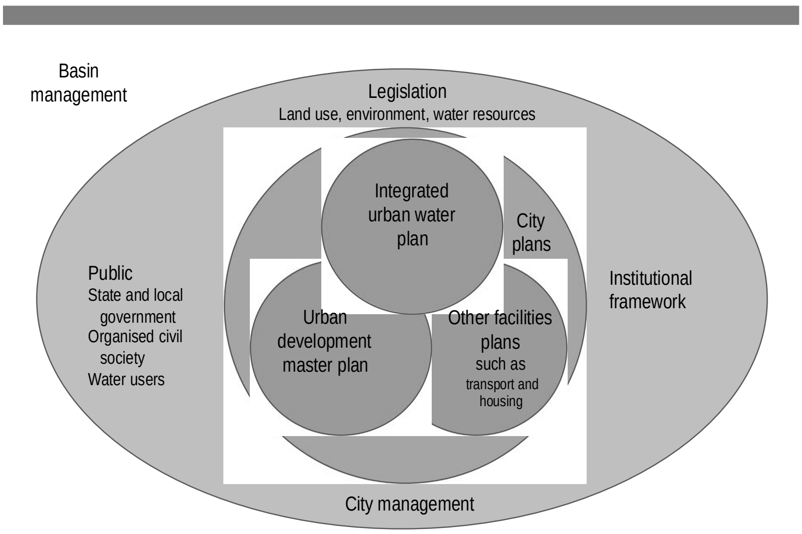

Figure 3: Institutional framework for municipal land and water planning (GWP 2013).

3. The green economy and water

The United Nations Conference on Sustainable Development (UNCSD) took place in 2012. The aim was to define pathways to a safer, more equitable, cleaner, greener and more prosperous world for all, in particular with the help of one important tool available in the context of sustainable development and poverty eradication—*the green economy*. The outcome document "*The Future We Want*" recognized that water is at the core of sustainable development as it is closely linked to a number of key global challenges. In particular, the report underlined the critical importance of water and sanitation within the three dimensions of sustainable development (United Nations 2012, 32).

According to Rotmans, the green economy is not only dealing with the new technological solutions, but it also requires sustainable ways of living, new institutions, and cultural changes (Rotmans 2012, cited by Hatakka 2013, 5). The concept of a green economy is not a replacement for that of sustainable development, but rather a way of conceiving the contribution of economic activities to sustainable development. If sustainable development is the "what," a green economy is the "how." (Federation of Canadian Municipalities 2011, 10).

There is, however, no internationally agreed definition or universal principles for green economy, and interrelated but different terminology and concepts have emerged over recent years. Allen and Clouth (2012, 63-64) gave several definitions developed by different organizations for the green growth and the green economy. Based on the review of emerging literature using a green economy policy typology, policies that were proposed in most of the publications included public investment in infrastructure (such as sustainable energy, water, transport and waste) as well as public investment in innovation (through measures such as funding for R&D and deployment) (Allen 2012, 40).

Water is fundamental to the green economy because it is interwoven with so many sustainable development issues, such as health, food security, and poverty. In developing countries, access to water and sanitation services is a fundamental precondition for poverty reduction and economic progress (UN-Water 2012a, 5). According to the UN-Water Decade Programme on Advocacy and Communication (2011b, 33-34):

1. Achieving a green economy is not possible without ensuring everyone has access to basic water and sanitation services.
2. Transitioning to a green economy in water requires a shift from current practice. Some key tools to promote the necessary change and support the transition: i) economic instruments; ii) green jobs; iii) cost recovery and financing; iv) investments in biodiversity; v) technology; and vi) water planning.
3. Creating incentives for improving efficiency is appropriate where basic water and sanitation services are already being provided.
4. There is an important role for social dialogue and for communities in the provision of water services. Community initiatives are vital in places where government action does not reach.
5. The transition to a green economy requires mobilising more funds, but also requires increasing efficiencies to make better use of the limited financial resources available.
6. Investing in the improvement of biodiversity is critical for sustaining or restoring the water-

related services provided by ecosystems.

7. Governments need to facilitate innovation and adoption of greener water provision and water use technologies, contributing to job creation and structural transformation towards greener economies.
8. Water planning is a powerful social tool for identifying the best way to use water resources to meet the competing needs of different users.

Direct benefits to society can be expected to flow from increased investment in the water supply and sanitation sector, including investment in the conservation of ecosystems critical for water. Research shows that by investing in green sectors, including the water sector, more jobs and greater prosperity can be created. Arguably, these opportunities are strongest in areas where people still do not have access to clean water and adequate sanitation services. Early investment in the provision of these services appears to be a precondition for progress. Once made, the rate of progress will be faster and more sustainable, thus making transition to a green economy possible. The costs of achieving a transition will be much less if the increased investment is accompanied by improvements in governance arrangements, the reform of water policies and the development of partnerships with the private sector. The opportunity to improve governance arrangements is one of the biggest opportunities to speed transition to a greener economy (UNEP 2011b, 146).

The World Water Council (2011) proposed three strategic directions, twelve priorities for action, and three conditions for success as the means to achieve progress in three strategic directions. They constitute strong enabling factors in addressing all the priorities for action (Figure 4).

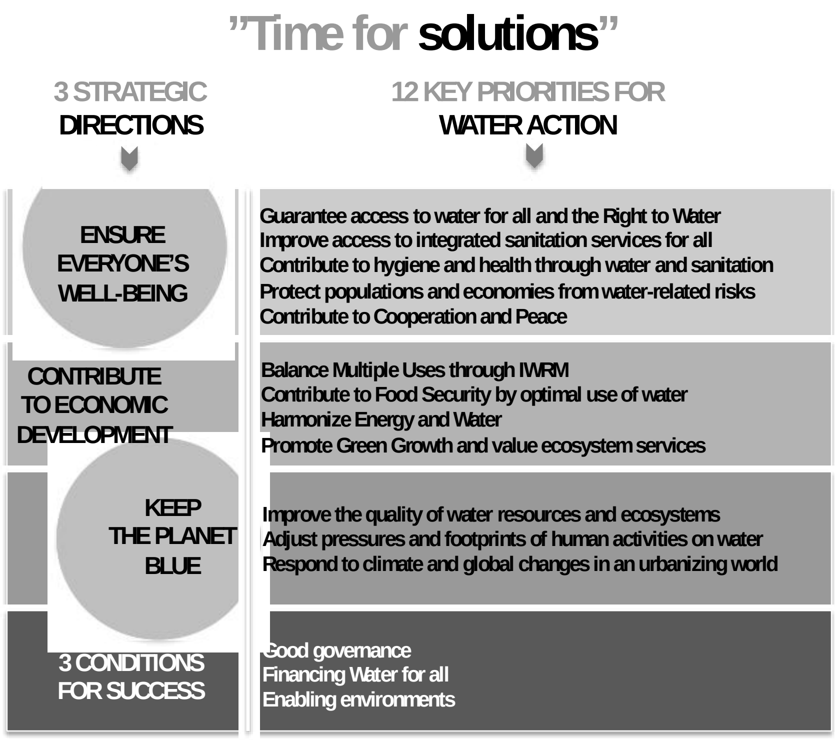

Figure 4: Three strategic directions, twelve priorities for water action and three conditions for success (World Water Council 2011).

Focusing on effectively managing assets to sustain services can be as important as focusing on new infrastructure (World Health Organization 2012, 3). The results of the abovementioned GLAAS 2014 Report show that to improve access and reduce inequalities beyond 2015, much needs to be done to effectively implement and monitor WASH policies at national level, including to (WHO 2014, ix):

- Secure, absorb and target sustained international and national financing;
- Renew focus on health facilities as a priority; to strengthen action in the crucial area of hygiene promotion;
- Support the operation and maintenance of existing infrastructure and services;
- Expand efforts in neglected rural areas where the need for improved services is greatest.

4. Institutional eco-innovations

The most popular definitions of an institution have at their core *social factors that influence, to some extent, human behaviour* (Davis 2009, 3). According to North (1991, 97) institutions are the humanly devised constraints that structure political, economic and social interaction. They consist of both informal constraints (sanctions, taboos, customs, traditions, and self-imposed codes of conduct), and formal rules (constitutions, laws, property rights). Kemper (1996) pointed out that in colloquial language the expression institution also applies to organizations. For more clarity, she used the term of *institutional arrangement*, which indicates the structural nature of institutions. According to her, institutional arrangements and actors, i.e. individuals, agencies and organizations, compose *the institutional framework*.

OECD (2011b, 1-2) notes that *innovation* will play a key role in implementing strategies for green growth. In the Oslo Manual, eco-innovation is defined as “the creation or implementation of new, or significantly improved, products (goods and services), processes, marketing methods, organizational structures and institutional arrangements which – with or without intent – lead to environmental improvements compared to relevant alternatives”. Figure 5 presents an overview of eco-innovation and its typology (OECD and Eurostat 2005, 46, cited by OECD 2009, 13):

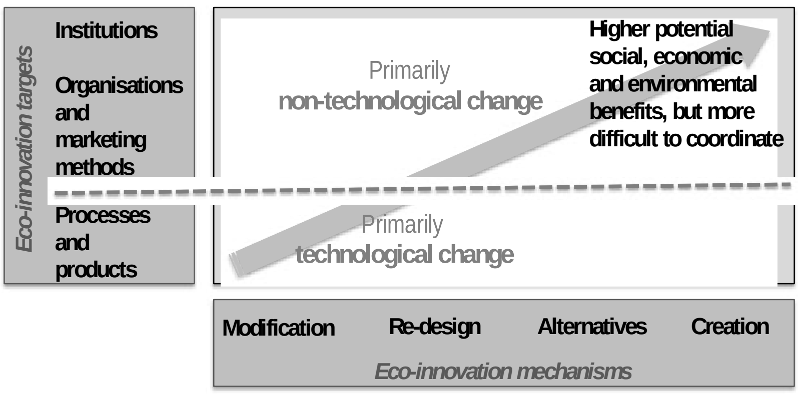

Figure 5: The typology of eco-innovation (OECD and Eurostat, 2005, modified by Hukka in 2015).

In this definition, institutional innovations such as changes in values, beliefs, knowledge, norms, and administrative acts are included, along with changes in management, organization, laws and governance systems that reduce environmental impacts. Innovation, therefore, is not simply about technological solutions (‘techno-fix’ approach). Rather, innovation is a process that has three different forms with different outcomes: 1) Technological innovations providing specific techniques for managing/processing materials and energy; 2) Institutional innovations for managing on a society-wide basis – or even globally – incentives, transaction costs, rents, benefit distribution, dispersal, contractual obligations, precautions, and individual obligations; and 3) Relational innovations for managing cooperation, social cohesion, solidarity, social learning and benefit sharing (UNEP 2011a, 36).

5. Conclusions

We conclude that to make a coherent transition to the green economy and to meet emerging needs of the poorest citizens, the Sustainable Development Goal 6 *“Ensure access to water and sanitation for all”* by 2030 must be achieved. Therefore, there is an urgent need to create enabling institutional framework for urban water services provision and production – in addition to the exploitation of technological innovations. First of all, the reformed institutional framework should ensure that there are more funds available for building new urban water infrastructure to extend access to services as well as more funds for rehabilitation and replacement of existing deteriorated infrastructure.

Secondly, the framework should have a strong focus on improving resilience, performance and maintenance of built infrastructure through effective strategic asset management processes, supported by proper enforcement structures, and on upgrading pricing of services and cost recovery practices. The framework should, therefore, also include improvements in governance arrangements, reforms of water policies, and development of viable cooperation between public and private sectors. Thirdly, the critical role of engineering in addressing water-related global challenges must be recognized more widely, and human resources development should be addressed accordingly.

We also recommend that in formulation of a new institutional framework, the typology and concepts of the green economy, along with principles, approaches and processes of Integrated Urban Water Management, and institutional innovations such as changes in values, beliefs, knowledge, norms, administrative acts, changes in management, organization, laws and systems of good governance should be carefully considered and adopted to build up universal coverage and resilience of urban water and sanitation services.

Acknowledgements

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Delivering Value with BIM: A Framework for Built Environment Practitioners

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Abstract

The built environment industry worldwide is facing significant external pressures such as increased competition, higher owner expectations, rapidly changing technology and skill shortages. Building Information Modelling (BIM) has been identified as a socio-technical system that can be used to improve team communication throughout the project life-cycle, produce better outcomes, reduce rework, lower risk, provide better predictability of outcomes and improve operation and maintenance of an asset, among other benefits. Within this context, proactively establishing quality improvement cycles based on standardised work processes and corresponding measures of effectiveness will ensure better project outcomes. These outcomes can be driven by continuously improving systems and active monitoring. This paper introduces a methodology for developing a whole-of-life asset management strategy for delivering value with BIM across the life-cycle of built assets. It also presents a framework to assess progress towards value-driven goals.

Keywords: BIM, value, whole-of-life, asset management, strategy

1. Introduction

The built environment industry has been facing significant external pressures worldwide such as increased competition, higher owner expectations, rapidly changing technology and skill shortages (Hampson, et al., 2014). Building Information Modelling (BIM) is "a digital process that encompasses all aspects, disciplines and systems of built assets within a single virtual model" (Sanchez, et al., 2015). It has been identified as a socio-technical system "that can be used to improve team communication throughout the project life-cycle, produce better outcomes, reduce rework, lower risk, provide better predictability of outcomes and improve operation and maintenance of an asset" (Sanchez, et al., 2014). There is a growing body of anecdotal evidence about benefits that can be achieved by implementing BIM (Gilligan & Kunz, 2007) and some firms are measuring some benefits (McGraw Hill Construction, 2014b; McGraw Hill Construction, 2014a). However, unclear business value and return on investment (ROI) are often identified as barriers for adoption (Barlish & Sullivan, 2012).

Identifying, monitoring and managing benefits throughout the life-cycle of a project or asset have been highlighted as a way to help achieve success during implementation of new technologies (Yates, et al., 2009). "By defining how each benefit will be measured and then providing evidence for the expected level of improvement that will result from the changes, rigorous and realistic business case and financial argument for the investment can be developed" (Ward, et al., 2007). Capturing and disseminating information to ensure intelligent decision making can also help reduce risk and deal with the large number of variables characteristic of construction projects (Roper & McLin, 2005).

Within this context, proactively establishing quality improvement cycles based on standardised work processes and corresponding measures of effectiveness can help ensure better project outcomes. Metrics play a critical role in driving this process (CURT, 2005). There is a great deal of literature on BIM adoption and benefits for specific applications, stakeholders and life-cycle phases (Bryde, et al., 2013; Arayici, et al., 2011; Migilinskas, et al., 2013; Eadie, et al., 2013; Azhar & Brown, 2009; Kasprzak & Dubler, 2012; Teichholz, 2013). However, there is a lack of comprehensive studies that focus on mapping and measuring the benefits of implementing BIM across the whole-of-life of built assets (Sanchez & Hampson, 2016). This paper introduces the research done to develop a framework to assess the actual benefits of implementing BIM throughout asset planning, delivery and management applicable to both buildings and infrastructure.

2. Methodology

This research was developed in Australia in consultation with national and international organisations encompassing client, designer, surveyor, contractor and facilities management organisations as well as industry organisation that represent thousands of individual organisations across the supply chain. The research aimed to:

(i) Define indicators to measure tangible and intangible benefits of BIM across a project's life-cycle in infrastructure and buildings; and
(ii) Pilot test a whole-of-life BIM value realisation framework on leading infrastructure and building case studies.

The research was informed by a thematic analysis of an extensive literature review covering over 400 academic and industry references. The framework was tested through expert consultation and three exemplar case studies in Australia that featured the use of BIM during design, construction and asset management. The expert consultation included 31 industry, government and research experts from across the supply chain with 10-30 years of experience in the field and roles related to BIM implementation and uptake at the organisational level.

It was important that the framework could be easily applied to both infrastructure assets and buildings. The research team studied a number of different approaches available to develop a strategy for measuring the value of information technology in construction. It was also consistently reviewed by a group of industry and academic experts from infrastructure and buildings, and at different levels of the supply chain. An introduction to the framework was also presented at the Australasian Regional Conference organised by the International Roads Federation (IRF) and Roads Australia in May 2015. This was done to obtain feedback from a wider audience and address common concerns of BIM guidelines being often directed only to buildings and architectural design. This research builds on Love, et al. (2014) who proposed the use of Benefit Realisation Management (BRM) by asset owners. However, the present work provides a different adaptation of the BRM method and extends it to be applicable to all built environment stakeholders across infrastructure and buildings. It was also modified to include the value of unplanned and flow-on benefits as later defined, as well as used to develop a step-by-step guide and an online interactive tool.

3. BIM Value Realisation Framework

The value of BIM is realised through its benefits for different stakeholders. Benefits arise because information technology systems such as BIM enable people to carry out tasks more efficiently and effectively. They do this by allowing and shaping new ways of working through the re-design of intra- and inter-organisational processes or facilitating new work practices (Peppard, et al., 2007). The Benefits Realisation Management (BRM) approach was originally developed in the 1980s and 1990s. This method offered a way of understanding the return on investment from information technologies and systems, and overcoming the limitations of traditional investment appraisal techniques. This aspect of project management has received increasing attention in the past few years (Breese, 2012). These practices have been shown to be associated to the creation of value (Martins Serra & Kunc, 2015) and been applied to a number of sectors and stakeholder groups (Bradley, 2010; Peppard, et al., 2007). However, tailoring this framework for specific organisations and sectors is an essential step towards optimising its value (NSW Government, 2014b). Love, et al. (2014) proposed the use of BRM and resource-based view (RBV) "to provide asset owners with the capability to realize its benefits". Although building on Love et al's idea, this research provides an alternative adaptation of the methodology to serve a larger audience and projects at different life-cycle phases. It was also used to develop a detailed step-by-step guide and online interactive tool to provide guidance for built environment practitioners on how to operationalise the overarching framework.

The framework (Figure 1) largely follows the traditional BRM structure and principles but acknowledges that value is realised not only through specifically identified end-benefits but also through unintended benefits. This has been addressed by including “flow-on” benefits. These are benefits that can be obtained once the end-benefit is achieved. While not being specific project goals with targets and associated milestones, they are included to account for the full value delivered by implementing BIM. The monitoring processes suggests the inclusion of other considerations such as project context and unexpected situations which may hinder the achievement of specific benefits. It additionally acknowledges the role of team and organisational capabilities in attaining value from implementing BIM. This broader view may enable more complete future benchmarks and better understanding of project-to-project different levels of implementation success. Finally, it proposes that enablers have associated risk which should be taken into consideration as they may bring “disbenefits”, these are non-value-adding outcomes which are counterproductive to the implementation goals.

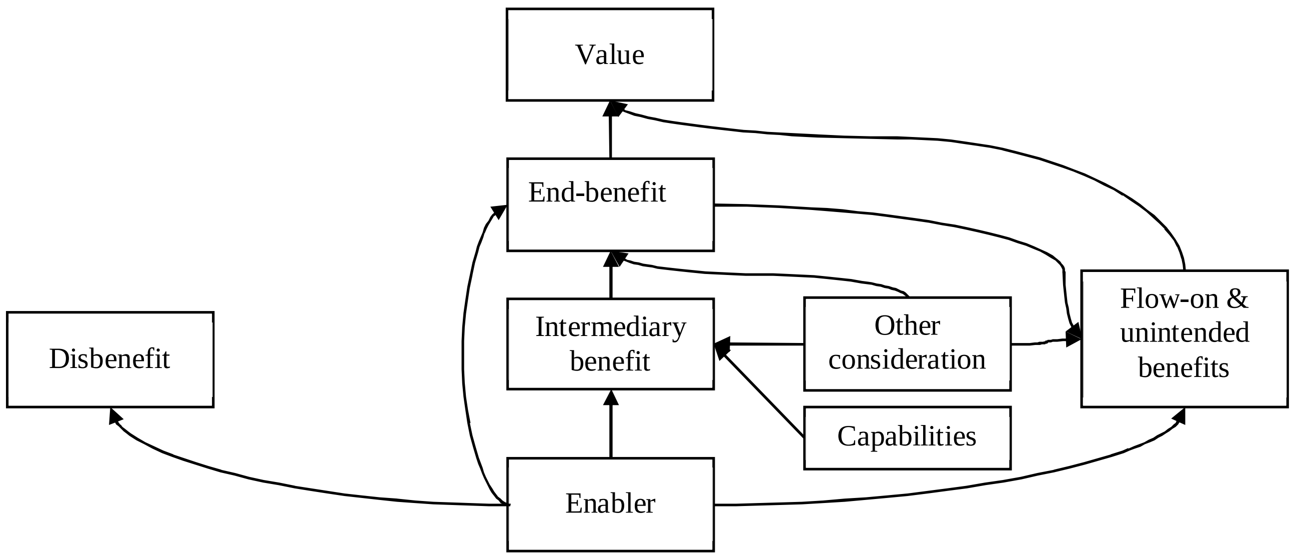

Figure 1: Framework principles

The BIM value realisation framework can be applied at any phase of the life-cycle of an asset and is meant to complement BIM implementation guidelines. The MacLeamy Curve (AIA, 2007) however applies to this process as well. This means that, as shown in Figure 2, the earlier changes and processes required to implement BIM are introduced, the larger impact they are likely to have on the outcomes of the project and realising its full value.

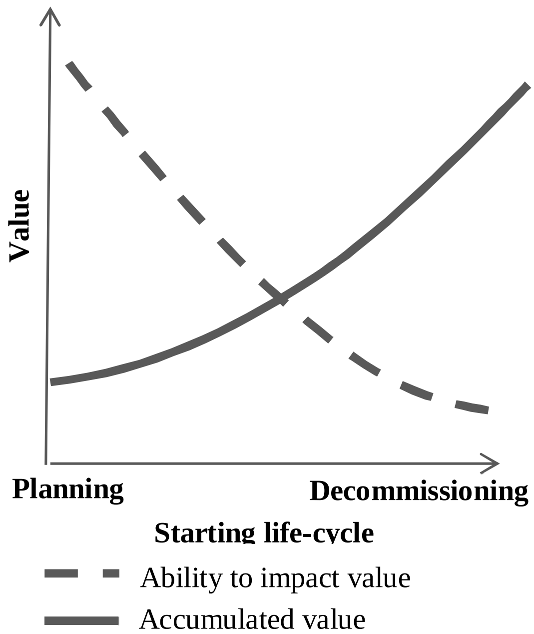

Figure 2: Value/life-cycle relationship

There is no single BIM software that covers all functionalities and processes. The value to each stakeholder is therefore delivered by identifying the specific benefits they aim to gain by implementing BIM-related tools and processes. This allows teams to have a clear understanding of the overall goals, select the path to these goals based on performance-driven objectives and establish a strategy to monitor their progress towards these goals. Thus, another key aspect of the framework is that it focuses on specific benefits driving the BIM implementation strategy and proposes specific asset and project management processes where this can be embedded.

3.1 Step-by-step Guide Summary

The detailed methodology and dictionaries were published in the book: *Delivering Value with BIM: A Whole-of-life Approach* (Sanchez, et al., 2016a). This section presents a brief summary of the main proposed steps.

Step 1 - Define end-benefits: end-benefits are the ultimate objectives. They are the value the team wants to have realised from implementing BIM – such as lower cost, improved safety and gaining competitive advantage. These are defined in a workshop environment with key stakeholders that include project manager, asset manager, designers, end-users and other relevant stakeholders. Including asset managers and end-users can help ensure a whole-of-life insight.

Step 2 - Define intermediary and flow-on benefits: these are the *story* behind each end-benefit and defined in the same workshop environment as the previous step. Intermediary benefits are those *expected* to occur between the implementation of early changes and the realisation of the end-benefits. Flow-on benefits are those that may be derived from achieving the end-benefit. There may also be unintended benefits arising from implementing specific enablers which may be identified at later stages.

Step 3 - Define enablers: enablers are processes and tools related to BIM uses and implementation. They help achieve the first intermediary benefit in the chain. A risk is associated to each enabler, and other considerations such as new skills requirements and cost need to be included in the assessment.

Step 4 - Assign metrics, targets and incentives: metrics provide the means to justifying investments made, comparing and ranking benefits, providing targets for success and benchmarking and monitoring progress towards goals. Assigning metrics to benefits is the basic requirement to provide effective accountability. Choosing as many metrics as possible related to the identified benefits may provide better insight into the success of the implementation strategy. Targets should be assigned to each metric and, if appropriate, financial incentives for exceeding targets.

Step 5 - Embed metrics and targets into progress report documentation and processes: this ensures accountability and provides a rich source of information based on which the group can make decisions and introduce changes in a timely manner in order to correct situations that may be hindering the achievement of the goals established in previous steps. Metrics, targets and incentives should be embedded in the project documentation including the regular progress report as well as the BIM model itself as appropriate. These should also include processes to record context information that may be used to understand different levels of success across different projects.

Step 6 - Workshop follow-up / feasibility and approval: this step is a reality check to evaluate what specific software solutions can be used as enablers to achieve the selected benefits most effectively. The associated cost, for example, will largely depend on the capabilities of the project team and previous experience with specific software packages as well as licences already purchased.

Step 7 - Progress review and correction initiatives: benefits require active monitoring and advancement towards targets related to benefits should be reported on and reviewed during project progress meetings.

Step 8 - Ongoing active learning: benefits are dynamic and will change as technology develops. Therefore, benefits, enablers and metrics dictionaries should be developed and regularly reviewed and updated.

Next steps: following the value realisation strategy, there are a number of considerations that will have to be addressed such as standards, protocols, BIM management roles, risk apportioning, skill development plans and system requirements. This methodology is proposed to be complementary to technical implementation guidelines and standards.

3.2 Dictionaries

BIM is not a single software package that teams can just buy and implement in isolation. It is a new way of working that commonly includes the use of a number of tools, processes and software solutions. One of the exemplar case studies carried out for this research project was based on the design and construction of the Perth Children's Hospital in Australia. This study identified 20 different BIM-related tools and processes that were associated with 26 different benefits (Sanchez, et al., 2015). The second case study was based on the design of the New Generation Rollingstock Maintenance Centre also in Australia and identified 17 tools and processes associated with 25 benefits (Utiome, et al., 2015). This can be overwhelming, especially for new users. To address this issue, the research team carried out an extensive literature review to develop a set of dictionaries.

The *Benefits Dictionary* includes 31 profiles of benefits that are currently achievable from implementing BIM. Benefit identification is a critical process in the BRM methodology “used to create a detailed plan of how those benefits are to be realised throughout the life-cycle of implementation and use of the new technology, process or system” (Sanchez, et al., 2016b). Benefits are defined as improvement on the status quo; as opposed to enablers which are those tools and processes used to achieve a benefit. This distinction is important because in many academic and industry publications enablers are often cited as benefits themselves. Clash detection is for example often mentioned as a benefit of using BIM. This however makes more difficult identifying appropriate metrics that can be used to monitor progress and create industry benchmarks. In this example clash detection is a tool/process; an element that cannot be measured in specific terms but just is or is not in use. The real benefit of clash detection is an improvement in the efficiency of the process of detecting clashes, brought by higher levels of automation and better communication and coordination; this in turn leads to fewer errors and lower cost. All of these are benefits that can be measured in different ways and specific levels can be targeted as success criteria.

Each profile provides a general description of each benefit and provides information about some interpretations that are specific to particular life-cycle phases. They also include a list of enablers that can help realise and maximise the value of BIM at different life-cycle phases, benefits that can flow-on from achieving the profiled benefit, main benefiting stakeholders, metrics that can be used to monitor the benefit and examples of projects where they have been achieved. The list was created based on a thematic analysis of the literature with input from the three exemplar case studies. It includes benefits at different scales that could be considered intermediary or end-benefits depending on the strategy chosen. This was done aiming to cater for progressive and incremental implementation strategies that may focus on different benefits at each step. This may be especially relevant to small and medium sized enterprises (SMEs) and cautious client organisations with limited resources.

The *Enablers Dictionary* contains information about 51 enablers grouped under two overarching categories and 28 sub-categories. The categories were developed using the Pennsylvania State University “BIM Execution Plan” (Penn State, 2011) as a starting point and further developing it based on input from industry experts. The two overarching categories are:

(i) Intrinsic/core: These are enablers that were considered to form the basis of BIM and maximise benefits from its use across different life-cycle phases. These included processes that were not standard practice in many countries yet but were considered an intrinsic part of BIM implementation strategies that aim to maximise its value for all stakeholders. Examples include “design authoring and data-rich accurate models”, “early and effective stakeholder engagement” and “object libraries”.

(ii) In Use: These are enablers which are either commonly used nowadays and/or that, although having had limited use in common practices, either are already growing in use or have the potential to do so in the near future and provide significant benefits. Examples include "3D laser scanning", "automated clash detection", "design reviews", "GIS-BIM" and "digital fabrication".

The *Metrics Dictionary* aims to provide a practical way of avoiding wasted efforts often seen in recording and tracking metrics which are being tracked elsewhere. The dictionary includes a comprehensive set of 43 metrics that were found to be practical and offer a set from which each project can select those that are most appropriate to their goals and needs. These metrics are mostly based on literature but also include indicators proposed by the authors based on professional experience, experts consulted and the three exemplar case studies. Metrics were categorised in four groups:

(i) People - serve to monitor benefits achieved through changes in behavioural patterns or that directly affect staff. Examples include "safety", "meetings", "stakeholder involvement" and "labour intensity".

(ii) Processes - monitor benefits achieved through changes to general process improvement and generally aim to measure the efficiency of these processes. Examples include "time predictability", "schedule conformance", "cost of change", and "latency".

(iii) Procurement - monitor benefits achieved during or through procurement and asset management processes. Examples include "cost per unit", "quality", "program capacity" and "globalisation".

(iv) Sustainability and future proofing - monitor benefits achieved in terms of better environmental sustainability outcomes and improved emergency management. Examples include "resource use and management", "carbon emissions and footprint", "emergency latency" and "emergency plan and response effectiveness".

It should be noted that, although case study participants highlighted sustainability as one of the drivers to implement BIM, the research team found it particularly difficult to find literature about metrics that could be included in this category. This is proposed as a potential gap in the literature for future research.

A complete list of benefits, enablers and metrics can be found online on BIM Value (see section 3.3) or in Sanchez et al. (2016a).

3.3 BIM Value

The experts consulted to test the practicality to the framework suggested that one of the main barriers to adoption is fast and easy access to information about benefits, enablers and metrics. This led to the research team translating the dictionaries into an open access online interactive tool to step through the first four levels of the framework. This tool, BIM Value (http://bimvaluetool.natspec.org/), provides a tailored information delivery system. It guides the user through six steps where they select the stakeholder group and life-cycle phases they are interested in and the tool provides a set of benefits that apply to those two parameters. The user can then select those benefits they are interested in and the tool provides a new list of enablers and metrics which apply to the selected stakeholder group, life-cycle phase and benefits. In the final step, it produces a report with a summary of descriptions of the different benefits, enablers and metrics selected that also includes examples and references to follow upon. The tool also offers the possibility of accessing the dictionaries directly and provides links to other sites with BIM-related videos and guidelines. In its first week and with close to no publicity, the tool had over 240 new users trying it out, mainly from the UK and Australia. Four months later, the tool has had over 4,000 views with a return rate in March 2016 of 49.3%. This is suggested to be a reflection of the industry's interest in accessing information about tangible and measurable benefits from implementing BIM.

3.4 Research Limitations

The methodology presented here, although based on an arguably proven approach such as BRM and submitted to a thorough review process with industry and academic experts has had a limited validation process. The framework was partially validated by the Sydney Opera House which was transitioning into a BIM-based asset management system. Feedback from this effort and the previously outlined consultation was used to finalise the framework into its present form. However, although originally planned, a more comprehensive validation process was not possible due to time and resources constrains. The research team will continue to work towards the validation of the complete process in the near future.

3.5 Future Research

Future research will aim to continue to develop and improve the BIM Value tool through new modules in order to increase its value to the industry. One of such modules is for example expected to form the basis for a world-first BIM benefits benchmarking system (BIM Value Benchmark). This new effort will also seek to understand how meta-data created from using the tool can be used to most benefit the industry.

4. Conclusions

This publication has introduced a methodology to identify and monitor benefits that will serve to realise and deliver value with BIM across the life-cycle of an asset to different stakeholders. This research was based on an extensive literature review, expert consultation and three exemplar case studies. An important aspect of the research was to collaborate with industry and government organisations across the supply chain to receive feedback on the practicality and completeness of the outcomes. This collaborative effort aimed to ensure that the outcomes of the research were most relevant to different industry stakeholder groups as well as complementary to outputs of other organisations active in this space. Outcomes of this research are expected to help achieve more informed value-driven assessment and continual improvement of the implementation of BIM across assets and life-cycle phases.

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Combining BIM and Lean Construction: Towards Enhanced Collaborative Working?

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Abstract

In this paper, the influence on collaborative working by using BIM and two Lean Construction inspired tools in a real-life design process is scrutinized. Statsbygg, as the building commissioner, expected that requiring the use of BIM, as well as the two Lean Construction principles; co-location and a takt-time planning would enhance the collaborative working among the design team. The case study is based on qualitative data which stems from semi-structured interviews, observational as well as document studies. The findings indicate that the combination of BIM and co-location helped to improve the collaborative working including fostered faster communication, and contributed to a good social climate in the design team. However, the data also suggest that not all parts of Statsbygg's contractual "BIM and Lean Construction package" were equally successful in practice. The takt-time planning tool was not used at all by the design team. An explanation for this disparity in successfulness is partly due to that BIM and co-location got more attention from Statsbygg compared to the takt-time planning tool in the implementation process. Moreover, the design team had experiences with BIM and co-location from an earlier project, and thus found it easier to make use of elements that were familiar. Based on the analysis, it is concluded that the combination of BIM and co-location have a potential to impact positively on collaborative working in the design phase by linking actors together both technological and organizational. However, such an outcome requires a careful planning and implementation process.

Keywords: BIM, building process, case study, collaboration, lean construction

1. Introduction

The architectural, engineering, and construction (AEC) industry creates complex and unique buildings. Construction work is organized as projects; temporary coalitions between two or more organizations (Jones and Lichtenstein 2005). Construction projects consist of teams from different companies who work together to realize the project's goals. These industry specific characteristics are of great importance for how the industry operates. As pointed out by numerous researchers, the construction industry suffers from several unfortunate conditions that affect the industry unfavourably. Some have characterized the relationships in construction as "loose couplings" (Dubois and Gadde 2002). This notion refers to temporary coalitions of companies and individuals that come together to complete a project, and then disband. An important feature is the fragmented nature of the industry. Consequently, potent collaboration between actors from different companies throughout the constructions process is required. Still, prior experience recognizes that this is really difficult to achieve. However, in the last decade we have seen promising technology in terms of building information modelling (BIM). With the use of BIM, a network of interdependent actors can collaborate to develop and utilize a 3D object of the planned building (Taylor and Bernstein 2009). Ideally, BIM technology should create a tight technological coupling among the actors who share models (Dossic and Neff 2010). The starting point of this paper is how potentially tight technological couplings work out in an industry known for its fragmented nature.

In this paper, an explorative case study from Statsbygg is investigated. Statsbygg provides guidance in the purchase and leasing of premises and, in respect of new buildings, act as building commissioner on behalf of the Norwegian government. This case deals with the detailed design phase of a refurbishment of a university building where Statsbygg acted as building commissioner. The case study is about Statsbygg's request of using BIM, and some Lean Construction principles including co-location of the design team as well as a takt-time planning system. Statsbygg's expectation was that this combination would enhance collaborative work among the actors in the design team. By collaborative work I refer to the joint working of various actors or different organizations to effectively accomplish a project (Xue et al. 2010). However, one cannot simply assume that improved collaborative working is automatically achieved. Previous case studies have shown that implementation and use of BIM and Lean Construction are affected by the interplay between the triangle of technology, people and process. To succeed, mutual adaptations regarded to the three elements are required by the involved actors (cf. Moum 2008). Thus, the following research question will be examined: How was the collaborative work among the design team in the case studied affected by the request of using BIM and Lean Construction?

2. Conceptual framework: Lean Construction and BIM

Taiichi Ohno is the person usually credited for having launched the Toyota Production System (TPS), which can be seen as a precursor to what is here referred to as Lean Construction. Lean thinking is generally based on the following five principles: 1. the value associated with the product as specified by the customer. 2. The value stream, identifying the value stream for each product and to avoid waste. 3. Flow, to create a value flow without interruption. 4. Pull, to let customer needs guide the production process. 5. Continuous improvement, creating a continuous improvement throughout the process (Womack and Jones 1996). Lean Construction is inspired by TPS, and emerged as a concept in the early 1990s. Lean Construction is based on an assumption that Lean manufacturing principles cannot be transferred directly to the construction industry. The construction industry is characterized by more variety and uncertainty about production compared to the manufacturing industry. Koskela (2000) proposed the use of the Transformation-Flow-Value (TVF) theory where production was conceptualized in three ways: 1. As a transformation of inputs to outputs. 2. As a flow, in addition to transformation there is waiting, inspection and moving stages 3. As value; where production is seen as means for the fulfilment of the customer needs. The conventional conceptualization of production within construction industry has been based on the transformation concept only. This implies that production management in this conceptualization is all about dividing the total transformation into tasks which is sought to be handled as efficiently as possible. Koskela (2000) claims that all three conceptualization are necessary and they should be used simultaneously. The TVF theory led to the birth of Lean Construction. The aim of Lean Construction is thus *"… to design production systems to minimize waste of materials, time, and effort in order to generate the maximum possible amount of value"* (Koskela et al. 2002, p. 211). It is significant to stress that the term Lean Construction may refer to the use of Lean in the entire construction process and not only the construction phase. However, in this paper Lean Construction is used to denote the use of Lean principles and tools in the design phase (cf. Emmit et al. 2004).

The acronym BIM can be used to refer to a product building information model, a structured dataset describing a building, or an activity building information modelling - the act of creating a building information model (Moum 2008). In this paper, BIM is a term referring to three-dimensional computer-aided and product-oriented design technologies and processes in the AEC-industry. With the use of BIM, a network of interdependent actors can collaborate to develop a model of the planned construction works (Taylor and Bernstein 2009). A frequent scenario is that the designers merge their discipline-specific models to a multidisciplinary model, and by using applications for visualization and collision controls get a better cross-disciplinary understanding of each other's requirements, detecting conflicts, errors and omissions across disciplines (Moum 2008).[1] It has been argued that the construction industry may be facing a new paradigm triggered by BIM (Azhar 2011). This paradigm shift is partly expected to change the traditional discipline's practices towards more integrated processes. It is also expected that BIM can result in a seamless flow of information across different actors and disciplines in the construction process. This implies that it is not only a change in technology itself, but that the change also affects procedures, tasks, roles, etc. Consequently, the new paradigm can be seen as organizational as well as technological. One of the most striking arguments for implementing BIM is that it has the potential to improve the collaboration among the actors involved in the construction process. To

1 In this scenario, BIM is not used to its full potential. See this link for a discussion of different BIM maturity levels: https://www.thenbs.com/knowledge/bim-levels-explained

accomplishing these promised improvements, the project team needs to adapt and work together in an integrated unit.

2.1 BIM, Lean Construction and collaborative working

Lean Construction and BIM are not dependent on each other. This means that Lean Construction can be adopted without BIM and BIM can be adopted without Lean Construction. However, evidence of interactions between Lean Construction and BIM has been identified. In a paper, Sacks et al. (2010) discuss interactions of Lean Construction and BIM. Based on a comprehensive analysis they find that Lean Construction and BIM have several overlaps. Consequently, the authors claim that: *"… the breadth and depth of interconnections between them [Lean and BIM] implies that any company or project on a lean journey should seriously consider using BIM for enhancing the lean outcomes. Conversely, any company or project implementing BIM should ensure that their adoption/change process is contributing to the fullest extent possible to making their processes leaner"* (Sacks et al. 2010, p. 979). Based on this conclusion, I assume that the potential for improvement of a construction process are enhanced when BIM and Lean Construction are integrated. As the discussion above shows, basic premises for both BIM and Lean Construction are about improving collaboration by different actors in the construction process. This was also present in Statsbygg's thinking in the project. Statsbygg assumed that BIM and Lean Construction positively affect each other and that the combination of the two would strengthen the collaborative work in the design phase. The relationship between BIM, Lean Construction and their impact on collaborative working as it is perceived in this paper, is illustrated in figure 1. In the following, figure 1 will be briefly explained. The introduction of BIM and Lean Construction in a project may have impact on collaborative work in all parts of the construction process. In addition, using BIM and Lean Construction can affect and influence different processes on several levels. Following Moum (2008), three levels can be identified: 1. the micro-level which focus on individual processes. 2. The meso-level covers processes and mechanisms within a group, for instance the design team. 3. The macro-level covers mechanisms on the overall project level. There has been increasing recognition in research that collaborative working is one of the most important and critical success factors for construction projects (Xue et al. 2010). In this paper, collaborative working constitutes the "dependent variable", while BIM and Lean Construction are the two "independent variables". This paper studies the impact of BIM and Lean Construction on collaborative working delimited to the *design phase*. This is no coincidence; a fundamental pillar of a successful construction project is a good design process (Moum 2008). Thus, I concentrate on BIM and Lean Construction's impact on collaborative working among the design team. This implies that processes primarily on the *meso-level* will be in the spotlight (highlighted in figure 1).

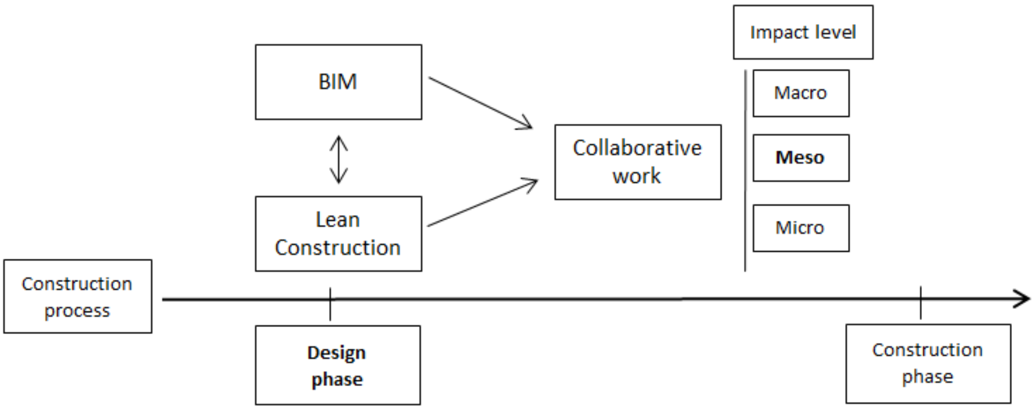

Figure 1. BIM, Lean Construction and collaborative work.

3. Methods

According to Yin (2003), a case study consists of an in-depth inquiry into a specific and complex phenomenon, set within its real-world context. Case studies are seen as appropriate to answer "how" and "why" questions and allow for the investigation of many variables consequently generating in-depth knowledge (Yin 2003). In this paper the impact of using BIM and Lean Construction on collaborative working in a real-life construction project is studied. Consequently, an in-depth case study seems necessary. The case study in this paper is based on qualitative data which are generated from semi-structured interviews with leaders and "hands on" project participants; this includes both people from Statsbygg and the design team. The purpose of the interviews was to get informants' own assessments of the project and how the use of BIM and Lean Construction affected different aspects of collaborative work. In the interviews, I asked questions about how co-location influenced collaboration across organizational boundaries, how BIM was used across disciplines as well as what takt-time planning meant for planning processes. All interviews were done in Norwegian. Consequently, the quotes used in this paper are translated from Norwegian to English by the author. All in all, it was conducted eleven semi-structured interviews. As a part of the data collection I have also observed five design meetings. About 10 persons attended each of these meetings. In this part of the study I chose a non-participant strategy (Yin 2003). Such a strategy implies that I was not a part of the activity taking place at the meetings, but simply visible observers. In addition, documents have been used as a supplement to other data types generated through interviews and observation. The documents are mainly project-specific documentation from Statsbygg. This includes contracts and tender documents, written information about the building, as well as more general information such as Statsbygg's current BIM manual.

4. The case: Urbygningen

Statsbygg is one of the industry partners in an ongoing Norwegian research project called SamBIM (Collaboration with BIM as a catalyst) financed by the Norwegian research council. This research project is based on a joint effort of Norwegian industry and research partners. In this project several actors from the construction industry wants to try out and develop BIM-driven processes and collaborative models that boost value creation in the SamBIM partners, in the building projects, and in the AEC-industry.

The case study in the paper deals with the detailed design phase of a refurbishment of a university building named *Urbygningen* at the Norwegian University of Life Sciences (NMBU) located outside Oslo. This building project is one of Statsbygg's contributions to the portfolio of case studies in the SamBIM project. The detailed design phase lasted from April 2013 to august 2014. The buildings gross floor area is 8.190 m2 and the budget for refurbishments is 307.5 million NOK. The rehabilitation of Urbygningen has been a long-drawn process. The preliminary design was completed in 2009. Then, the project was abandoned for several years while waiting for the necessary government funding. In January 2013, Statsbygg received an assignment from the

Norwegian Ministry of Education and Research to start up the process for rehabilitating the building Urbygningen at NMBU. In March 2013, Statsbygg put the project out to tender. The task was about hiring a design team for carry out the detailed design phase. Because of the connection to SamBIM, the building project's ambitions were raised compared to a more “normal” Statsbygg project according to some of the informants from Statsbygg. In the contract documents it was also emphasized that the project should be executed as what is referred to as a “Lean project”. One of the tender documents had a distinct focus on collaborative working, BIM and Lean Construction. This document was titled “Collaboration memo” and describes how Statsbygg envisioned BIM and Lean Construction in this project. In the document we can read the following: *“… Lean construction should be used in this project, both during the detailed design phase and construction phase. Lean is introduced in the project together with BIM and logistics planning. Lean is about creating flow between individual actors, disciplines, phases and tasks in a construction project allowing holistic process. An important factor succeeding with Lean is that everyone in the project participates and is willing to take part of the process”* (Statsbygg 2013). Altogether, Statsbygg anticipated that the use of BIM and Lean Constriction should lead to a project with more collaborative working among the actors in the design team thus leading to better design phase (Statsbygg 2013).

4.1 Implementation: How was the design phase carried out?

Based on a competitive tendering, a design team was selected. The chosen design team was a constellation of five Norwegian consultant companies. This group started their work in the spring of 2013. In the very beginning of the design phase the whole design team attended a training course where they were given a brief introduction to the main ideas of Lean Construction and takt-time planning principles. According to my informants the takt-time planning principles were neither used nor particularly mentioned throughout the design phase. This lack of use was by my informants related to the fact that the design team itself did not have any experience with such principles. In addition it was emphasized that the planning principles was not further requested by Statsbygg during the design phase. In other words, it was mainly the design team’s responsibility to determine the organizing of their work, albeit based on Statsbygg's contractual specifications. It was in particular the use of BIM and co-location of the design team in a so-called big room which got most attention and became the fundamental work principles. This kind of working implied in this project that the design team should be co-located in a common office two days a week. This form of working is inspired by Lean Construction and some principles taken from so-called Virtual Design and Construction (VDC) (Chachere et al. 2009). There exists several touch and overlaps between Lean Construction and VDC. An important shared feature is the focus on activities that bring value to the project and minimize waste activities. When working co-located, all relevant actors are gathered in a big room where they work simultaneously using technology such as BIM. In this construction project, the big room was furnished with desks, one interactive whiteboard as well as an old fashioned screen and projector. In addition, adjoining offices were made ready for separate meetings, phone calls etc. They also had a fairly large room where everyone had a permanent work station. Statsbygg and the design team agreed upon a weekly schedule. The schedule meant that the main disciplines should be present two days each week together with representatives from Statsbygg. Representatives from the end-user would also be present when needed. The intentions with this form of working were to strengthening collaborative working, including the interdisciplinary collaboration as well as reducing waiting time.

5. Findings

In my interviews, I was concerned about getting deeper insight into how the use of BIM and Lean Construction affected the relationship and collaborative working among the actors in the design phase. These are processes which primarily are located at the meso-level as discussed in the paper's conceptual framework (figure 1).

All actors interviewed were familiar with BIM from earlier projects. Most of them had worked on several BIM-enabled projects. When asked about BIM and collaboration, almost all informants told that BIM had led to a better understanding and knowledge of the other designers' work and had brought valuable opportunities for interdisciplinary control. Below is a quote that demonstrates what a number of informants told in the interviews:

"BIM is a significant improvement. It is easier to work together when we have a common model. I can see what's have been done by others. I can also see how other designers have planned and how I must relate to their work" (Designer).

In the quote above, aspects related to the interdisciplinary work are highlighted as favorable by using BIM. Nevertheless it was especially the combination of BIM and co-location in a big room my informants emphasized as particularly useful. All informants' from the design team had earlier experience from projects where co-location and BIM were used in combination. This experience was by several pointed out as something valuable because the team knew about the working methods and what that entailed. In addition, the design team was familiar with each other from a Statsbygg project some months in advance, were the combination of BIM and co-location was tested. Some informants claimed that this familiarity gave the project a flying start because the team did not have to "go up a completely new path". Below follows a quote from an informant who underlined the significance of being familiar the "new" way of working form prior projects:

"This [the co-location of the design team] was not completely new to me. I have been working on another project with Statsbygg where we were co-located two days each week biweekly. Several persons from the design team [in this project] were also involved in that project" (Designer).

5.1 More and better inter-organizational collaboration

Several of my informants upheld that the combination of BIM and the co-located type of working had facilitated the group working together as a unitary team. This was partly explained by pointing out that it was much easier to approach designers from other disciplines and companies when the team was co-located and the intention was that they should work together. Some informants pointed out that this kind of working contributed to erase the organizational boundaries between the different companies. The two following quotes illustrate some of what is discussed in this section; in addition they show that the informant's claim that they behave differently towards people they get to know better:

"… it is about that we get a different relationship, a better relationship, with the other persons in the project when are co-located and working together compared to the 'usual projects'. This is my experience at least" (Designer).

"I think maybe I behave a little differently towards the other people in the project [when co-located]. I mean, differently towards the people I do not usually work together with in my company" (Designer).

The next quote illustrates the dynamics that may occur when the design team is co-located. The informant points out that designers who initially was not a part of a discussion easily can join in and contribute to the interdisciplinary development of the project:

"I think it is very positive to be co-located… If I have a problem I need to discuss with another discipline. Traditionally, I would make a phone call. However, when we are co-located and talk together often also other consultants are drawn into the discussion make important contributions. This would not happen if just the two of us talked about this on the phone" (Designer).

Some of my informants also claimed that working co-located with BIM had a positive impact on what they referred to as the team spirit. Because of the co-location the actors spent quite some time together socializing; working, held meetings and had lunch breaks twice a week. In my interviews, the social aspects were a recurring theme. Two informants put it like this:

"We have spent much time together, it's nice and I think that it has helped us to create a good social atmosphere in the group" (Designer).

"Co-location has a positive effect on faster communication. In addition it can also prevent conflicts, and create a better atmosphere [in the design team]" (Designer).

5.2 Faster communication and shorter waiting periods

Several informants were particularly concerned about being co-located, which they perceived as leading to short lines of communication and better opportunities to make decisions quickly; "*decisions can be made right away on the spot"*, as one designer said. Especially the combination BIM and co-location opened for faster ways of communication. Using BIM co-located made it feasible to go quickly into the model together, to watch and discuss different scenarios. Some informants argued that such a combination meant that they could make clarifications and quick decisions, as compared with traditional projects that could take several days if the communication took place on telephone or email. This may imply that the design phase in full can be completed faster with this way of working. In the interviews, the informants told a great deal about faster communication and reduced waiting time. Below is a quote that summarizes an essential part of what I was told in the interviews:

"The greatest profit in my view is that we have access to everyone who know something about the project in less than a minute - often it takes only 10 seconds [to contact other members of the design team]. This makes things very efficient. In that sense, other projects can learn a lot" (Designer).

5.3 A challenging aspect: "professional loneliness"

Even though a number of positive sides of working co-located with BIM for the collaborative working were mentioned, some more difficult aspects came up in the interviews. Several informants told that being away from the workplace and then from their own professional environment could be challenging. This is due to the lack of co-workers or others with more or less the same educational background for discussing professional issues. Such an aspect can be denoted to as a kind of professional loneliness. One informant told about the professional loneliness in this way:

"You lose some of the contact with others in your profession. In my previous project, the whole group was co-located, it was better. It was an advantage. In this project I feel a bit 'lonely'. At my workplace I have a lot of colleagues to discuss with" (Designer).

Most of the processes discussed in this paper are group processes at the meso-level. However, professional loneliness primary concerns individual design team members at the micro-level (cf. figure 1).

6. Discussion

Prior research has pointed out that collaboration problems in construction processes are partly caused by industry characteristics. The industry is project based, meaning that construction projects most often consist of participants from several different companies working together for a limited time span (Jones and Lichtenstein 2005). The central question in this paper is then if the combination of BIM and Lean Construction can help to remedy this problem and thus lead to enhanced collaborative working among the design team?

My data suggest that this to some extent occurred. In particular, it turned out that the combination of BIM and co-location of the design team generated quite good results on the collaborative working. This is in accordance with the framework presented in section 2.1. Hence, the findings point to that BIM and Lean Construction influence each other positively in enhancing collaborative working. First and foremost, virtually all my informants were very satisfied with the use of BIM. Several informants told that BIM makes it easier to collaborate across disciplines and companies. The informants highlighted the opportunity to work on a common model, carry out clash controls, and the visualization possibilities as especially useful and important for strengthening the collaborative working. In addition, almost all informants stressed that the use of BIM in combination with co-location of the design team fostered fruitful climate of collaboration. Several informants also stated that communication is going faster under such conditions; the co-located team can quickly find good solutions while using BIM technology to visualize complex problems and potential solutions. These kind of situations opened up for making decisions “on the spot”, which was particularly advantageous. In addition, quite a few told some more about social aspects; when working closely together each week the member of the design team becomes more familiar with each other and that could result in a greater level of understanding for others professional perspectives. In other words, my findings point toward that such an approach helped to improve the inter-organizational and interdisciplinary collaboration, fostered faster communication and made improvements in waiting time, as well as it contributed to build understanding among the involved actors. As a whole, this contributed to enhance the collaborative working among the actors in the design team. Despite many positive experiences, some informants also expressed that co-location could lead to a form of professional loneliness. This happened as a result of missing colleagues with more or less the same competence to discuss professional issues when co-located.

However, the data also reveals that not all parts of Statsbygg’s contractual “BIM and Lean Construction-package” were successful in practice. This relates especially to the intended use of a Lean Construction inspired takt-time planning concept. In the findings I described that the building commissioner Statsbygg specified some specifications. However it was largely the responsibility of the design team itself to take care of the implementation. The empirical presentation and discussion in previous sections has shown that the informants consider that they succeed quite well with implementing BIM and working co-located, but not with takt-time planning. According to the informants from the design team, the lack of using the takt-time planning system could partly to be explained by fact that it was not further requested by Statsbygg during the design phase. In addition, the design team did not have any experience with such a system. The lack of demand combined with limited experience made it easy for the design team to take the presumably easiest path; they chose what they had done some months ago, namely BIM and co-location. This is not necessarily a bad choice. It implies that the design team applied a model they knew worked quite well and that they could further improve in this project. A drawback is that such a decision easily can lead to a kind of lock-in situation where old certainties are exploited rather than searching and exploring for new and perhaps more superior ways of working (March 1994). Because of the design team’s lack of experience, it would probably be favorable if Statsbygg as an actor with a lot of resources to a larger extent had been helping to facilitate the implementation process in this case. This can be seen in connection with another SamBIM case project where Statsbygg played a much more active role in the implementation process. In that project Statsbygg was a driving force in the implementation of BIM and various Lean Construction tools in the design phase. At the same time Statsbygg emphasized to involve the design team in decisions about BIM and Lean Construction (Bråthen and Moum 2015). Bråthen and Moum (2015) claim that Statsbygg’s active role combined with the involvement probably was essential for the successful implementation. As the analysis points out, BIM and co-location had a quite good effect on the collaborative work in the case studied. However, this positive effect could possibly be even better if the takt-time planning system had been adopted together with BIM and co-location as initially planned by Statsbygg. Earlier research such as

Sacks et al. (2010) emphasize that great advantages can be realized when several processes and tools are combined.

7. Conclusion

The various processes and tools that Statsbygg planned to test out in this construction project turned out quite differently in practice. The disparity in successfulness is probably partly due to that different elements being emphasized in varying degrees by Statsbygg in the implementation process. Put differently, elements which are given little or no attention in the implementation process are less likely to lead to good results. Due to no knowledge within the design team combined with little attention from Statsbygg in terms of takt-time planning, there was not created a necessary ownership and a common vision for the use of this planning system in the project. These shortcomings were probably significant for the less successful result of the takt-time planning system compared to the combination of BIM and co-location. This argument may also have a more practical implication for actors like Statsbygg who wants to take an active role in the development of the construction industry. To succeed with new working methods, the actual implementation and development process "on the ground" is just as important as formulating well considered and innovative contract specifications.

Despite this, it is important to be aware of the limitations of this case study. There are certainly some factors in this pilot case which distinguishes it from "the usual construction project". One factor is related to the fact that the design team knew each other quite well and had worked co-located with BIM in another Statsbygg project some months earlier. This "earlier experience factor" may have led to better results than usual since the constellation already knew each other and had partly adapted work principles. In addition, the findings in this paper are limited to a single case study. Further research from other contexts is thus needed to draw firm conclusions which could be applied to the construction industry at large. Despite the abovementioned limitations, it appears that BIM and co-location have a potential to impact positively on the collaborative work in the design phase of construction projects by linking actors closer together both technological and organizational. For that reason, the previously proposed conceptual framework finds support in the empirical evidence. Indeed, such a successful outcome requires a careful planning and implementation process.

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The Information Modeling and the Progression of Data-Driven Projects

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Abstract

The aim of this paper is to investigate different approaches adopted to define the content of a Building Information Model (BIM). In order to improve the effectiveness of the Built Asset during the whole life-cycle, the Construction Industry is moving towards a digital eco-system. Thus, the implementation of Data-Driven Projects based on Building Information Modeling is wide-spread and becomes more and more a mandatory requirement. The Building Information Modeling methodology is based on an Information Model that contains the updated and amended information related to the project, starting from Briefing and Conceptual Design. So to achieve a performing process, it is essential to provide any needed information at the right time. For this reason, several concepts related to the definition of data sets belonging to BIM, such as 'Level of Development' and 'Level of Detail', have been established. The main focus of this study is to provide an overview on this topic and to investigate possible different approaches. The study is based on both literature review and interviews. The findings indicate that there is not a univocal approach suitable to manage this issue, and numerous definitions and acronyms have been defined in different Countries, especially in US and in UK. However, it is possible to compare them and to find similarities. The findings can be used to gain an in-depth understanding on this topic, especially for experts who work with BIM in various Countries.

Keywords: Building Information Model, Level of Development, Level of Detail, Level of Definition, Level of Information.

1. Introduction

In order to achieve whole life-cycle effectiveness, the Construction Industry is moving towards a digital eco-system. The implementation of Data-Driven Projects based on Building Information Modeling is spreading and becoming more and more a mandatory requirement. Indeed, several Countries such as the UK, Germany, Spain and France are actively mandating governmental strategies, seeking to promote a Smart Construction Industry. The Building Information Modeling methodology is based on a Building Information Model (BIM) that virtually represents the design and project, and contains updated information (Eastman et al., 2011). In order to attain any expected outcomes, it is essential to provide needed information at the right time to the right person. For this reason, several concepts related to the definition of data within the BIM have been developed. Different data are needed for different purposes; thus, from the early beginnings it is important to clearly define the authorized uses and responsibilities. Authors themselves realized that nowadays there is not a clear understanding of these concepts and the literature does not provide enough findings. Thus, the focus of this paper is to provide an overview on this topic and to investigate possible approaches as well as similarities. Finally, a possible future scenario concerning the data management is discussed.

2. Methodology

First, in order to obtain information on the data management within Information Modeling, a literature review has been performed. The concept and application of this topic is still relatively new, thus, there are limited scientific existing studies. The literature review therefore does not include only academic publications, such as journal papers and books, but it incorporates also guidelines, specifications, protocols, standards and reports published by governments and other regulatory bodies, blogs and articles published in respected online newspapers. Different types of databases have been analysed: both scientific (e.g. *ScienceDirect*®) and non-scientific (e.g. *BuildingSMART*®) available online. The same keywords ('Building Information Modeling' and 'Building Information Model' associated to 'Level of Detail', Level of Development', 'LOD') have been used to find references. Sixty-two documents have been analysed, but only part of them were useful for the research work and are included in the reference list. Later, semi-structured interviews were carried out with five public agencies that delivered publish standards (in UK and US) as well as with their consultants. The interviewees were selected based on their role (e.g. BIM Managers) and experience in this topic to better understand how documents and tools, related the management of data within a BIM, are implemented as well as possible benefits and challenges. The interviews were conducted in person and they were recorded. Afterwards, in order to analyse data, responses were transcribed into statements where evidence was convergent.

3. An Overview on the Progression of Data-Driven Projects

This paragraph is based on literature review and it presents the principal initiatives to support information production and exchange within a BIM. At the end of the paragraph, Table 1 summarizes such initiatives and compares different definitions, acronyms and classifications.

3.1 The origin of 'LOD': from Information Levels to Level of Detail

Denmark has been one of the first Countries to define a classification for information within BIM (van Berlo et al., 2014). The *3D Working Method 2006* introduces seven (0-6) *Information Levels* to set the content of discipline models at a given time in the design process. The Information Level is a '*stage of information content and/or quantity*' and it is related to '*individual discipline models and building elements and/or geometrically limited building sections*' (BIPS, 2007). The seven levels describe a rising degree of detailing and correspond to the traditional construction phases, but they can be customized to allocate roles based on the nature of tasks (BIPS, 2007). The document suggests to use a table in order to clarify Information Levels for each phase and working practices (BIPS, 2007). Moreover, for each Information Level the document shows *Graphical representation*, *Alphanumeric representation*, *Objective*, *Parties/responsibilities*, *Content*, *Use*, *Degree of detailing* and *Classification* to be used (BIPS, 2007). It is possible to affirm that the Information Level is related to geometrical as well as non-geometrical data that different parties can rely on. This concept has been incorporated in the Australian CRC document in 2009, but Information Levels are associated with *Model Development phases* (0-6) and *Object data levels* linked to Level of Detail (A-E). The Level of Detail refers to '*detailed geometry and with additional or different information attached to the objects*' (CRC, 2009).

In 2004 the software company Vico Software started to work on a standard apt to facilitate the management of information within a BIM (Bedrick, 2008; Vico Software, 2015). Indeed, Vico developed the Model Progression Specification (MPS) defined as '*a language that owners, designers, and builders can use to define every element and task in the building construction process. It serves as a coordination point for information about the building, what is being modeled, and to what level of detail it is being modeled, estimated, and scheduled. It provides the efficient framework for the project stakeholders – a written checklist that matures from a very schematic level of detail to a high level of detail in terms of 3D geometry, cost, and time*' (Vico Software, 2015). Vico created a standard to manage BIM in an effective way, introducing the MPS concept as well as the 'Level of Detail'. The Level of Detail plays an important role within the MPS and is defined as '*the specificity required for a particular element at a particular stage of the project*' (Vico Software, 2015). Moreover, the '*level of detail for a BIM model must correspond to the needs of the modeler, the project engineer, and the estimators and schedulers. LOD identifies how much information is known about a model element at a given time. This "information richness" grows as the project comes closer to breaking ground*' (Vico Software, 2015). Thus, for Vico the 'Level of Detail' concept is associated to the reliability of information in a particular period of time and it also refers to a quantitative aspect that progressively increases. The acronym 'LOD' for the first time is used for 'Level of Detail'.

The company Webcor Builders teamed with Vico to further develop this concept, and later they brought it to the technology subcommittee of the American Institute of Architects (AIA) California Council's Integrated Project Delivery (IPD) Task Force (Bedrick, 2008; Vico Software, 2015). In 2008 Bedrick defined the Level of Detail as '*descriptions of the steps through which a BIM element can logically progress from the lowest level of conceptual approximation to the highest level of representational precision. It was determined that five levels, from* *conceptual through as-built, were sufficient to define the progression. However, to allow for future intermediate levels we named the levels 100 through 500. In essence, the levels are as follows: 100. Conceptual; 200. Approximate geometry; 300. Precise geometry; 400. Fabrication; 500. As-built*'. The definition is linked to a '*BIM element*' and not to the entire model. Bedrick (2008) also provided a definition of each level in a table and he reported some '*Authorized uses*' of the BIM. The Level of Detail can be used in two different ways: (1) to define phase outcomes and (2) to assign modeling tasks (Bedrick, 2008). In the first case, the Level of Detail of various elements must be defined because even if elements progress from one level to the next one, they can have different rates at the design develops (Bedrick, 2008). This concept is very important because it moves from the concept of scale in traditional design process where all elements are represented in a homogeneous way. Thus, it is clear that the requirement of a BIM at e.g. LOD 200 no longer makes sense. The second use, instead, deals with the ownership of the geometrical representation of elements (Bedrick, 2008). Indeed, the *Model Component Author (MCA)* is introduced as *'responsible for creating the 3-dimensional representation of the component, but not necessarily for other discipline-specific information linked to it'* (Bedrick, 2008). In this case, a separation between the geometrical representation of a component (3D geometry) and any data associated with it is clear. Thus, the MPS can track only who is in charge of the geometry creation and not who is responsible for the information, which usually is the most important part of a BIM.

3.2 The introduction of Level of Development

Later, the work performed by the AIA California Council's IPD Task Force was adopted by the AIA National Documents Committee to be developed (Bedrick, 2008). In 2008 the concept was incorporated in the *E202™–2008. Building Information Modeling Protocol Exhibit*[1] (AIA, 2008). The AIA evolved the notion into 'Level of Development' (Bedrick, 2013a). The AIA (2008) document does not contain any references to the Level of Detail and the acronym 'LOD' stands for Level of Development. The *E202™–2008* defines the protocols, expected LOD and Authorized Uses of the BIM for a specific project. Moreover, thanks to a Model Element Table, specific responsibility (Model Element Author/MEA) is assigned for the development of each Model Element to a defined LOD at each project phase (AIA, 2008). The Level of Development is defined as '*the level of completeness to which a Model Element is developed*' (AIA, 2008). The *E202™–2008* defines five progressively detailed levels (100, 200, 300, 400 and 500). Each subsequent LOD builds on the previous one and includes all previous characteristics (AIA, 2008). Moreover, for each level it gives a definition of the *Model Content Requirements* and it explains the *Authorized Uses* that can be customized (AIA, 2008). The LOD refers to the reliance on Model Elements; so, even if they could include more data than required, any user may rely only on the accuracy and completeness of the stated LOD (AIA, 2008). In the AIA (2008) document the MEA is responsible for both geometrical and non-graphical aspects of the Model Element and from LOD 200 to 500 also non-geometric data can be attached.

[1]Definitions from AIA Documents have been reproduced with permission of The American Institute of Architects, 1735 New York Avenue, NW Washington, DC 20006.

After the publication of *E202™–2008*, Vico continued to develop the MPS releasing version 2.0 in 2010 included 'Aspects' and 'Classes' concepts (Vico Software, 2015; Trimble Navigation, 2013). For each 'Classes' a *Target Level of Detail* can be defined (000, 050, 100, 200, 300, 400, 450, 500, 550, 600) (Vico Software, 2015). However, a clear definition of each Target Level of Detail is not available. In 2011 the latest version MPS 3.0 introduced different types of generic building elements called 'Primitives' (Vico Software, 2015; Trimble Navigation, 2013). Trimble Navigation (2013) developed a guide for each 'Primitives' showing Model 'Classes' with written requirements (mostly geometrical) and images. The guide (Trimble Navigation, 2013) does not provide any reference to suggested Level of Detail for each Model 'Classes'. The main focus of Vico is on 5D; for this reason the structure of MPS mainly supports effective cost and schedule evaluations rather than the overall process.

3.3 The use of LOD in several Guidelines and the introduction of 'Model Granularity' and 'Grade' definitions

In 2010, the Department of Veterans Affairs (2010) published 'The VA BIM Guide' that includes a spreadsheet, 'Object Element Matrix', to define BIM objects, properties, and attributes for each Level of Development (LoD). Both acronyms 'LoD' and 'LOD' are used and definitions of Level of Development are based on the *E202™–2008* (Department of VA, 2010). Later, the NATSPEC published the National BIM Guide (2011) including the *NATSPEC BIM Object/Element Matrix* based on the Department of Veterans Affairs matrix. In addition, the NYC DDC (2012) introduces the *Model Level of Development (LOD)* concept as '*level of detail to which a Model is developed and its minimum requirements. The Level of Development is accumulative and should progress from LOD 100 at Conceptual Design through LOD 400 at completion of Construction*'. However, it also '*describes through five categories, the completeness of elements in a Building Information Model. Completeness will range from geometric detail to element information*' (NYC DDC, 2012). There are some inconsistent aspects between the two definitions because the first refers to the '*Model*', while the second to '*elements*' of the BIM. In the appendix, there are Object requirements tables to set LOD from 100 to 400, however, the guideline presents also LOD 500; for this reason, Table 1 contains a (?). The DDC Level of Development has been developed in alignment with the *E202™–2008* and it introduces the *Model Granularity* concept as the '*representation of geometry needed to support specific BIM use*' (NYC DDC, 2012). It is associated to the '*level of detail needed*' that can '*vary by object and by model, and the BIM itself may not represent the exact design intent of real live elements*' (NYC DDC, 2012). Another US institution, the Pennsylvania State University (2012), has adopted the *E202™–2008* Level of Development standard for their projects, but it expanded the LOD 500 category (510, 520, 530, 540, 550) to more adequately meet their needs for operation and maintenance phases. Table 1 contains a start (*) under LOD 500 to remind that this level has been further developed.

In 2012, the US Army Corps of Engineers (USACE) released the BIM Minimum Modeling Matrix (M3), a spreadsheet for modeling requirements. It contains three levels of Development (LOD) from 100 to 300 (USACE, 2012) based on *E202™–2008*. Moreover, the *Element Grade (GRADE)* is added to the LOD concept because '*within each Level of Development, there is the potential to represent information in various formats. In practice, it has been proven that there* *are certain elements for which there is a greater benefit in providing 3-dimensional representation, while in others drafting or representation in the form of narratives is sufficient for a particular deliverable'* (USACE, 2012). The M3 contains two columns to specify the Grade (A, B, C, '+'); there is not a column for the MEA, but a *Primary Discipline* can be set.

In the UK, the AEC (UK) Initiative released for the first time a BIM Protocol in 2009 and in 2012, published version 2.1. It introduces the *Model Development Methodology* concept that is related to the Level of Detail, also called *Grade* (AEC (UK), 2012). Even if the protocol recognizes that the '*graphical appearance is completely independent to the metadata included in the object*', there is only a classification for geometrical aspects (*G0-G3*) (AEC (UK), 2012). This concept has been included in the first version of the AEC (CAN) BIM Protocol (2012) together with new acronyms ('LOD^{ev}' for Level of Development and 'LOD^{et}' for Level of Detail). However, the last version (2014) includes only the Level of Development (LOD) concept that is related to both Model Elements and Model.

In Netherland, even if the concept of Level of Development has been used, there has been a lot of confusion on the real meaning (van Berlo et al., 2014). Thus, seven *Information Levels* (0-6) have been created following the Danish standard (BIPS, 2007) together with a matrix, a practical guide and a project template (van Berlo et al., 2014). The practical guide contains the purposed use of *Information Levels* supported by pictures and use case examples (van Berlo et al., 2014). The project template is used as a spreadsheet that holds a demarcation of the project and for each section; responsibilities, status of that model, classification system and minimal Information Level can be defined (van Berlo et al., 2014). In this case, the Information Level could be assigned to the model or part of it, and not only to Model Elements.

3.4 The new version of AIA documents and the BIMForum LOD Specification

In 2013, the AIA published three new documents related to the management of a BIM that should be incorporated into an agreement between parties and used in conjunction: *E203™–2013*, *G201™–2013* and *G202™–2013*. In addition, the AIA published the *Guide, Instructions and Commentary to the 2013 AIA Digital Practice Documents*. According to the *E203™–2013*, the Level of Development (LOD) describes '*the minimum dimensional, spatial, quantitative, qualitative and, other data included in a Model Element to support Authorized Uses associated with such LOD*'. Indeed, the Level of Development of a given Model Element informs project participants about '*how developed the information is expected to be, and the extent to which that information can be relied upon, at a particular point in time in the development of the Model*' (AIA, 2013d). Thus, the main focus of the LOD concept is still related to the reliability of data within the BIM. The new document (AIA, 2013c) defines content of model elements as '*minimum*' and not '*specific*' requirements, as reported in the previous version (AIA, 2008). There are still five levels, however, instead of '*Model Content Requirements*' (AIA, 2008) the new version (AIA, 2013c) uses '*Model Element Content Requirements*'. Starting from LOD 200, each definition (AIA, 2013a) is divided in two parts: graphical and non-graphic representation. The definition is discussed for each LOD; instead, a general statement is used to define non-graphical information (AIA, 2013c). The structure of the Model Element Table (AIA, 2013c) is similar to the one already included in the previous document (AIA, 2008) with the exception of note sections that are added for each project milestone (AIA, 2013c). Moreover, the MEA is no longer seen as a modeler (AIA, 2008), but as a responsible party for the management and coordination of the development of elements (AIA, 2013a). For the first time, the *AIA Guide* (2013d) clearly explains the difference between Level of Detail and Level of Development making a comparison between the traditional approach and the BIM-based one, where there could be elements with high Level of Detail but very low Level of Development. The definitions of LOD in the AIA document (2013c) are a point of reference for other Countries such as France (Le Moniteur, 2014).

In 2011 a new group in the US, called BIMForum, started to work on a LOD Specification (BIMForum, 2013). In 2013, the *Level of Development Specification* was published including AIA's basic LOD definitions (2013c) for each building system and graphical examples of most of them (BIMForum, 2013). Definitions included in the *LOD Specification* (2013) were developed to address '*model element geometry*', taking into account three of the most common uses: quantity take-off, 3D coordination and 3D control and planning. The working group believed that by taking this approach, the interpretations would be complete enough to support other uses (BIMForum, 2013). Also in this case, the acronym LOD means Level of Development. The Specification should be used in conjunction with a project BIM Execution Plan, providing a '*means of defining models for specific information exchanges, milestones in a design work plan, and deliverables for specific functions*' (BIMForum, 2013). Also this document (BIMForum, 2013) provides a clear explanation on the difference between Level of Detail and Level of Development; the first can be considered as '*input to the element*', while the latter as '*reliable output*' (BIMForum, 2013). There are two main differences related to the LOD definitions between the Specification (BIMForum, 2013) and the *G202™–2013*. The first deals with the introduction of LOD 350 to enable coordination between disciplines (BIMForum, 2013). Only the *Guide* (AIA, 2013d) contains a reference to this new LOD (AIA, 20013, p. 60), even if it is not included in the *AIA Document G202™–2013*. The second difference is related to LOD 500 that has not been further defined and illustrated by the BIMForum working group (BIMForum, 2013). In 2014, a new version of the Specification was published adding new graphic illustrations in compliance with common building codes and at the end of October 2015 a new version was released with relevant updates (BIMForum, 2015). Indeed, for the first time non-graphical attributes were added and the Specification was divided in two parts: (1) Part A and (2) Part B (BIMForum, 2015). Part A, *Element Geometry*, basically defines required geometry and it is an extension of the previous version with a new appendix (BIMForum, 2015). Moreover, an interpretation of LOD definitions has been added for LOD 100, 200, 300, 350 and 400 (BIMForum, 2015). Part B, *Associated Attribute Information*, instead, is a Model Development Specification (MDS) spreadsheet that defines required attributes (numeric and/or textual) (BIMForum, 2015). Part B contains a Model Element Table where LOD, MEA and Notes can be defined for milestones (BIMForum, 2015). Moreover, there are Attributes Tables divided in three parts: attribute description, LOD profile and project-specific milestone (BIMForum, 2015). More attention should be paid while using this spreadsheet in order to create univocal information, because there is not an automatic correlation between the Model Element Table and Attributes Tables (e.g. to create consistent project-specific milestone). BIMForum Specifications have been a point of reference for contractual documents (e.g. ConsensusDocs©301 (2015)) as well as several guidelines and protocols (e.g. Massport (2015) and Canada (AEC (CAN), 2014)). The NATSPEC (2013) published a BIM Paper on the use of BIM and LOD to promote the adoption of the BIM Object Element Matrix for non-geometrical data and LOD Specification (BIMForum, 2013) for appropriated geometry. This document should be updated to include parametric requirements of the latest BIMForum Specification (2015). In addition, the document (NATSPEC, 2013) refers to the use of 'Grade' developed by USACE (2012).

3.5 The UK introduces new definitions and acronyms

In the UK new definitions and acronyms have been set. Indeed, the *PAS 1192-2:2013* does not include the Level of Development but it defines the Level of Definition as '*collective term used for and including "level of model detail" and the "level of information detail"*'. The Level of Model Detail (LOD) is '*the description of graphical content of models at each of the stages*' and the Level of Model Information (LOI) is '*the description of non-graphical content of models at each of the stages*' (BSI, 2013). *PAS 1192-2:2013* defines seven levels of model detail and information (1-7). Moreover, Figure 20 contains example pictures for each level and other information such as permitted uses, output and parametric information (BSI, 2013). The CIC BIM protocol (2013) introduces the Model Production and Delivery Table (MPDT), a key document that '*both allocates responsibility for preparation of the Models and identifies the Level of Detail ("LOD") that Models need to meet at the project stages or data drops stated in the table*'. However, there is no any reference to the LOI. In February 2014, the Technology Strategy Board decided to develop a free-to use digital BIM tool and since October 2015, the final version of the 'NBS BIM Toolkit' has been available. Its aim is to integrate the classification system with the Digital Plan of Work to control the presence of required data at each phase. Indeed, for each stage (0-7) of the RIBA Plan of Work, the Employer's Information Requirements (EIRs) can be defined including the Level of Definition of each element. Thanks to this tool, at each stage of each project, it is possible to define details, roles, tasks and deliverables. In addition, for each deliverable a LOD, a LOI and a responsible entity should be set. The tool changed the definitions from 'Level of Model Detail' to 'Level of Detail' and from 'Level of Model Information' to 'Level of Information' but the same acronyms are used. Finally, the tool can verify a BIM against defined requirements. This tool is the first example of a digital platform for the definition of data within a BIM, taking into account the entire life-cycle of built assets. Recently, the new version of the AEC (UK) was released (2015) including definitions from the *PAS 1192-2:2013*. The protocol contains a new classification of *Component Grade* to be conformed to the Level of Detail (1-6) (AEC (UK), 2015). The acronym LOD has been added and 'Grade' is used as synonym for Level of Detail. Finally, the CPIC (2013) document requires a *Responsibility matrix for information production* to define 'who models what (the BIM Author) and to what Level of Detail (LOD)' for specific *Model Authoring* and *Model Analysis*; together with a *Task Information Delivery Plan* (TIDP) and a *Master Information Delivery Plan* (MIDP).

Table 1: Comparison of different classifications related to the management of data in the BIM

Source	Name	Authorship	Definition	Level						
Denmark: BIPS	3D Working method	Parties/ Responsibility	Information Level	0	1	2	3	4	5	6
Australia: CRC	Object data levels	Responsibility	Level of Detail	-	*A*	*B*	*C*	-	*D*	*E*
Vico Software	Model Progression Specification	-	Target Level of Detail/ Level of Detail	-	*100*	*200*	*300*	-	*400*	*500*
US: Department of VA	BIM Object/Element Matrix	Model Element Author	Level of Development (LoD/LOD)	-	100	200	300	-	400	500
Australia: NATSPEC	NATSPEC BIM Object/Element Matrix (BOEM)	Model Element Author (MEA)	Level of Development (LOD)	-	100	200	300	-	400	500
US: NYC DDC	Object Requirements	-	-Model Level of Development/ Level of Development (LOD) -Model Granularity	-	100	200	300	-	400	500 (?)
US: Pennsylvania State University	BIM Information Exchange – Level of Detail Matrix	Model Element Author (MEA)	Level of Development (LOD)	-	100	200	300	-	400	*500* *
US: US Army Corps of Engineers	USACE BIM Minimum Modeling Matrix (M3)	-	-Level of Development (LOD) -(Element Grade/Grade (A, B, C, +))	-	100	200	300	-	-	-
Netherland	Matrix and Project Template	Aspect-model	Information Level	0	1	2	3	4	5	6
US: AIA *E203™–2013*	Model Element Table	Model Element Author (MEA)	Level of Development (LOD)	-	100	200	300	-	400	500
France: Le Monieur	-	-	Level of Development (LOD)	-	100	200	300	-	400	500
US: BIMForum 2015	LOD 2015 Element Attributes Tables	Model Element Author (MEA)	-Level of Development (LOD) -Level of Detail -Element Geometry -Associated Attribute Information	-	100	200	300	350	400	500
Canada: AEC (CAN) 2014	Information exchange worksheet or modelling matrix	Responsibility	Level of Development (LOD)	-	100	200	300	350	400	500
UK: PAS 1192-2:2013	-	-	-Level of model Definition -Level of model Detail (LOD) -Level of model Information (LOI)	1	2	3	4	5	6	7
UK: CIC	Model Production and Delivery Table (MPDT)	Model Originator	Level of Detail (LOD)	1	2	3	4	5	6	7
UK: NBS BIM Toolkit	NBS BIM Toolkit	Responsibility	-Level of Detail (LOD) -Level of Information (LOI)	1	2	3	4	5	6	7
UK: AEC (UK) 2015	-	-	-(Level of Definition) -(Level of Information (LOI)) -Grade/Level of Detail (LOD)	1	2	3	4	5	6	-

Finally, it is important to take into account that CityGML (2015) has developed five Levels of Detail (LOD 0-4) to define geometrical details and semantic precision (Tolmer et al., 2014) to link BIM with Geographic Information System (GIS) data (Kang and Hong, 2015).

4. Discussion and Future scenarios: from static assembly to dynamic entities

Nowadays, there is still confusion on how to manage the content of a BIM and definitions are differently interpreted. This lack of consistent understanding could be due to the presence of different definitions and acronyms in the industry that have changed during the years, vary from different Countries and, sometime, are inconsistent. For example, the 'Level of Detail' was originally associated to the reliability of both geometrical and non-geometrical data (BIPS, 2007), but recently it deals more with the level of geometrical attributes (e.g. BIM Forum, 2015; AIA, 2013c; BSI, 2013). The same acronym 'LOD' is used for both Level of Detail (e.g. BSI, 2013) and Level of Development (e.g. BIM Forum, 2015); similar concepts are differently called (such as 'Level of Information' (AEC (UK), 2015) and 'Associate Attribute Information' (BIM Forum, 2015)); and the Level of Development is associated both to elements (e.g. BIM Forum, 2015; AIA, 2013c) and the entire model (e.g. NYC DDC, 2012; Massport, 2015).

Usually, space programming and BIM authoring follow an elemental approach mirrored in the EIRs and BIM Execution Plans. However, thanks to the BIM Toolkit, the progressive maturity of the assemblies might be decoupled. The LOD Specification allows managing the different speed on the elemental basis, whilst the NBS BIM Toolkit makes it affordable on a sub-elemental degree, because LOD and LOI could be split and data might be misaligned. Such an assumption has to be felt as disruptive, because it implies that different players could concurrently manage shareable and accountable data upon the same element or assembly according to different progressions. Thus, in spite of pursuing the traditional BIM uses, the linear progression of the design stages is clearly hampered, because the original space programs could be troubled by the architectural digital sketches as far as general construction is concerned. For this reason, Drobnik and Riegas (2015) suggest to introduce a Level of Development (LOD) 0 as well as a negative one (e.g. LOD -100) due to the complexity of the iterative design process. Meanwhile, heterogeneous elements have to be handled within a Common Data Environment (BSI, 2013) or rather, within a digital eco-system merging hardware and software on the internet of buildings, infrastructures, grids and things. Unfortunately, such a stressing elemental perspective, where the design teams are asked for anticipating the progressions and are stimulated for optioneering the solutions, is additionally burdened by the behavioral and interactive design. The simulated users' and passengers' behaviors, as well as the simulated flows and motions, engender some spatial syntaxes and options which could be, on a real time basis, interactively checked and validated by means of immersive environments (CAVEs or portable devices). Indeed, dealing with game engines, more and more, the BIM will have to take into account not only *discrete* Level of Detail, but also *continuous* LOD (CLOD) (DigitalRune, 2013). Moreover, the validation plays a key rule for the success of Data-Driven Projects and Model Checking should be used to control the content of the BIM as discussed also by Hopper (2015). Today, the control of different Levels (e.g. of Detail, Information and Development) is still difficult and the NBS BIM Toolkit tries to fill this gap. However, more effort is needed to validate the information flow related not only to EIRs, but also to the Facility Management data. In addition, the pre-occupancy management requires the involvement of potential users within the early design stages, because more and more an intelligent clientship deals with a ‘to be’ servitized and sensored built asset. Therefore, a question is arising, stemming from the aforementioned remarks: could such a design process be consistent with the traditional elemental approach centered more on static (objectual) assembly rather than on dynamic (motional) entities?

5. Conclusions

This study indicates that there is not a univocal approach to define and manage the content of a BIM and several definitions and acronyms have been defined in different Countries, especially in US and UK. However, it is possible to compare them and find similarities. Results can be used to get an in-depth understanding on this topic, especially for experts who work with BIM in several Countries. Finally, the authors believe that in the future Model Checking should be included in the process and more flexibility is needed moving from static assembly to dynamic entities.

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The Perceived Business Value of BIM: Results from an International Survey

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Abstract

Building Information Modelling (BIM) has emerged as an IT-based solution towards the construction industry's challenges. The expectations on BIM are high in both research and industry and there has been an increasing interest in evaluating the benefits and business values of BIM. Many of the reported benefits and business values in research have been the same or very similar. This suggests that there might exist certain categories of benefits of BIM and that the benefits also might interrelate with each other. However, weather this is the case has not been explored in previous research. The purpose of this study is to explore how the business value of BIM is perceived by exploring what categories of benefits of BIM there are and how these benefits interrelate with each other. Results from a large international survey on the perceived business value of BIM are analyzed. The findings show that there are two categories of benefits of BIM. The first is project progress related and relates to managing and minimizing project managerial issues. The second is project outcome related and relates to increasing efficiency and optimization. The interrelation of the benefits is also shown by which category of benefits they contribute to and by their relative importance in these categories. The findings have both theoretical and practical implications.

Keywords: Business value, BIM, project management, survey, factor analysis

1. Introduction

The construction industry is an important player in economies and societies throughout the world and significantly contributes to GDP and employment (e.g. Ortiz et al 2009). Is also an industry characterized by challenges in terms of low productivity (e.g. Teicholz et al 2001), slow adoption of new information technologies (e.g. Brandon et al 2005), low innovation (e.g. Styhre 2011) and negative impact on the environment (e.g. Ortiz et al 2009). Building Information Modelling (BIM) has by many proponents been suggested as an IT-based solution towards the industry's challenges (e.g. Succar 2009, Rezgui et al 2009, Crotty 2013). BIM has been described as "a set of interacting policies, processes and technologies generating a methodology to manage the essential building design and project data in digital format throughout the buildings life cycle" (Succar 2009). The high expectations on BIM can also be reflected in that there are currently many governmental BIM initiatives promoting the use and implementation of BIM (e.g. UK Cabinet Office 2011, Trafikanalys 2015).

In order to understand if the implementation of BIM meets the high expectations, the effects of the BIM implementation must be evaluated. Firms implementing BIM have also stated that a major challenge towards their adoption of BIM has been that that they themselves have not had sufficient time to evaluate the business value of BIM and experience a lack knowledge about the business value of BIM ((McGraw-Hill 2009, 2010) FMI and CMAA 2007). There has been much research aimed at evaluating and measuring the benefits and business values of BIM (Table 1). Many of the studies have come to similar conclusions about the effects of BIM and have tended to repeat the same benefits and business values of BIM (Table 1). Many of the benefits and business values are also similar to each other (Table 1) and are likely to interrelate in ways that previous research have not yet investigated. For example, a commonly reported benefit of BIM is cost reductions, which is likely to be impacted by and interrelate with other commonly reported benefits of BIM, such as earlier completion times or fewer errors. The similarity and repetitiveness of the many benefits and business values of BIM reported in previous research suggest that there might be certain categories of benefits of BIM and certain interrelations between the benefits. This issue that has however not been investigated in previous research. The purpose of this study is to explore how the business value of BIM is perceived by exploring what categories of benefits of BIM there are and how these benefits interrelate with each other. This is accomplished by analysing the results from a large international survey on the perceived business value of BIM through factor analysis.

2. Rationale for investing in BIM

An underlying assumption behind a firm's choice to make an investment, such as investing in new IT, can be described by the theory of the firm and transaction cost theory (Coase 1937). Firms decide to make an investment when the investment provides a return that that is greater than its initial investment costs (Coase 1937). The theory of the firm and transaction cost theory are based on the assumption of rationality in organizational decision making. Firms are assumed to make rational choices based on complete and perfect information and to make investments that maximize the profit of the investment. However, firms actually make decisions in uncertain and changing environments where the firms are left with an uncertainty and unpredictability about the future, where they do not have complete access to all the available information and where the information is often incomplete and imperfect (Coase 1937, Simon 1959, Simon 1991). These conditions limit the extent to which firms can make rational decisions and inhibit the seeking of maximization (Simon 1959, Simon 1991). The individuals of the firm also suffer from bounded rationality meaning that they are bounded and limited in their cognitive ability to analyse and process all the available information, to discern which of the incomplete and imperfect information that is of relevance for the decision making process and to make rational decision in complex and uncertain situations. These conditions results in that firms often decide to make an investment given that the investment yields a satisfying return rather than a maximizing one (Simon 1959, Simon 1991). Firms are described as being content with making decision that satisfy rather than maximize a target return. Thus, the decision-maker is a satisfier and one seeking a satisfactory solution rather than the optimal one (Simon 1959, Simon 1991).

The argument and rationale for making decisions to invest can be applied to construction firm's decisions to invest in BIM. Drawing on the theories in Coase (1937) and Simon (1959, 1991), firms make decisions to invest in BIM given that the investment in BIM yields a return that is satisfying enough. In order to evaluate weather the investment in BIM yields a satisfying return, the investment in BIM has to be evaluated and measured and the benefits and business values of BIM assessed. Research also shows that particularly in the constriction industry, managers often need to prove that the investment in new IT, and in particular BIM, will yield a certain return or satisfy a certain target before they receive the funds to invest in new systems and processes (e.g. Becerik-Gerber and Rice 2010, Marsh and Flanagan 2000). Therefore, the benefits and business values of BIM need to be evaluated.

3. Benefits and business values of BIM

There have been numerous studies that have attempted to evaluate and measure the benefits and business values of BIM (Table 1). The benefits of BIM have been studied from both qualitative and quantitative research approaches and by both researchers and industry actors (Table 2). A total of 23 peer-reviewed journal papers and 9 industry reports were analyzed in order to map the benefits and business values of BIM.

There were a total of 38 different benefits and business values of BIM identified in the literature review. The most common benefits of BIM in research include reduced errors, rework and changes (e.g. Becerik-Gerber and Rice 2010, Barlish and Sullivan 2012), faster completion times (e.g. Dawood and Sickka 2008, Hartmann and Fischer 2008), cost savings (e.g. Kam et al 2013, Suermann and Issa 2009, Haymaker and Fischer 2001), improved information management (e.g. Grilo and Jardim-Gonclaves 2010, Mäki and Kerosuo 2015), more accurate design (e.g. Demian and Walters 2014, Gilligan and Kunz 2007) and improved collaboration and collaboration among different disciplines and actors (e.g. Demain and Walters 2014, Zuppa et al 2009).

Table 1: Benefits and business values of BIM in research and industry reports

Benefits of BIM	*Frequency*	*Benefits of BIM*	*Frequency*
Less errors, rework & changes	*21*	*Fewer RFI*	*8*
More accurate design	*20*	*Less conflicts and disputes*	*8*
Improved information management	*18*	*Risk management*	*7*
Faster completion times	*17*	*Marketing new clients*	*6*
Reduced costs	*17*	*Improved simulations*	*6*
Higher quality	*16*	*Better decision*	*5*
Improved collaboration	*15*	*Client satisfaction*	*5*
Improved coordination	*13*	*Stakeholder engagement*	*5*
Improved communication	*13*	*Increased ROI*	*4*
More design alternatives	*11*	*More engaged staff*	*4*
Better estimations	*11*	*Improved team work*	*3*
Clash detections	*11*	*Reduces waste*	*3*
Improved life cycle management	*10*	*Code compliance*	*3*
Increased productivity	*10*	*Increased profitability*	*2*
Improved scheduling	*10*	*Creativity*	*2*
Increased safety	*9*	*Employment satisfaction*	*2*
On-site efficiencies	*9*	*Less administration costs*	*1*
Competitive advantage	*9*	*Faster bid preparation*	*1*
Higher efficiency	*8*	*Innovation*	*1*

Table 2: Sources in literature review on the benefits and business values of BIM

Authors in peer-reviewed journals		*Industry reports*
Aranda-Mena et al 2009	*Hartmann et al 2012*	*Autodesk 2007*
Azhar 2011	*Hartmann & Fischer 2008*	*BSI 2010*
Barlish & Sullivan 2012	*Kam et al 2003*	*FMI and CMAA 2007*
Becerik-Gerber & Rice 2010	*Kaner et al 2008*	*Gilligan & Kunz 2007*
Bryde et al 2013	*Khanzode et al 2008*	*Haymaker & Fischer 2001*
Chien et al 2014	*Manning & Messner 2008*	*McGraw-Hill 2009*
Davies & Harty 2013	*Mäki & Kerosuo 2015*	*McGraw-Hill 2010*
Dawood & Sikka 2008	*Suermann & Issa 2009*	*Open BIM network 2012*
Demian & Walters 2014	*Zuppa et al 2009*	*buildingSMART UK 2010*
Dossick & Neff 2010	*Coates et al 2010*[1]	
Eadie et al 2013	*Yan & Damian 2008*[1)]	
Grilo & Jardim-Gonclaves 2010		

4. Method

In order to explore what different categories of benefits of BIM there are and how these benefits interrelate with each other, the results from a large international web-based survey on the perceived benefits of BIM is analyzed through factor analysis. The survey was created based on a literature

[1] In Conference Proceedings

review of the benefits and business values of BIM in previous research (Table 1) and on in-depth semi structured interviews with nine experienced BIM representatives in the Swedish AEC industry from clients/owners, contractors and consultants about the perceived business values of BIM. The BIM representatives were selected by purposive sampling based on their experience of BIM, their current position, and their engagement in BIM communities.

The survey consisted of three parts. This paper addresses the second part of the survey where the respondents were asked questions about what benefits they had perceived from implementing BIM in a specific ongoing BIM project of their choice. Based on the literature review and interview study, 15 benefits of BIM were included in the survey (Table 3). The respondents were to assess to what extent they had perceived each of these 15 benefits of BIM as beneficial to their specific BIM project on a seven point Likert scale, where 1 equaled no perceived benefit and where 7 equaled a large perceievd benefit (see Table 3). The survey was addressed to and administrated to a group of BIM users in the AEC industry that were perceived to be knowledgeable and experienced in working with BIM - the members of the worldwide buildingSMART network (http://www.buildingsmart.org). The survey was administrated to the target respondents in three steps. In a first step, the target respondents were contacted via each buildingSMART regions contact person listed on the buildingSMART website. The contact person was asked to distribute the link to the web-based survey to their members in their respective chapters. One potential bias of contacting representatives of an organization to distribute the survey to their members is that the response rates are typically lower of this procedure when compared to distributing the survey directly the population of individuals of that organization (Baruch 1999). Therefore, in a second step, the individual members of the selected 12 buildingSMART chapters were contacted directly via email. In a third step, the members of the selected 12 chapters were also contacted via groups on LinkedIn.

The purpose of factor analysis is to reduce larger sets of data and variables into a smaller set of variables in order to identify if there are certain types or categories in which thee variables tend to group in (Kim and Mueller 1978, Stevens 2012, Thompson 2004). Factor analysis is suitable when there are many variables in a dataset and when these variables are suspected to group in certain types or categories (Kim and Mueller, 1978) (such as there are in the respondent's answers to the 15 benefits showed in Table 3). In factor analysis, the aim is to find the linear combination of the variables that achieves the maximum amount of variance. A first factor (category) is given by the linear combination of the original variables that accounts for the maximum possible variance. A second factor (category) then captures the information that was not captured by the first factor and is also uncorrelated with the first factor (Kim and Mueller 1978, Stevens 2012, Thompson 2004). Only those factors (categories) are retained that fulfill the Kaiser criterion. The Kaiser criterion stipulates that only those factors (categories) that have an eigenvalue > 1 can explain the variance and are thus retained as factors (Stevens 2012). Those components with eigenvalue less than 1 contribute little to explaining the variance and are thus not retained. The factors retained then represent different types or categories of the variables analyzed. The factor loading of each variable indicates which variables that belong to which factor (category). The variables that are retained in one factor are uncorrelated with the variables retained in another factor (Stevens 2012). In the next section, the results of the factor analysis and the interpretation of the results are presented.

5. Results

Of a total of 988 respondents contacted to answer the survey 234 responded, corresponding to a response rate of 23,7%. For web and email based surveys, response rates usually range around 20%-30% (Kaplowitz et al 2004, Baruch and Holtom 2008). In Table 3, the respondent's answers to the question about what benefits they had perceived from working with BIM on a seven point Likert scale are presented.

Table 3: The responses in the survey regarding the perceived benefits BIM

The perceived business value of BIM							
What benefits do you/did you expect from using BIM in the specific project?	*(1= no benefit, 7= very large benefit)*						
	1	*2*	*3*	*4*	*5*	*6*	*7*
Increased worksite safety	*22*	*21*	*23*	*37*	*41*	*22*	*20*
Improved coordination	*1*	*0*	*2*	*7*	*29*	*45*	*102*
Increased client satisfaction	*2*	*2*	*10*	*24*	*38*	*56*	*54*
Higher profits	*9*	*11*	*16*	*42*	*47*	*33*	*28*
Lower overall costs	*6*	*7*	*15*	*37*	*42*	*42*	*37*
Earlier completion times	*2*	*10*	*15*	*32*	*55*	*43*	*29*
Improved energy performance	*15*	*14*	*21*	*42*	*35*	*31*	*28*
Less modifications (e,g, errors, rework, changes)	*1*	*4*	*5*	*11*	*36*	*54*	*75*
Improved communication (e,g, fewer RFI)	*2*	*1*	*8*	*17*	*33*	*51*	*74*
Improved understanding of project purpose	*7*	*2*	*9*	*12*	*37*	*54*	*65*
Increased productivity	*2*	*2*	*10*	*25*	*51*	*47*	*49*
Higher quality of final product/service	*3*	*3*	*2*	*12*	*45*	*55*	*66*
New business (e,g, new clients/services)	*14*	*13*	*19*	*31*	*41*	*33*	*35*
Reduced conflicts	*2*	*4*	*3*	*18*	*44*	*55*	*60*
More accurate estimations (e,g, quantity take-offs)	*3*	*6*	*4*	*27*	*38*	*52*	*56*
Total number of responses	*92*	*102*	*165*	*378*	*617*	*679*	*785*

Factor analysis was performed on the 15 benefits in order to examine whether there were existed certain types or categories of benefits of BIM and to examine how the benefits interrelate with each other. The results from the factor analysis are shown in Table 4. Two factors, i.e. two categories of benefits of BIM, emerged (with eigenvalues >1). The first factor (first category of benefit of BIM) seemed to be more significant as it had an eigenvalue of 6.86 (compared to the eigenvalue of 1.14 of the second factor). The factor loadings in Table 4 show which variables (which of the 15 perceived benefits of BIM) that belong to each of the two factors (two categories). The larger the factor loading, the more relevant the variable is in explaining the factor (category). The benefits of the first category are uncorrelated with the benefits of the second category, and vice versa.

Table 4: Results from the factor analysis on the 15 perceived benefits of BIM

Factor analysis on the perceived benefits of working with BIM	*Eigenvalue Factor 1 6.86*	*Eigenvalue Factor 2 1.14*
	Factor loadings for Factor 1	*Factor loadings for Factor2*
Increased worksite safety	*0.31*	*0.49*
Improved coordination	*0.74*	*0.17*
Increased client satisfaction	*0.55*	*0.43*
Higher profits	*0.20*	*0.83*
Lower overall costs	*0.19*	*0.78*
Earlier completion times	*0.36*	*0.69*
Improved energy performance	*0.31*	*0.58*
Less modifications (e.g. errors, rework, changes)	*0.77*	*0.21*
Improved communication (e.g. fewer RFI)	*0.73*	*0.31*
Improved understanding of project purpose	*0.53*	*0.33*
Increased productivity	*0.50*	*0.62*
Higher quality of final product/service	*0.67*	*0.33*
New business (e.g. new clients/services)	*0.28*	*0.52*
Reduced conflicts	*0.73*	*0.25*
More accurate estimations (e.g. quantity take-offs)	*0.54*	*0.34*

From Table 4, the first factor (the first category of benefits of BIM) consists of the following benefits of BIM (in relative order):

1. Less modifications - fewer errors, rework, changes (largest factor loading 0.77)

2. Improved coordination (largest factor loading: 0.74)

3. Reduced conflicts (largest factor loading: 0.73)

4. Improved communication (largest factor loading: 0.73)

5. Higher quality of final product (largest factor loading: 0.67)

6. Increased client satisfaction (largest factor loading: 0.55)

7. More accurate estimations (largest factor loading: 0.54)

8. Improved understanding of project purpose (largest factor loading: 0.53)

From Table 4, the second factor (the second category of benefits of BIM) consists of the following benefits of BIM (in relative order):

1. Higher profits (largest factor loading: 0.83)

2. Lower overall costs (largest factor loading: 0.78)

3. Earlier completion times (largest factor loading: 0.69)

4. Increased productivity (largest factor loading: 0.62)

5. Improved energy performance (largest factor loading: 0.58)

6. New business - eg new clients (largest factor loading: 0.52)

7. Increased worksite safety (largest factor loading: 0.49)

The benefits in the first category of benefits of BIM seem to be related to managing and minimizing project managerial issues (i.e. project progress related). The benefits in the second category of benefits of BIM seem to be related to efficiency and optimization (i.e. project outcome related).

The factor analysis shows the relative importance of the benefits. In the first category of benefits of BIM that were project progress related (i.e. related to managing and minimizing project managerial issues), the benefit of less modifications (such as fewer errors, rework and changes) had the highest factor loading and was the most significant benefit in explaining the category. Then followed, in relative order, improved coordination, reduced conflicts, improve communication, higher quality of final product, increased client satisfaction, improved understanding of project purpose and more accurate estimations. In the second category of benefits of BIM that were project outcome related (i.e. related to efficiency and optimization), the benefit of higher profits had the highest factor loading and was the most significant benefit in explaining the category. Then followed, in relative order, lower overall costs, earlier completion times, increased productivity, improve energy performance, new business, and increased worksite safety.

6. Discussion

In the outset of this paper, it was argued that previous research has come to repeat the same benefits of BIM and/or very similar benefits of BIM. Many of these benefits were also claimed to likely interrelate with each other in ways that the previous have not explained. This study aimed to contribute to this gap. The theoretical contribution of the findings is an increased understanding of the different categories and types of benefits BIM and increased knowledge about the dimensions, variations and nuances of these benefits. Although the 15 benefits of BIM examined in this paper are not entirely new by themselves (se literature review of the benefits of BIM), the novelty of the findings lie in showing the perceptions among BIM users worldwide of the different types of benefits of BIM and the relative importance of these benefits. The novelty also lies in showing to what type of project management activities that these benefits contribute to. For example, BIM was found to contribute to both project progress related activities and project outcome related activities. The findings also contribute with increased understanding about where the impact of BIM seems to be largest. The impact of BIM was larger on the project progress related benefits (related to managing and minimizing project managerial issues), such as improved coordination and fewer conflicts, as indicated by the larger factor loading of 6.86. The findings thus have practical implications as well and contribute with increased knowledge about how BIM can be applied in the daily management of projects in order to create business value.

The main impact of BIM on project progress related activities (and not on project outcome related activities) contribute with a contrast to previous research on the benefits and business value of BIM. In reports, project outcome related effects, such as increased return on investment and other economic effects, were identified as the main contributors to the business value of BIM (e.g. McGraw-Hill 2009, 2010 and FMI and CMAA 2007). In research, the efficiency and optimization related benefits of BIM are often promoted (e.g Kam et al 2013, Barlish and Sullivan 2012, Suermann and Issa 2009, Manning and Messner 2008). However, the findings in this study showed that the project outcome related effects of BIM (e.g. higher profits, lower costs, earlier completion times and other economic effects), almost did not qualify as a category of benefits of BIM in the factor analysis. With an eigenvalue of only 1.14, it almost did not qualify according to the Kaiser criterion that implied an eigenvalue>1. Thus, for practitioners and policy makers investing or planning to invest in BIM, this study suggest that the major business value of BIM lies in the daily project managerial activities in improving project management such as improving coordination and communication among all project actors, reducing conflicts and disputes and minimizing the errors make by the partied involved in projects.

There are also limitations to this study. For example, targeting the members of the buildingSMART network in the survey implies that their responses are more likely to be biased and reflect a more optimistic view of BIM as opposed to a more neutral view of BIM. In analyzing the results, the author was aware of this sampling bias, yet there is a need for future studies that explore how the business value of BIM is perceived among different kinds of users of BIM who have both positive and neutral views of BIM and who are both experienced and less experienced in BIM. Suggestions for future research also include examining how to implement BIM in order to achieve the two categories of benefits of BIM. Future research could also examine how various project and profession specific factors positively or negatively contribute to how the benefits of BIM are perceived.

7. Conclusions

The expectations on BIM are high. There has been many studies examining the benefits and business values of BIM and many of the benefits and business values found have been the same or very similar. From a large international survey on the perceived business value of BIM, two types of categories of benefits of BIM were discovered. The most important category of benefits of BIM was project progress related and evolved around managing and minimizing project managerial issues. The findings had both theoretical and practical implications. They made a contrast to previous studies on the benefits and business values of BIM and showed where the impact of BIM on the day to day management of project was largest.

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Clients' and Users' Perceptions of BIM: A Study in Phenomenology

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Abstract

Although Building Information Models (BIM) are declared as singular and correct expressions of buildings, these still are merely representations of designs and complete buildings. The digital model is not the building and is not the design. The digital model does allow visualisations of the buildings allowing stakeholders a new perception of the building through its 3D representation with the ability to choose viewpoints and to travel dynamically, but virtually, through the represented building. This paper explores what is perceived by clients and users in building information models using phenomenology. It emphasises the differences in perception and explores the meaning of this for design and construction. The work has involved interviews and experimental studies with users using models in different forms including static 3D, walk-throughs, 2D and room data sheets. The results show that different people view models with a difference in focus, intent and expectation. This makes models not have a singular and correct expression which means that the engagement with stakeholders still needs to be worked on and actively managed during design and construction. Digital tools then are not finished expressions but examples to be worked with dynamically and used to demonstrate differences proactively to help work on these different perceptions so that a higher performing building can be produced. The future of BIM to deliver value for both the client and users then lies in its ability to provide soft informated representations.

Keywords: Building-use, users, performance, perceptions, representations

1. Introduction

The application of digital technologies is developing rapidly and is now being adopted by the Architecture, Engineering and Construction (AEC) industry. In AEC, Building Information Modelling (BIM) is considered to be the new improvement solution for the construction industry as it allows the transition to better communication of information so that it can be shared and exchanged between different stakeholders (Drettakis *et al*., 2007). Bullinger *et al*., (2010) have pointed out that although the existence of such technology has supported the integration of multi-stakeholders, the involvement of the end-user has so far been limited; this is considered to be a major issue in current approaches. This is due to the promotion of BIM, more as a vehicle to drive productivity and efficiency for the construction industry, rather than to increase value in its outputs (Miettinen and Paavola, 2014). This is hiding the client and user perspectives on BIM and not utilising its potential for radical improvement.

The paper is part of a larger research study on enhancing building performance in buildings during design using BIM. The focus of this paper is on the way clients and users perceive their buildings in design and how BIM might be used to allow user input. The key point is the way that BIM represents the building to help this process. The issue of representations in building design is not new but the development of digital representations is explored. This presents theory of how BIM is perceived in a more phenomenological manner where it is the subjective experience that is crucial. This paper uses data from interviews with client teams and interviews and experimental studies with users. The latter, used BIM models in different forms including static 3D, walk-throughs, 2D plans and room data sheets. The results are explored both comparing the positions of client team and users and emphasising the user perceptions of BIM and their particular needs. The conclusion identifies how BIM needs to be modified to handle soft information to enable a more user involved design as well as greater understanding of user needs by the client team.

2. Literature Review

2.1 Design and Users

There has been a growing movement to make design more performance orientated (Kolarevic and Malkawi, 2005). This concept is embedded in Vitruvius's 1st century BC requirements for buildings of commodity, firmness and delight as well as the more detailed and quantitative design quality indicator (CIC 2003). The ratio 1:5:200 (1 = construction cost; 5 = maintenance and building operating costs; 200 = business operating costs) (Evans *et al*., 1998) focuses attention on the fact that the business operation of a building, costs several orders of magnitude more than its design and construction costs. Even though this ratio is challenged (Hughes *et al*., 2004), the idea that buildings should be designed to assist the work of the business is crucial. However, there is a gap between the expectations of design and how a building actually performs (Bordass et al., 2001). Jensen *et al*. (2011) and Sanoff, (2000), argue that involving users in the design and operation of the built environment taps into their knowledge and preferences and so creates spaces that work more effectively. Vischer's (2008) built environment theory identifies building use and user as critical design determinants of buildings. Sanoff (2000) has pointed out the difficulty of delivering this experience, due to, for example, the gap between the demands from the users and the design provided by the architects. Forty (2000) claims that building space appears to be a homogeneous concept, partly because architects consider space via representations (abstract space) rather than experiencing space by living it (lived space). However, Hensel et al. (2009) argue that bridging the gap between lived and abstract space requires another level of complexity, which is stopping any change from current practice. The solution to greater building performance requires user involvement and the handling of the complexity of technically undertaking this and including it in the process (Barratt and Stanley 1999). The sophistication and integration provided by BIM offers the opportunity to address this problem explicitly but this has only currently been researched in a limited manner.

2.2 BIM, Design and Users

Building Information Modelling provides a repository in a centralised data location for a full design model integrating structural, architectural, mechanical, electrical and plumbing (Kensek 2014). Its use in design has developed rapidly as a tool for composition, testing and construction delivery with full national government support. There is a complexity associated with the technical side of BIM within its software and hardware that limits the size of the model and their ability to represent all the information explicitly, and this remains a problem within the AEC industry (Johansson *et al*., 2015). This creates a challenge for the development of BIM for it to be useful for design rather than just as a repository for the end design (Whyte 2013). There has been little consideration of challenges associated with user involvement during the design stage (Kunz and Fischer, 2009). Kim *et al*. (2015) have reviewed user involvement during both pre and post construction showing how simulation tools can be employed by architects to understand the relationships between users and spaces. They concluded, however, that one of the current challenges is 'formalising' this involvement process, and there was a need for further inquiry into virtual design and construction tools. Khemlani (2008) reported that 3D and 4D simulation (e.g. Navisworks) have enhanced users' understanding of the design allowing a third person view to support users' in obtaining a sense of scale, but this navigation is relatively simplistic. There are some recent attempts to involve end-users and facility management; e.g, Lee and Ha (2013) have proposed a BIM-based tool for residential buildings to meet different customer needs which would allow them to be involved in decision-making. It was found that collaboration using the tool helped to meet customer needs for the optimum use of space. Shen et al. (2012) proposed a user activity simulation and evaluation method (UASEM) that aimed to enhance the user's visual experience of the built environment, but did not explore whether such simulations have an impact on improving design solutions. Oerter *et al*. (2014) pointed out that the use of avatars within the BIM environment can support by providing feedback to the users' and clients. None of these studies acknowledged the problems of perception of BIM environments.

2.3 Digital Representations and Users

The shift to a digital world in construction involves the creation and use of digital representations. According to Allen (2009), 'representations' are an entire intellectual and social construct that allows the imagination to construct new fragments of reality. Representations are the interface between the data and individuals as the representation conveys meaningfulness in a form to enable the data to become information. Thus, the design process requires a study of representations suitable for users to be integrated into the design process. Many theories of knowledge-use see mental activity working on representations thus it is possible to see representations as reality (Zhang and Norman, 1994) and for computing to work as this representation as reality. This has been opposed most vociferously by philosophers such as Dreyfus and Dreyfus (1986) who argue that thinking can occur without mental representations and Lorino *et al*., (2011) suggest that external representations have a communicative role in the activity itself. According to Hatfield (2003), the visual experience aims to represent a visual space in relation to the physical space. In the study of visual space, it is often assumed that the observer has an internal representation of surrounding physical space where he/she attempts to measure properties of the visual space to establish how well various properties of physical space are preserved in the mapping to visual space (Loomis *et al*., 1992). Ishii (2006) argues that people have an active interface with digital information with two components: control and representation. These can also be described as input and output where controls refer to what input users provide to manipulate information, while representations refer to what is perceived with the human senses.

There is a growing body of work on the phenomenology of digital environments. Turk (2001) explored how the product models in BIM are not as conceptually robust and material as they are presented and discussed. Meaningful work requires engagement with people with virtual worlds which has been reviewed by Farr et al (2012) who call for the greater use of the concept of embodiment to support user interaction.

3. Research Methodology

This research reported here sought to gain a richer understanding of users' and client's perceptions of BIM with a view to using it to improve user involvement in design. Given this problem of alternative perspectives, the research question was set to determine how BIM might help this situation during the design phase. This study adopted a critical realist position (Mingers 2000) and used qualitative methods. The study investigated three case study building projects at different times of their design, construction and operation phases all of which had used digital design. Two of the buildings were university teaching blocks and the third was a local authority office. Data were collected using semi-structured interviews with the client design teams and users and an experiment where 2D and 3D representations of the buildings were shown to users who at the same time answered questions in a questionnaire. Overall, the study involved four participants representing the client side, and nine participants representing the building users side.

It was recognised that the building users' perspective is best conceived phenomenologically. A phenomenological position focuses on the subjective experience of individuals thus is concerned with being, consciousness, and awareness (Seamon 2007). As such individuals experience a context, i.e. the building or work on a building, modified by their own beliefs about themselves and their well-being. Users' perceptions are created from the interaction of this 'being' with the physical and social environment provided by the building. In Christopher Alexander's terms this requires a wholeness of conception of a building (Seamon 2007). The study was phenomenological in that it asked questions into the thinking and feelings of the respondents. In particular, it asked questions about their lived experience which composed their perceptions. The phenomena in this research where firstly the way the design team and users saw buildings and secondly the way they interacted with the representations of the buildings as generated by BIM models. In the first phase, the study asked open ended questions about the nature of building performance in the buildings they engaged with for their work. It did this without defining performance in order to stimulate a subjective response. These responses were analysed in a form of discourse analysis to draw out the phenomenological perceptions. In the second phase, the study aimed to gain insights into the respondent's engagement with BIM. The case study was delivered using BIM, and thus the client was already familiar with the outputs of BIM whereas the users had to be briefed on what BIM was in order to gather meaningful data. A questionnaire was used to collect data from a group of users as they were shown 2D representations and 3D walkthroughs. However, the questions were again open-ended to allow the subjective impression to be captured. Different types of spaces within the building where shown and the participants had to write down what their perceptions were of the represented spaces. The data were analysed to explore how users could assist client teams during design.

4. Results and Findings

<u>Different Perspectives of Performance</u>

The first set of data was gathered during interviews with both the client team members and users about the buildings they were engaged with for their work. The data showed a number of characteristics that separated the building client team and the building users. Firstly the users' requirement for performance is concerned with how they could act in a space.

'I want an environment that allows me to perform a certain task or daily job comfortably' (PS u1, 2013)

"Building performance is gauged by how comfortable an environment is, so it provides the right temperature, access to fresh air and the right level of lighting" (WS u1, 2014)

"In terms of community space, it is any space that can take you completely out of work, so you can sit, relax, allow to do work, but most important that it makes you feel like offline" (WS u2, 2014)

The users' expressions do contain functional aspects like temperature, fresh air and lighting but these are actually subjective characteristics. However, they do refer to a way of being in the building environment that involves performance supported by an environment that is beyond their aware attention. The notion of 'right' is here self-defining giving it a very subjective character. This is emphasised more when users express problems of the space.

"Some problems we have now, some facilities don't fit within their spaces, and we don't necessarily have the right furniture" (PS u3, 2013)

"the furniture within the open spaces is too big, and some of the sockets do not sit down properly" (PS u3, 2013)

"It is important to consider the positioning of some facilities such as projectors, one of the major concerns I have now, is whether our current spaces provide the right environment to work or lecture within" (PS u3, 2013)

"I think as a team we don't really have enough space to perhaps store some of the things that we need, so when you work, you want things, you want the things around that you would normally need, so you want them to be accessible and to hand, but it becomes hard when things are pile up because you haven't got enough space" (WS u2, 2104)

This draws out how users see things particularly which get in their way and so come to their attention. This is both as an individual experience but also a social experience e.g. the need for a team to have things at hand to perform their task.

The building client team performs a role as well as using experience, both of which centre on the delivery of buildings.

"For XXXX building, we tend to drive specification to a need, so what we are really controlling over, not necessarily the legislative side, but more a specification side, so when you walk into room, you still feel like a university building" (PS c2, 2013)

'the space is defined by four sides with single or multiple accesses and designed to perform a particular function' (PS c3, 2013)

"For such a modern educational building, we had to ensure the balance between aesthetics, robustness and durability, thermal comfort, appropriate levels of natural and artificial light, energy usage, flexibility to suit changing uses, acoustic performance, capital budget and on-going maintenance costs, brand identity for the university," (PS c4, 2013)

"From my perspective, building performance is related to maintenance, energy and operation, and also all the systems within the building, so it's about maintaining all the level of understanding" (PS c1, 2013)

"I think that performance is about saving money, so what we are looking for is a cost effective building, value for money, deliver what we want for the occupants, and try and reduce as many issues as possible" (WS c1, 2014)

Clearly, this is much more technical view than the users' where problems exist in relation to what is deliverable and controllable against a functional brief and view of building operations.

BIM and Design

The second set of data gathered from the client team and users considered how BIM could help them see performance in design. The users' results are responses to 2D and 3D images. Although users are not proficient with building representations, these representations did provide the users with information. Firstly, in response to the static 2D images which were building plans:

Hard to get a real feel of size/ Doesn't show the scale (CS, u1, 2D, 2014)

Good for seeing layout of furniture/ Can't tell how many people will fit in room (CS u2, 2D 2014)

Certainly, the users did not feel that they could appreciate any spatial quality from the 2D representations. However, the 3D and dynamic images were also challenging:

Doesn't show colour/it might change feel if [colour] shown/ 3D gives better visualisation, but you can't visualise how much space your computer will take up (CS u4, 3D, 2014)

I hate revolving doors /Spaces don't look comfortable/ Desks look small – need to see what it looks like with the PC on it./ Cannot tell the space, ventilation, light (CS u2, 3D, 2014)

Probably stuffy, Small, Shared space / Unsure have ability to open windows /Room access is difficult to tell whether it is scan or lock or other (CS u1, 3D, 2014)

Users need details that are not important for the delivery model. The users were inclined to be upset by what they could not see. These details are needed as an experiential scaffolding to understand how the spaces can be used and how easily this is. The users did not trust the 3D representations; they thought they might be used to make it look attractive by using reduced size furniture or hide problems. This goes back to the organisational context within which the new building was being designed.

Turning to the client team, they saw 3D helping them with their role:

"The representations provided information on the areas within the building, and allowed me to gauge it against the brief" (CS, c1, 2014)

"The visualisation has provided accurate briefing on predicted space use by occupants" (CS, c2, 2014)

However, as these were experienced members of the client team, they did understand the inadequacies of BIM for delivering subjective performance information and how the users (or even non expert clients) were disappointed with the BIM representations; e.g.

"Spatially, it's quite restricted what you can do beyond an appreciation for the space itself, so one thing is that BIM in its current iteration lacks is that visual connectivity to the building itself so it gives you an understanding of the form and shape but not necessarily how it actually physically looks. So when people look at the model, they actually look quite disappointed expecting much more of a 3D representation of what's physically out there not just the shape and form." (CS, c2, 2014)

This was interesting as the client team promoted BIM strongly but from experience they also saw its current limitations for other than technical delivery.

5. Discussion

5.1 Users and Clients

The case study data explicitly shows that users and client teams perceive the buildings in different ways. The client team's perceptions are driven by their experience and need for building delivery producing a requirement to control and be explicit through measurement about aspects that they have specified. The users' perceptions are driven by their experience of working in buildings producing a need for comfort and ease of action. In a sense the two perspectives are connected but the users' perspective is describing a function in relation to their task. The client team has a more abstract view, not concerned with user tasks, but around measurable functions; but this abstraction can hide many problems of user tasks. This was shown by the client *(PS c2, 2013)* when demanding that certain specifications were delivered but these were not there for the occupants' needs. It is argued that the differences between the views of the client and users are not currently explored during design. Indeed, the client teams seemed somewhat reluctant to engage users, other than departmental managers, as they provided too complex or unspecifiable requirements, plus users gave often contradictory and unrealistic requirements which could be contrary to the client team's delivery objectives. The case studies also showed that clients have a corporate perspective on buildings as being expensive and their strategy is to cut this cost and make building-use more efficient; often referred to as space rationalisation. This was conducted purely at a space cost vs space area per activity level. Most often space per activity was set as a standard for that activity throughout the building even making savings by explicitly reducing this standard globally by say 10%. Client design teams do not investigate the business performance of space and how this might enhance work or how their designs might impede work. The idea that such decision-making might cost money from ineffective business operations was not in any way acknowledged. The users' perspective (e.g. *(PS u1 2013)* and *(WB u2 2014)*), had a focus upon the use of spaces in terms of how they operated as facilities and whether they provided comfort; thus, performance for users is much more from their individual perspective and not from some general or standardised basis.

5.2 Perceptions on digital representations

Not surprisingly given their drivers for buildings, the client team and users also perceived the digital representations (2D and 3D) presented to them differently. Looking at the client's side *(e.g. CS c1, 2014)* their perception of the representations is directly associated with the brief they had formed at the design stage. Some of the representations supported the quantitative aspects, such as area and occupancy level. Others were used as a reference to aid them in visualising aspects within the 3D representations such as furniture type, access to services (e.g. electricity sockets) and lighting (e.g. *CS c2, 2014*); which do support predicting how the space is can be utilised by the occupants. However, the client team use the visualisations and the completeness of the model to satisfy them about the successful delivery of the building.

The case was different from the users' perspective, as each representation triggered a number of concerns. They struggled to use the representations to experience the spaces. According to Oliva *et al*. (2010: 108) "we often acquire information about our surroundings by moving our head and eyes, getting at each instant a different snapshot or view of the world". The users try to use both their past experience as well as the representations to make sense of what they saw. Their concerns related to both operational and usability aspects but also the inadequacy of getting a feeling for the space. For instance, the user *(CS u1, 3D, 2014)* had concerns about space accessibility and whether windows could be opened. We argue that the gap between client and users is phenomenological where the client's concern focuses on the tangible aspects of the built environment whilst the users engage with intangibles that directly influence their experience.

5.3 New Interactions with BIM

The inquiry then into whether BIM can support the use of user experience in design is problematic. In this study a pragmatic approach was adopted to see what could be seen from the BIM models. Whilst acknowledging that virtual environments have been used as a collaborative design tools (e.g. Iorio *et al*., 2011), which allow information exchanging and sharing; these do not acknowledge the differing information requirements from the client's and users' perspectives. The current immersive virtual environments, which allow a sense of presence (e.g. Heydarian et al 2015), do not recognise how such environments can support the users' input into the design. The visualisation tends to focus on objects (e.g. Heydarian et al 2015) as this is easily provided by a virtual world that people experience in games. The difficulty of distinguishing a gaming virtual world and an understanding of the experience of a real physical world then becomes critical. The IT world is obsessed by creating an apparent simulated reality even when this is not possible. The evolution of virtual reality applications has focused on the interface provided to visualise objects rather than what information is needed to design user productive space.

Current visualisation does not allow people to feel a space merely showing a connection of detail. This detail is all that is necessary for computer games where the gaming aspect, e.g. the action hero killing elves, is set within a context. In the building design world, it is the context and our engagement with it that is the critical aspect not the detailed representation of the objects. In fact, it may be that, because perception is phenomenological, simple representations that are engaged with interactively and dynamically, may be more successful. Such a change in outlook for digital representations requires a change in aspect and intent. The intent has to be about inducing feeling and experience and the aspect has to be more holistic. The idea that the interaction is metaphorical rather than simulated reality (Dade-Robertson 2012) and the phenomenological aspects (Murray 2000) needs to be explored in greater detail. Future interaction with BIM would require further constructive approaches where lived experience is informing the digital experience, which potentially can support producing more informative representations. This needs to be undertaken within a metaphorical informating environment involving a social situation, an interactive process and a dynamic enquiry.

6. Conclusions

Given that there is much evidence that buildings do not meet user needs (Bordass et al, 2001) methods are required to address this. The advent of BIM provides the opportunity to engage users more in design and so to deliver buildings that perform better. This paper has adopted a phenomenological position on the use of BIM. Using a study of client team and user views of BIM, it established that they have different needs and different perceptions of building performance and BIM. For the client the performance is described by functional and quantitative aspects that can be controlled for building delivery. However, for the user, the performance is experiential and so is not containable by functional terms or aesthetic considerations. This phenomenological aspect has not been acknowledged and certainly does not feature in the current BIM debate. There is an assumption in BIM promotion that visual representations are all that is required to accommodate experience where this paper demonstrated that this is not the case. Although gaming worlds are experiential they have not been created for this application and engage people at a superficial level.

The evidence suggests that it is not virtual realism that is needed as regards experiential engagement; it is a user interactive process with a range of information that can elicit experiential understanding. Some of this may be quantitative or visualisations but other representations and interactive enquiry are needed. The paper suggests that BIM needs to support much softer information and this will be more metaphorical, interactive and developmental placed within a social situation of design. This also means that it is not possible to automate such activities and work is needed on the processes of design not just the product. The future of BIM then to deliver value for both the client and users lies in its ability to provide soft informated representations.

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Implementing Building Information Modelling in Building Services Engineering: Benefits and Barriers

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Abstract

Building information modelling (BIM), which involves the use of computer-generated n-dimensional (n-D) models to manage and integrate information in different phases of a building's life cycle, has rapidly evolved over the past decade. Yet there is still limited use of BIM in the Hong Kong construction industry, especially in building services engineering (BSE) which covers various disciplines such as electrical, air-conditioning, fire services, and plumbing and drainage. In order to explore how to achieve wider adoption of BIM in BSE, a study was commenced. Through an extensive search and review of relevant literature in the initial stage of the study, benefits of and barriers to implementation of BIM in building projects were identified. With reference to the characteristics of design, construction, operation and maintenance works, analyses were made to ascertain the applicability of the benefits and barriers in different building lifecycle phases. The findings will be used for designing a questionnaire for a focus group meeting that will be conducted in the next stage. Reported in this article include the outcomes of the above works and the tasks ahead.

Keywords: Barriers, benefits, building information modelling, building services engineering, construction industry

1. Introduction

In the 21st century, advanced information technology (IT) has rapidly changed the work processes of almost every industry. In the construction industry, one of the most significant IT developments has been the proliferation of the Building Information Modelling (BIM) technology. BIM is an IT-enabled approach that involves development and use of computer-generated n-dimensional (n-D) models to manage and integrate the essential building design with project data in different phases of a building's life cycle.

Recently, the global construction industry has entered a new era where adoption of state-of-the-art BIM has begun. More and more governments and public authorities have even set up a scheduled roadmap for full adoption of BIM. Though the Hong Kong government, for example, has decided to promote BIM implementation, there are only a few BIM-enabled construction projects. Whilst the Hong Kong Housing Authority has intended to implement BIM in all public housing projects from tendering stage in 2015, whether and when the best potential of BIM could be realized are yet to be seen.

Although the topic of BIM has been widely studied, very few studies are focused on the use of BIM in building services engineering (BSE), which covers various disciplines such as electrical, air-conditioning, fire services, and plumbing and drainage. As such, a study was commenced to explore how to achieve wider adoption of BIM in BSE.

2. Literature Review

2.1 BIM and Buildings

The concept of BIM has been in existence for a long time (Xiao and Noble, 2014). The first notion of virtual buildings came about in the 1970's (Eastman et al., 2011) and it did not came to the forefront of thinking until the term 'Building Information Modelling' was used as the title of a white paper by Autodesk in 2003, where the acronym "BIM" was also introduced. However, to define BIM is problematic as no single definition of BIM seems to exist. According to NIBS (2007), BIM is considered as "*a digital representation of physical and functional characteristics of a facility creating a shared knowledge resource for information about it forming a reliable basis for decisions during its life cycle, from its earliest conception to demolition*". Gu and London (2010) had the same idea. They considered that BIM is an IT approach that enables the management of digital building information in different project phases in the Architecture, Engineering, Construction and Operation (AECO) industry.

BIM can be defined with more inclusive definition. Eastman et al., (2011) defines BIM as "*a verb or adjective phrase to describe tools, processes, and technologies that are facilitated by digital machine-readable documentation about a building, its performance, its planning, its construction, and later its operation*". It is important to note that BIM is far more than a simple transition of 2D objects to n-D modelling offered by software vendors but manages graphical components and attributes of building information, allowing computer-aided generation of drawings and reports, design evaluation, project scheduling clash detection and resource organization from project design till building operation (Chan, 2014; Smith and Tardiff, 2009). BIM applications connect all parties such as architects, contractors, surveyors and owners to work together on a common information system (Eastman et al., 2011). This allows all parties to share information with each other and increase the confidence and consistency among them.

Today, BIM has been used in different stages of construction projects - from conceptual design phase to operation and maintenance phase. Many BIM studies have been conducted by academics, professional groups and software vendors (Autodesk, 2010; Bryde et al., 2013; Lu et al., 2014; McGraw Hill, 2014; Popov et al., 2010; Zhang et al., 2013). One group of these studies documents the use of BIM on specific successful project cases so as to demonstrate where BIM should be applied in building projects (Bryde et al., 2013; Hanna et al., 2014). A number of other studies, focussing on the software development of visualization and coordination at design stage, simulate improvements in future construction work for avoiding redundant work or demolitions caused by design changes or errors (Popov et al., 2010; Lu et al., 2014).

2.2 BIM and Building Services Engineering

Building services engineers are mainly responsible for design, installation, operation and maintenance of mechanical, electrical and plumbing systems required for the safe, comfortable and environmentally friendly use of buildings. Nevertheless, the BSE sector is considered to be one of the riskiest sector in the construction industry because it is a follow-up trade - its involvement in a project's construction sequence hinges on other critical trades, such as architecture and structural engineering (Hanna et al., 2013).

The rising interest of BIM in the BSE sector can be seen by referring to the potential benefits it can bring to the consultants and contractors for controlling change, increase in productivity and better coordination during the design and construction of buildings. Studies found that 10-30% conflicts can be resolved by using BIM prior to the construction stage (Eastman et al., 2011). Additionally, an approximate 2% cost saving and 3% time saving were attributed to the use of BIM (Korman et al., 2008).

The existing research on the use of BIM in the BSE sector is limited. Previous studies concentrated on the coordination practices and they tried to find out, for instance, which software was popular (Hanna et al., 2014; Korman et al., 2008; Yung et al., 2014). On the other side, some studies provided insight into the use and value of BIM. Simonian et al. (2009) found that the electrical contractors are able to expand their services with BIM implementation. The adoption of BIM could also enhance the delivery and value of the contractor's expertise; streamline workflow; improve communication with clients, consultants and contractors; broaden the services they offer to clients; and increase the revenue per employee.

A number of reports and papers have also been published to provide insight into the use of BIM and recommend improvements to BIM practices in the mechanical and electrical construction industries (Azhar and Cochran, 2009; Azhar et al., 2008). Whilst such research found that the advent of BIM in the industries can contribute to significant cost and time savings and quality improvements, several barriers to BIM adoption were also identified, including the lack of BIM knowledge and technological experience, software compatibility issues and high initial investment costs.

Hanna and his colleagues highlighted the state of BIM practice in the US and Canadian mechanical and electrical industries (Boktor et al., 2014; Hanna et al., 2013; 2014). The study results indicated that there was a significant increase in the use of BIM in electrical contracting when compared to the previous results obtained in 2008 and 2009. It was found that the use of BIM in the electrical construction industry has helped productivity and profitability; however, electrical contractors are still struggling to overcome the challenges of BIM implementation (Hanna et al., 2014).

The above parts show that the existing literature of BIM focused mainly on the benefits, barriers and implementation framework of BIM in the construction industry in general. Potential benefits and barriers which are specific to BIM implementation in the BSE sector are not entirely clear. Therefore, as reported in the following, a review of the relevant literature was made to identify the applicable benefits and barriers in relation to the use of BIM for BSE.

3. Benefits of Implementation of BIM for BSE

After an extensive literature review, it was found that a significant volume of studies agree that BIM adoption can bring along multiple benefits to the AECO industry. These benefits, as listed in Table 1, are applicable to the BSE sector.

Table 1: Benefits of Implementation of BIM for BSE

Benefits	*Justification*
(a) Better cost management	· *BIM can be used to check for structural, architectural and building services clashes so as to reduce the cost spent on rework and requirement changes (Bryde et al., 2013; Construction Industry Council, 2014).*
(b) Better time management	· *By using the integrated BIM model to visualize, explore and analyze the impact of changes, the project stakeholders can have better monitoring to the change in scope and progress of the whole project (Construction Industry Council, 2014; Guo et al., 2014; Hanna et al., 2013; Hanna et al., 2014; McGraw Hill Construction, 2014)*
(c) *Better quality control*	· *As a project moves into the construction phase, the depth of information contained within the n-D BIM model improves the contractor's ability to understand the design details and resolve problems (Bryde et al., 2013).*
(d) *Better risk management*	· *BIM increases the surety of investment and decision-making by improving visualization with respect to clarity, confidence and risk management (Bryde et al., 2013; Construction Industry Council, 2014).*
(e) *Better safety management*	· *BIM assists with the development of a method statement and enhances the understanding of construction safety issues that may arise (Construction Industry Council, 2014; McGraw Hill Construction, 2014).*
(f) *Better security*	· *BIM can assist the owners to better plan for security control during construction through early identification of the adequacy of relevant*

Benefits	*Justification*
	equipment provided in the construction site (Construction Industry Council, 2014).
(g) *Better project management*	· *BIM systems having model production enables the construction sequence to be simulated prior to construction, which also facilitates activity programming for project management (Bryde et al., 2013; Construction Industry Council, 2014; Hanna et al., 2013; Hanna et al., 2014).*
(h) *Better decision making*	· *Visual representations of BIM can help to enhance project stakeholders to understand the design details, resolve problems and aid decision-making (Construction Industry Council, 2014).*
(i) *Better visualization of design and construction process*	· *BIM shows what different options look like, not only upon completion but before and during the works. Its visualization capacity can help project participants to better understand the design and construction process (Boktor et al., 2014; Chan, 2014; Guo et al., 2014; Hanna et al., 2013; Hanna et al., 2014).*
(j) *Better design and drawing*	· *Using BIM in the design phase can help to ensure consistency among a project's many plans and drawings and monitor changes easily throughout the design process (Chan, 2014; Construction Industry Council, 2014; Hanna et al., 2013; Hanna et al., 2014).*
(k) *Better assembly of data and information*	· *With consistent and standardized exchange of information, BIM can reduce the information lost during handover from designer to contractor (British Standards Institution, 2010; Construction Industry Council, 2014).*
(l) *Improved quantity take off and tendering*	· *When BIM is correctly aligned with the method of measurements, the programme can generate the necessary quantity of materials for measurement purpose (Boktor et al., 2014; British Standards Institution, 2010).*
(m) *Improved construction workflow and method*	· *BIM provides previews of the site planning and construction works, which facilitates the enhancement of construction sequence and method (Construction Industry Council, 2014; McGraw Hill Construction, 2014).*
(n) *Improved interdisciplinary communication, coordination and engagement*	· *BIM enables significant improvements in inter-disciplinary coordination and communication through the use of consistent and standardized information (Construction Industry Council, 2014; McGraw Hill Construction, 2014).*
(o) *Enhanced the value of different discipline*	· *BIM help the professionals to execute labour intensive work (e.g. CAD drafting, quantity measurement), thereby freeing professionals to focus on value-added work and activities (Construction Industry Council, 2014).*
(p) *Better lifecycle asset management and performance*	· *An accurate BIM model captures the requirements, design, construction and operational information etc. facilities management of the building. Through more detailed asset and life cycle planning, lifecycle costs are better understood and performance is more predictable (BIM Task Group, 2013; Boktor et al., 2014; Construction Industry Council, 2014).*
(q) *Earlier occupancy*	· *By utilizing BIM, the efficiency of construction can be improved and hence earlier use of the building can be achieved (ASHARE, 2009; Construction Industry Council, 2014).*
(r) *Improved environmental performance and promote sustainability*	· *The full 3D energy consumption analysis can be performed by the BIM model and simulation programme with a short lead time (ASHARE, 2009; BIM Task Group, 2013; British Standards Institution, 2010; Construction Industry Council, 2014).*
(s) *Improved productivity and*	· *As a clearer link between design decisions and cost implications are developed through BIM adoption, clients are able to attain better*

Benefits		*Justification*	
	business outcomes		*productivity and business outcomes for the company (Construction Industry Council, 2014; McGraw Hill Construction, 2014).*
(t)	*Better customer service*	·	*By improving communication and understanding of the clients' needs for the project at the at the planning and design stage, BIM can help the construction professionals and contractors to provide better service to the client (Construction Industry Council, 2014).*
(u)	*Improved stakeholder and public engagement*	·	*BIM improves a project team's ability to present the specifics of a design and their intentions to stakeholders and the public. Proposals can be better understood by the public through accurate visualizations (Chan, 2014; Construction Industry Council, 2014).*
(v)	*Provision of a forward thinking platform*	·	*BIM "pre-builds" a project, allowing problems to be addressed as and when found throughout the design process (Construction Industry Council, 2014).*

With the above-identified potential benefits, it is considered that BIM implementation can provide a number of major benefits to the BS engineers in managing the time, cost and quality of a construction project from the design till the operation and maintenance stage (Table 2). With BIM, BSE data and information are more easily shared, value-added and integrated into the architect design model at any point in time. BS engineers do not have to wait until the completion of architectural design concept to proceed with their work. Digital BSE product data can assist BS engineers in providing more accurate cost estimation and management in the design and construction stage, with lifecycle costs more predictable in the subsequent operation and maintenance stage. Quick and versatile simulation functions of BIM software also help to achieve better production quality of BSE.

In addition, BIM can provide benefits in the design stage - facilitating aesthetic considerations, design decision, system function and performance and quality control by the BS engineers. With BIM, BS engineers are able to detect any clash between building services and building structure, which means mistakes are identified before work commences on site. The BIM visualization can also help the BS engineers to quickly analyse and compare several design alternatives, conducive to quality control in later stages.

Other than its benefits to the design stage, BIM application is also beneficial to the construction, and operation and maintenance stages for it can enhance sequencing and installation consideration, accessibility, sustainability, occupancy, safety requirements, data assembly, interdisciplinary cooperation and engagement for the BSE sector. Using BIM enables clash detection and hence early resolution of conflicts in the design stage. Thus, the schedule of BSE activities can be accurately prepared. When BSE coordination work starts, different professionals in the BSE team can rely on BIM models when they need specific information, instead of searching information from different engineers in the traditional manner. Safety analysis can also be conducted by using simulation tools to check for safety and health issues in the planning of BSE works.

Table 2: Benefits of Implementation of BIM for BSE in different building lifecycle phases

Benefits	*Design*	*Construction*	*Operation and Maintenance*
(a) *Better cost management*	*X*	*X*	*X*
(b) *Better time management*	*X*	*X*	*X*
(c) *Better quality control*	*X*	*X*	*X*
(d) *Better risk management*	*X*	*X*	*X*
(e) *Better safety management*		*X*	*X*
(f) *Better security**	*X*	*X*	*X*
(g) *Better project management*	*X*	*X*	*X*
(h) *Better decision making*	*X*	*X*	
(i) *Better visualization of design and construction process*	*X*	*X*	
(j) *Better design and drawing*	*X*		
(k) *Better assembly of data and information*	*X*	*X*	
(l) *Improve quantity take-off and tendering***	*X*	*X*	
(m) *Improve construction workflow and method*		*X*	
(n) *Improvements in interdisciplinary communication, coordination and engagement*	*X*	*X*	*X*
(o) *Enhanced the value of different disciplines*	*X*	*X*	*X*
(p) *Better lifecycle asset management and performance*			*X*
(q) *Earlier occupancy*		*X*	*X*
(r) *Improved environmental performance and promote sustainability*		*X*	*X*
(s) *Improved productivity and business outcomes*	*X*	*X*	*X*
(t) *Better customer service*	*X*	*X*	*X*
(u) *Improve stakeholder and public engagement*	*X*	*X*	*X*
(v) *Creation of a forward thinking platform*	*X*	*X*	

*The benefit of better security is controversial (CIBSE, 2015). ** Whether quantity take-off is involved in the design or construction stage depends on the procurement method.

4. Barriers to Implementation of BIM for BSE

Although many benefits can be gained by the implementation of BIM, the pace of its adoption for BSE is much slower than anticipated. This may be because BSE companies and practitioners are struggling to overcome the barriers to BIM implementation. Such challenges are summarized in Table 3.

Table 3: Barriers to Implementation of BIM for BSE

Barriers	*Justification*
(a) *IT infrastructure and software related problem*	· *There is lack of a common standard and protocol for data interoperability and data management of which BIM models cannot be efficiently shared between different disciplines (BIM Task Group, 2013; Construction Industry Council, 2014; RICS, 2011).*
(b) *Project participants related issues*	· *Project participants may not appreciate the value of collaboration among different parties working on the same project throughout its duration (Boktor et al., 2014; Construction Industry Council, 2014; RICS, 2011).*
(c) *Lack of client demand*	· *Adopting BIM incurs the client to pay more professional fees to the design professionals. Private clients will demand BIM in their project design and construction when they realized the benefits of BIM (Chan, 2014; RICS, 2011).*
(d) *Lack of training or education*	· *Although there is a wide range of BIM short courses offering in the market, the quality of these BIM courses varies considerably as no clear BIM guidelines are available for institutions to follow (RICS, 2011).*
(e) *Lack of studies to quantify the value of BIM*	· *There is a lack of local studies to quantify the exact local benefits and value of BIM, which also affects the industry to adopt BIM (Burcin and Kensek, 2010).*
(f) *Lack of government support*	· *Government support is strongly related to the ambitious of BIM implementation in the construction industry (Chan, 2011; RICS, 2011).*
(g) *Lack of legal standards or specification to cope with BIM adoption*	· *There is a lack of relevant contract terms and legal standards that reflect the changes in data ownership, confidential information, risk allocation, and procurement practices that will be affected by the adoption of BIM (BIM Task Group, 2013; Chan, 2014; Construction Industry Council, 2014; RICS, 2011).*
(h) *Lack of new or amended form of contract*	· *Prior to BIM adoption, there is a need to review existing contract provisions as to ensure the responsibilities and risks among contracting parties can be properly reflected (Chan, 2014; Construction Industry Council, 2014; RICS, 2011).*
(i) *Widespread of mistakes and errors produced*	· *BIM's integrated concept blurs the accuracy and control of data entered into the model of which an error will be propagated among stakeholders if a mistake is produced (Chan, 2014).*
(j) *Timing issues*	· *Most construction projects have a tight design schedule and intensive construction period in terms of return on investment philosophy. However, design consultants cannot avoid the uncertainty of design changes according to clients' requests. This not only increases the difficulties for design consultants to reduce time on project documentation, but may also contribute to delay in construction phase. The delay in construction may also impede the BIM utilities (BIM Task Group, 2013).*
(k) *Investment and costing issues*	· *Investment of BIM is strongly related to high level management commitments as adopting BIM incurs initial investment costs related to management and administrative processes, including staff time, hardware, software and training (Azhar and Cochran, 2009; Construction Industry Council, 2014; Hanna et al.,2013; Hanna et al., 2014).*
(l) *Too new and complicated for use*	· *Adopting BIM is difficult for certain amount of design professionals as they are educated and trained in the conventional 2D CAD environment and do not know much about BIM (Azhar and Cochran, 2009; Chan, 2014).*
(m) *No opportunity to use*	· *In the construction industry, due to the tight design schedule and intensive construction period, design and construction companies normally will not consider the adoption of BIM in the project until it is required by the clients or owners. Thus, without the requirement of the client, there is no opportunity for BIM to be used by the construction professionals (Azhar and Cochran, 2009).*

The barriers to implementation of BIM for BSE can be categorized into different categories (Lai and Yik, 2006): knowledge, finance, motivation, information and timing (Table 4). The knowledge category refers to the limiting factors related to lack of familiarity and understanding of the relevant software and contractual requirements for BIM adoption. When moving to adopt BIM, new requirements are needed to ensure effective interoperability and information exchange. However, the traditional training for BS engineers may not facilitate them to readily pick up new BIM technology and requirements. The absence of standard BIM contract documents in protecting the BSE information also prevents BS engineers from adopting BIM in the construction project. The financial category is about money-related limiting factors and the motivation category is about lack of support from different parties. The BSE sector consists of many small companies which have trouble to afford high initial investment to purchase the needed BIM software. With insufficient number of case studies showing the potential financial benefit of BIM, the BSE sector does not show much interest in investing towards the change in technology. The information category refers to the supporting cases and technology limiting factors. Timing issues affect the opportunity of using BIM in the BSE sector.

Table 4: Categories of Barriers to Implementation of BIM for BSE

Barriers	*Knowledge*	*Financial*	*Motivation*	*Information*	*Time*
(a) IT infrastructure and software related problem	*X*	*X*		*X*	
(b) Project participants related issues	*X*		*X*	*X*	*X*
(c) Lack of client demand			*X*		
(d) Lack of training or education	*X*				
(e) Lack of studies to quantify the value of BIM				*X*	
(f) Lack of government support			*X*		
(g) Lack of legal standards or specification to cope with BIM adoption	*X*				
(h) Lack of new or amended form of contract	*X*				
(i) Widespread of mistakes and errors produced	*X*				
(j) Timing issues					*X*
(k) Investment and costing issues		*X*			
(l) Too new and complicated for use	*X*				
(m) No opportunity to use		*X*		*X*	*X*

5. Conclusion and Future Work

Although it has been widely believed that BIM is an advanced technology that improves the performance and productivity of building projects, there has been a relatively slow uptake of BIM in the Hong Kong construction industry, especially in the BSE sector. This paper has identified the possible benefits and barriers for implementing BIM in BSE. It is clear from the above findings that BIM can help to enhance productivity, profitability and project performance in terms of time, cost and quality in various building lifecycle phases. On the other hand, BIM is still in an evolving process and there are many barriers to its implementation.

The findings provide a solid basis for designing a questionnaire for use in a focus group meeting to be held in the next stage. In order to obtain as many useful findings as possible from a focus group discussion, careful selection of the group members who are experienced and representative in the field is necessary (Berg, 2009; Fern, 2001; Hesse-Biber and Leavy, 2004). The meeting, during which opinions of BSE related experts will be solicited, will validate the applicability of the above benefits and barriers to BSE.

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Understanding the Current Context and Challenges of BIM Adoption on Construction Sites

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Abstract

The deployment of Building Information Modelling (BIM) on construction sites has been slower than many anticipated and has lagged behind BIM adoption by design teams. The greater social and organisational complexities surrounding the on-site construction process suggest that BIM implementation faces multiple challenges. However, today's information technologies also offer opportunities for improvements in overcoming some of the barriers to construction process integration and efficiency.

The socio-technical environment has changed considerably over the past five years - smartphone use has become ubiquitous, tablet computers have become familiar and widespread as have wireless technologies, cloud computing, social media, and mobile data. Thus the current context for BIM implementation is quite different in terms of hardware, software, users and their expertise and expectations to what it was in 2010. In contrast, the research publication cycle is relatively slower and much of our accumulated knowledge and understanding of the construction site context vis-a-vis BIM as represented in the academic literature dates back to an earlier time.

This paper reports a survey of Estonian construction managers' opinions regarding BIM use on site obtained through semi-structured interviews. The survey found that BIM use on Estonian construction sites has been largely experimental to date and that most construction managers have little or no experience of it. Clear steps towards BIM implementation are not generally apparent and individual needs and priorities for BIM differ markedly. It is recommended that specific, problem-based interventions would contribute to BIM adoption.

Keywords: BIM, construction innovation, construction sites, Estonia, site managers

1. Introduction

The adoption of IT on construction sites has historically been slower than expected and the implementation of Building Information Modelling or Building Information Management (BIM) on sites remains limited with information exchange on most sites still in 2D and often paper-based (Davies and Harty, 2013; Dib *et al.* 2013; Cao *et al.* 2015). While initial efforts to develop BIM tools concentrated more on design and pre-construction planning (Sacks *et al.* 2010), an increasingly wide range of applications to support the construction phase has since become available (Ding *et al.* 2015; Karan and Irizarry, 2015; Matthews *et al.* 2015). Although BIM use is reported to be widespread in the design phase (McGraw Hill Construction, 2010), it is yet to become standard practice even in countries which are relatively advanced in BIM adoption terms (NBS, 2013). Merschbrock and Figueres-Munoz (2015) noted that current BIM practice in design still relies on local 'work-arounds' to overcome obstacles in implementation. Given the greater diversity of firms and personnel engaged in the construction phase, it is unsurprising that the application of BIM tools in support of construction management has been problematic (Hartmann *et al.* 2012).

In terms of enabling the adoption of BIM on sites, recent research has questioned the effectiveness of top-down impositions of BIM technology and new ways of working to accommodate the new technology (Hartmann *et al.* 2012). In addition, Davies and Harty (2013) draw attention to the dichotomy between firm- and project-level innovations in the adoption of BIM on sites. Miettinen and Paavola (2014) note the importance of the social and human conditions for the implementation of new technology.

Despite Estonia's relatively well-developed IT sector (in terms of e-government, cyber security, widespread use of digital signatures, etc.) and the considerable movement and interaction of construction personnel (particularly subcontractors) between Estonia and Scandinavia in what is increasingly a regional construction market, BIM adoption on Estonian construction sites appears to be lagging well behind that in the Scandinavian countries. In the World Economic Forum's Global Information Technology Report 2014, Estonia ranked overall 21st in the world but this hides a far more complicated picture. It ranked relatively higher in terms of government usage (12th) than individual usage (17th) with business usage being ranked lower (28th). The lowest ranking it received was in terms of the affordability of IT (61st) (WEF, 2014). Although government has actively and successfully promoted IT development in some areas this has not been the case with regard to construction and, to date, there has not been a coordinated effort by government to impose or promote the use of BIM in public construction projects.

This paper describes an initial investigation to gain a clearer understanding of the current state of BIM adoption on Estonian construction sites and an appreciation of the current attitudes and opinions of construction managers in relation to BIM. It is intended to provide a basis for further research efforts aimed at enabling BIM adoption in the construction process. Section 2 of this paper describes the research methodology adopted for this initial study. The results of the investigation are presented in Section 3, and these are further analysed and discussed in Section 4. Conclusions including recommendations for further research follow in Section 5.

2. Research methodology

The lack of progress to date with BIM adoption on Estonian construction sites and the intention to design future research studies aimed at enabling BIM use on sites suggested the need for an initial study to gain a better understanding of the current situation regarding BIM adoption on sites. To ensure as rich an understanding of the context as possible while attempting to limit the imposition of the researchers' own notions of the situation but still allowing for comparison between responses, a qualitative approach of semi-structured interviews was adopted for the study. The construction managers responsible for construction site operations were considered the most appropriate and convenient stakeholders to interview since they were directly affected by the adoption of BIM, were central to any BIM implementation initiative and had an overview of all the issues involved.

The interview questions were divided into three main groups:

1. IT use on construction sites currently and in the future – the current situation, what and who determines IT use, expectations, needs, barriers/challenges;
2. Modes of communication and collaboration between the on-site management and the various other parties to enable the construction process;
3. BIM – what the term means to each interviewee, their experience with BIM to date and the steps being taken towards adopting it on sites.

Particular attention was paid to ensuring that different personal definitions of BIM would not limit the scope of the information obtained from respondents yet, at the same time, it was intended to discover what these personal definitions of BIM were. For this reason, the term BIM was avoided until the end of the interview and the earlier questions referred to all 'IT solutions' and all forms of 'communication and collaboration'.

From the research of Davies and Harty (2013), it was acknowledged that the firm versus project dichotomy may have an important bearing on BIM adoption on sites and, therefore, both Site Managers and Project Managers (who are less site-focused) were included as interviewees. The sample of interviewees selected comprised one Project Manager and one Site Manager from each of six firms – three of the largest general contractors in Estonia (with annual turnovers approaching or exceeding 1 billion euros) and three medium-sized construction firms. This arrangement allowed for the possibility of drawing comparisons of both Project Managers versus Site Managers as well as large versus medium firms. Small construction firms were considered to be outside the scope of this study as their working arrangements and the issues they faced with regard to BIM would not be typical to general contractors.

The interviews were carried out individually by 3 different researchers according to a common set of open-ended questions which corresponded to the 3 main question groups in the list above. All the interviews were conducted in Estonian language. The interviews were audio recorded and the audio recording was later transcribed. The content of each of the transcripts was then analysed.

3. Results

Eleven interviews were conducted during July and August 2015. The interviewees comprised one Site Manager and one Project Manager from each of five construction firms but only one Site Manager from a sixth construction firm.

Table 1: Summary of prevalent responses from the interviewees

Higher Level Categories	*Nodes most referenced by interviewees*	*Number of Interviewees*
Current IT use on construction sites	*E-mail*	*11*
	Project server	*6*
	AutoCAD (in 2D)	*6*
	Dropbox	*6*
Project specificity of IT use	*IT use depends on project complexity*	*5*
	IT use doesn't depend on the project	*5*
Current needs for additional IT	*Clash detection*	*4*
	Avoiding mistakes	*3*
Which party determines IT use?	*Client*	*9*
	Main contractor	*6*
Current barriers / problems / challenges	*Knowledge of subcontractors' personnel*	*7*
	Hardware constraints	*3*
Positive trends / reducing barriers	*None - problems will remain the same*	*3*
Expected current and future benefits from IT use	*More accurate information*	*5*
	Improved time planning	*5*
	Better visualization	*5*
Modes of communication / collaboration	*[Responses are shown separately in Table 2]*	
What does the term 'BIM' mean to interviewees (in the construction context)	*3D model*	*6*
	Coordination through the building lifecycle	*4*
Interviewee's experience with BIM	*Little or no experience*	*7*
	Some, limited experience	*3*
Expectations for BIM in the future	*More complete information*	*3*
Steps currently being taken by firms towards BIM adoption	*Training of personnel*	*2*
	Setting up new systems and standards	*2*
	Hiring new (BIM) personnel/experts	*2*
	Non-specific (small) steps	*2*

An initial system of classification for analysing the contents of the interview transcripts was set up on the basis of the interview questions. This classification system comprised 12 higher level categories (refer to Table 1 above). Under each of these higher level categories, an initial set of 'nodes' was generated based on the anticipated responses to the questions. The transcripts were then analysed and evidence in support of each node was identified and referenced to the appropriate node. Additional nodes were added as necessary to accommodate the full range of responses given by the interviewees. In this way a refined list of nodes was generated and all interview responses within the complete set of transcripts were represented in terms of their references mapped to this list of nodes. Table 1 (above) summarises the nodes which were referenced by the highest numbers of interviewees under each higher level category with the exception of the higher level category: 'Modes of communication and collaboration' which is separately summarised in Table 2 (below).

Table 2: Current modes of communication and collaboration on construction sites

Communication / collaboration modes	*Proportion of interviewees referencing these responses*				
Between:	*On-site and off-site managers (contractor)*	*Within the on-site team (contractor)*	*Contractor and designers*	*Contractor and sub-contractors*	*Contractor and client*
Face-to face (informal)	*91%*	*82%*	*18%*	*73%*	*9%*
Regular meetings	*36%*	*36%*	*18%*	*55%*	*82%*
Telephone	*64%*	*45%*	*73%*	*64%*	*36%*
E-mail	*73%*	*73%*	*100%*	*73%*	*55%*
Online collaboration	*0%*	*0%*	*9%*	*0%*	*0%*
Shared file server	*9%*	*18%*	*0%*	*0%*	*0%*

4. Further analysis and discussion of results

In addition to the compilation of the total number of interviewees referencing each identified response node and the total number of references from the transcripts associated with each node, the results were further analysed in terms of whether the responses from Project Managers differed substantially from those of Site Managers and also whether the responses from interviewees from the larger construction firms were substantially different to those from medium-sized firms. The findings from these analyses are reported below according to each of the 12 higher level categories listed in Table 1 above.

4.1 Current use of IT on Estonian construction sites

As shown in Table 1, the use of e-mail was, unsurprisingly, reported by all respondents. The importance of e-mail to Site Managers and Project Managers is difficult to overstate as, in their words: *"e-mails are automatically archived and are equivalent to signed documents in law"* and because *"e-mails leave a mark of the conversation"*.

Just over half of the interviewees reported use of 2D AutoCAD, and file sharing systems (either a project server or Dropbox) while 4 out of 11 referred to the use of 3D models and only 2 interviewees mentioned the use of software for viewing these (both referring to Tekla BIMsight).

The use of project servers was reported by 6 of the interviewees. All 6 of these were from large construction firms and this was the main reported difference in IT use between large and medium-sized firms. A second difference between large and medium-sized firms appeared to be greater use of 3D (virtual building) models by the larger firms (reported by 50% of large firm interviewees) compared to their use being reported by only 1 of the 5 interviewees from medium-sized firms.

A slight difference between the Site Managers' and Project Managers' reported IT use seemed to reflect a more technical, hands-on role of the Site Managers in that more Site Managers reported the use of AutoCAD, 3D models and Tekla BIMsight than did Project Managers.

4.2 Project specificity of IT

Interviewees' opinions differed markedly on whether project characteristics affected IT use (Table 1). The view that IT use is not dependent on the project was held by similar proportions of Project Managers (40%) as Site Managers (50%) as well as large firm representatives (50%) and medium-sized firm representatives (40%). For those interviewees who suggested that IT use was indeed project specific, project *complexity* was the most commonly cited project characteristic determining IT use but project *budget*, project *size* and project *manager* were also mentioned as determinants. In the words of one Project Manager: *"the budget determines everything"*.

4.3 Current needs for additional IT solutions

As shown in Table 1, the most popular suggestions for current needs which could be satisfied through IT solutions were clash detection and avoiding mistakes. Both of these suggestions were supported more by the medium-sized firm representatives (60% and 60% respectively) than by their large firm counterparts (17% and 0%). Two interviewees from large firms who reported that 3D models were in use did not indicate clash detection as a current need. However, it is unclear from the data whether this was because clash detection was already being used or that they didn't consider it a current priority or neither of these and it simply wasn't mentioned during the interview.

Both clash detection and avoiding mistakes as well as other suggestions appeared to reflect the Project Manager / Site Manager role differentiation to some extent in that Site Managers tended to offer more specific and technical suggestions (clash detection, combined 3D model and time schedule, documentation of changes, easier and faster quantity take-offs, visualization tool, construction model) whereas Project Managers offered more general suggestions (project bank, single system for communication and file sharing).

4.4 Which party (client, designers, contractor) determines IT use

The majority of interviewees (82%) considered that the client determines what IT solutions are used on construction sites. This was a view held equally by Project Managers and Site Managers and by large and medium-sized firm representatives. From the interview context, it is clear that the interviewees were referring here to the use of new and innovative IT solutions such as those associated with BIM rather than to standard, ubiquitous IT applications such as e-mail. The notion that the client should require BIM in order for it to be used suggests an assumption that BIM use would be a burden on the contractor rather than an opportunity for efficiency gains. These sentiments were variously echoed in the interviews: *"I haven't heard of someone asking for BIM to be used [on site]"; "the client doesn't know what BIM is and therefore doesn't ask for it"; "there are projects, where the private client is quite sophisticated and price isn't the only important thing anymore"; "the [BIM] software, to be honest, slowed down the work".*

However, this was not the only perspective nor a necessarily exclusive one, as 55% of interviewees also indicated that the contractors themselves determined IT use on sites.

Only two interviewees suggested a role for the designers in determining IT use on sites. But the role of designers appears complex - whereas one interviewee noted that the designers have helped to encourage BIM use on site: *"the 3D constructive model was probably made out of the good will of the designer"* another implied that their actions might be impeding progress in this area: *"as a rule, many designers use BIM but then they convert their models to AutoCAD and changes can't be made. The 3D model isn't sent to us."*

4.5 Current barriers / problems / challenges for IT use

Although the actual question avoided using the term 'BIM' and so referred to the adoption of any new IT solutions, it appears to have been generally understood by the interviewees that it referred to barriers to the adoption of BIM-related innovations.

The problem most widely cited by interviewees (64%) was the knowledge and capabilities of subcontractors' personnel: *"The men themselves must be able to use it."; "On site, it largely depends on the subcontractors who actually do the work... I would waste a lot of my time making it clear to them."*; "*A lot of subcontractors have not yet reached to the level of [proficiently using] AutoCAD"*; *"The biggest barrier are the project managers of subcontractors, who do not see the big picture".*

This challenge was referred to by similarly high proportions of Project Managers and Site Managers, and by representatives of both large and medium-sized firms. It was the single most highly referenced response node in the entire analysis with interviewees making a total of 23 references to this issue.

'Hardware constraints' was the second most cited challenge (by 3 interviewees) with knowledge / capabilities of main contractors' personnel (*"but also we ourselves are unable to* *use these models, so it is difficult to order things which we don't know nor can we check"*), software constraints, financial constraints and a perceived older generation resistance to new technology each being referenced by two interviewees. In addition, the following further barriers were identified (by only 1 interviewee in each case): creates additional work, clients' (un)willingness to pay for them, the current education system, time constraints, no single standard / protocol for IT/BIM use, insufficient support from IT personnel, details in BIM model differ from the real world, insufficient information in the BIM models, not cost effective on small projects.

4.6 Positive trends that are serving to reduce barriers to IT use

The most cited response was pessimistic – that there are none and problems will remain (3 interviewees) - as one put it: *"There will always be problems, as people are involved"*. Less cited but more positive suggestions included increased interest in BIM and improved computer literacy (both cited by 2 interviewees) and experience (cited by 1). *"When people get experienced and use gets more effective and quicker, then [BIM] certainly will get used"*.

No direct mention was made of improved and more available software or of new and improved hardware being positive trends.

4.7 Expectations of current and future benefits from IT use

A considerable list of potential benefits was suggested by the interviewees, these can be summarised as being the expected consequences of more accurate and complete information being available quicker and in a format which makes it easier to understand and, particularly, to visualize. As shown in Table 1, the three most highly cited of these benefits were more accurate information, improved time planning and visualization (each cited by 5 interviewees). A difference in the number of Project Managers (1 in each case) and Site Managers (4 in each case) citing these can be observed and this is likely to once again reflect the greater engagement that the site managers appear to have with the technical details of the projects. In most cases of expectations put forward, Site Managers make up the majority of or are the only interviewees who referenced them. The notable exception to this was the response: 'more efficient communication' which was cited by 2 Project Managers and no Site Managers.

4.8 Current modes of communication / collaboration between the different parties on- and off-site

In analysing the reported modes of communication and collaboration, it is convenient to consider three groups (refer to Table 2 above): those engaged in the works (the contractor's team and the subcontractors/suppliers), the designers, and the client. From the results obtained, it appears that communications between Project Managers / Site Managers and each of these groups are distinct.

Between Project Managers / Site Managers and those engaged in the works, the primary mode of interaction is informal, face-to-face meetings (presumably on the site) – *"People tend to meet face-to-face very regularly"*. This form of communication was particularly dominant among Site Managers – all of whom reported such informal meetings with the contractor's off-site personnel, with the on-site team and with the subcontractors and suppliers. The next most important modes of communication among this group were e-mail and then telephone.

Between the interviewees and designers, the primary mode of communication is e-mail (100% of interviewees) and then telephone (73% of interviewees). The automatic archiving and the accountability associated with e-mail noted in subsection 4.1 above are undoubtedly important here and one interviewee gave insight into why telephone communication remains a popular alternative: *"a phone call ensures a response"*.

Communications between Project Managers / Site Managers and the client are mainly within regular scheduled meetings (82% of interviewees) with e-mail (55%) and telephone (36%) also having some significance.

The modes of communication differ somewhat between Project Managers and Site Managers and this appears to relate to their separate roles. Project Managers (100%) reporting higher telephone use than Site Managers (50%) in communicating with designers. Conversely, Site Managers (83%) reported higher telephone use than Project Managers (40%) in communicating with subcontractors and suppliers.

Notably, there was only one reference to collaboration with designers. This took the form of online, asynchronous collaboration. There were no reports of online collaboration in real time or any formal collaboration through colocation (Big Room, knot-working, or similar).

4.9 What the term 'BIM' means to the interviewees

As anticipated, the term BIM carried different meanings for the interviewees and some of them acknowledged this: *"Everyone thinks that they understand BIM the same way, but in reality it is not the case"*. A slight majority (6 interviewees) noted the 3D model component and 4 interviewees' responses reflected the notion of 'coordination through the building lifecycle'. Beyond these were a further 12 suggestions offered by only one or two interviewees as follows: collaborative design, joint management of the construction process, communication platform/tool, 4D model (3D model with integrated time schedule), information for operation and maintenance, information model for construction, overview of work done and work to do, notifies what needs ordering and when, visualization tool, all information in a single model of the building, platform to manage time and cost.

4.10 The degree of experience that interviewees have had with BIM

Of the 11 interviewees, 3 described themselves as having some limited experience with BIM while 7 professed to have little or no BIM experience. One interviewee did not provide an answer to this question. The experience with BIM was slightly greater amongst Site Managers than Project Managers and representatives of large firms rather than medium-sized firms.

4.11 Expectations for BIM in the future

The responses elicited from the interviewees in terms of expectations from BIM in the future was somewhat similar to those given for their expectations of current and future benefits from IT use described in subsection 4.7 above. Once again, the responses related to expectations of more complete, more accurate information being available earlier and Site Managers provided the majority of these responses.

4.12 Steps that the interviewees' firms were reported to be taking to implement BIM

Very little common ground is evident in terms of the reported steps being taken by the interviewees' firms towards BIM implementation. Although 4 reported types of actions being taken (training of personnel, setting up new systems and standards, hiring new (BIM) personnel/experts and non-specific (small) steps) were each referenced by 2 interviewees, it is only in the case of the last of these (non-specific (small) steps) that the 2 interviewees were representatives of the same firm and, since this action is 'non-specific' it is more likely a function of a coding decision than precise agreement between the two interviewees.

Among the responses provided by single interviewees (research and development activities, keeping aware of BIM developments, creating 3D models, self-development activities by individuals, no steps are currently being taken) the two last ones equate to nothing being done at the firm level. The overall impression, therefore, is of a few, minor initiatives and, generally, that the interviewees are aware of very little being done towards the implementation of BIM within their firms.

5. Conclusions

The depiction of IT use and communications on Estonian construction sites gained from the interviews indicates that BIM use appears to have been primarily experimental to date. The Project Managers and Site Managers interviewed had some awareness and knowledge of BIM but little actual experience of it and clear, common steps towards BIM adoption by their firms were not apparent. There seemed to be a widely held view that BIM adoption on sites should be imposed and paid for by the client rather than evolving from internal needs and innovation.

Thus, it appears that BIM adoption has yet to convince the majority of Estonian project and site managers that it is cost and time effective – as one put it: *"It seems that paper on the wall is still the best solution at the moment."* However, benefits are expected from BIM in the future and there are undeniable changes including improved computer literacy, hardware and software that are enabling BIM adoption. The interviews also revealed the intense pressure felt by contractors' middle management to get on with the present job and this may be dissuading them from investing their time and effort for potential but uncertain efficiency gains in the future. *"If money and time weren't issues, I would of course make a model."*

It therefore suggests that interventions to promote BIM adoption on sites should focus on demonstrating clear efficiency gains and value for money without requiring major time and money investment. This initial research indicated numerous challenges including subcontractors' knowledge and capabilities, the considerable diversity between individual needs, views and expectations from BIM and relative satisfaction with existing, non-BIM methods. However, there was also some common ground in the form of the specific needs and current expectations for the future of BIM that were identified in the interviews. This provides an initial list of possibly fruitful areas for intervention including: clash detection, mistake avoidance, better planning, the improved accuracy and timeliness, more appropriate formatting and easier visualization of information.

The complexities implied by the revealed role, knowledge and capability differences among construction site stakeholders, as well as the current ways of working and the reasons why these are found to be advantageous suggest that a thorough examination of a specific construction site process would have to precede any BIM intervention design if it were to have any possibility for success. It is therefore recommended that further research would take the findings of this initial study into account in order to identify specific 'candidate' processes for BIM improvement interventions. These processes should then be studied in detail and on a specific site from the perspectives and with the collaboration of all the stakeholders involved in them. Experimental BIM interventions could then be collaboratively designed together with performance measurement indicators relevant to all the stakeholders prior to their deployment and subsequent evaluation. This suggests an action research approach would be appropriate in the first case to identify specific, problem-based interventions before more general BIM adoption recommendations could be made.

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Organising the Implementation of BIM: A Study of a Large Swedish Client Organisation

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Abstract

Building information modelling (BIM) is currently much discussed in the construction industry. It has been brought forward as a way to address the problems with slow increase in productivity perceived in the industry. To support and drive the industrywide implementation of BIM, many large public client organisations are currently in the process of implementing BIM. The purpose of this paper is to explore how a large client organization organises their BIM implementation. In order to reach this objective a case study of the BIM implementation process at the largest public infrastructure client in Sweden has been conducted. This case study is supplemented with interviews with the management of the implementation project together with interviews with project managers in pilot projects implementing BIM. Based on the results of this study, it has been found that the BIM implementation is mainly focused on the technical requirements to support the shift from traditional drawings, to object oriented information. How this shift towards object oriented information will influence changes to work practices is however not defined within this implementation project.

Keywords: BIM, building information modelling, implementation, causal structure

1. Introduction

Today, Building Information Modelling (BIM) is frequently brought forward as a way to address many problems in the construction industry. For many years the industry has been described as fragmented with problems of low increase in productivity (Egan, 1998 and NIST, 2004). In research, BIM is described as being able to provide several potential benefits as shown in studied pilot projects (e.g. Eastman et al., 2011). At the same time, the implementation of BIM within the industry has been very tentative and there is a view that BIM has not yet shown its promised benefits (Gustavsson et al., 2012; Jung & Joo, 2011, Fox, 2014).

The role of government and public actors in this implementation process has been discussed in BIM related research. This role has been described as a driving force towards BIM in many countries and as being critical for successful implementation (Wong et al., 2010, Wong et al., 2011). There is also a view that the industry has to be convinced of the importance of BIM adoption in order to drive implementation. Khosrowshahi and Arayici (2012) argue that there is a need for researchers in the field to intervene in order to reach higher levels of BIM maturity. Furthermore they present a roadmap for BIM implementation in the UK construction industry to address the disinterest currently found in parts of the industry (Khosrowshahi & Arayici, 2012). In many countries there are and have been BIM initiatives by the government. Several large public client organisations are starting to demand the use of BIM in order to drive development. In the UK for example, there is currently a demanding that all public contracts awarded from 2014 and onwards contain requirements that all project participants will work collaborative through the use of BIM (CabinetOffice, 2011:14). In Sweden several BIM related initiatives are being conducted, many public client organisations are defining their requests for BIM use in projects (BIM i Staten, 2014). In parallel with this process the Swedish Transport Administration, the largest Swedish client for infrastructure projects, is initiating their implementation of BIM. With the expressed goal of increasing productivity both in their organisation and the industry as a whole, they are aiming to implement BIM in all of their projects.

This argued importance of BIM connected with public actor's central role as driver for change highlights the relevance of studying this implementation process. The purpose of this study is to explore how the Swedish Transport Administration organises their implementation of BIM. With the objective of analysing how BIM is expected to influence organisational change, both internally as a client organisation and how other actors are expected to be influenced, this article studies the BIM initiative and the implementation process by this client actor.

2. Method

In order to explore how the BIM implementation process is organised within this public client organisation a case study of the 'BIM initiation project' at the Swedish Transport Administration has been made. This qualitative case study has focused on analysis of documents produced as a result of this project. Furthermore it has been supplemented with 4 semi-structured interviews with the management of the project together with 4 semi structured interviews with BIM responsible persons in the pilot projects most influential to the 'BIM initiation project'. The results from this case study has been analysed based on a literature review studying BIM implementation initiatives in other countries. This literature review has gone beyond the BIM field and studied research on the implementation of other IS/IT and how such implementation generates increase in productivity.

2.1 Delimitations

This study is limited to the analysis of the first stages of the BIM implementation process by a large Swedish infrastructure client. The studied process contains the initial implementation project by this actor which was later continued with two more simultaneous projects in different branches of the organisation. How the implementation process actually influences change is not part of this study. Rather this study focuses on how the BIM implementation is organised, the successfulness of this process will be analysed in later studies. That is to say, this paper does not analyse any actual increase in productivity, but rather focus on what steps this organisation took in order to implement BIM.

3. Literature review

BIM is described by many as a paradigm shift in the construction industry (Azhar, 2011). Several substantial benefits have been shown. In order to take advantage of the numerous potential benefits there are many barriers to BIM adoption that has to be bridged (e.g. Eastman et al. 2011), and implementation of BIM is described as a major managerial task (Khosrowshahi & Arayici, 2012). Not only technical solutions are required, rather, there is a need for corresponding changes in work practices and skill sets of the project participants to be made (Froese, 2010). In addition to these changes, substantial changes in business practices and rearrangements of contractual agreements are needed (Mihindu & Arayici, 2008; Succar, 2010; Tylor, 2007). The BIM concept is also unprecise; it can be implemented and used in many different ways, on many different levels. Each of these levels of BIM-use presents different possibilities combined with various challenges in order to achieve successful implementation (Succar, 2009). To achieve BIM implementation at higher maturity levels there is a need for proper implementation at the organisational level together with its integration at the industry level (Khosrowshahi & Arayici, 2012). It is also suggested that the greatest gains can be found at these higher levels of BIM maturity (Khosrowshahi & Arayici, 2012).

3.1 The role of public actors

Client organisation has been argued to be the actor who benefits the most from BIM implementation (Eadie et al., 2013). It is also the actor, together with the main contractor, who is in power to demand compulsory BIM use (Linderoth, 2010). The adoption of BIM is also perceived as slow within the construction industry (Gu, 2010, Smith 2014). An unwillingness to adopt BIM has been observed, firms are satisfied with continuing using traditional CAD (Khosrowshahi & Arayici, 2012). Together, this has open for suggestions that public client organisations and governments should intervene and support BIM use. A study by Wong et al.

(2011) stated that “the role of the government is critical in the implementation of BIM in any country”. It is also argued that government mandates demanding BIM in their projects is effective in driving implementation (Smith 2014). These types of initiatives are taking place in many different countries, where the different governments are involved with setting up BIM policies (Wong et al. 2010).

Several papers discuss how BIM implementation rates can be increased in the construction industry. Wong et al. (2011) presents six steps for BIM implementation by the government. The initial step is the need for a specific BIM policy, establishing BIM as something that should be implemented and used in all new projects. Further these steps focus supporting BIM-use by external actors, such as contractors and consultants, thereby enabling inter-organisational use of BIM (Wong et al. 2011). One major issue is interoperability between different software and formats, governments have been shown to be able drive the development towards more open standards to increase interoperability (Porwal & Hewage, 2013). Khosrowshahi and Arayici (2012) state that education and awareness about BIM is critical to address resistance to change. Further they state, as BIM implementation is often supplemented with process improvement, a need for support services for actors implementing BIM processes in their organisation.

3.2 Information technology and increased productivity

The main reason for the BIM interest is the expected increase in productivity. Such an influence on productivity has been shown in several case studies (e.g. Azhar, S. 2011; Eastman et al. 2011). The actor who is expected to acquire the greatest benefits is the client (Eadie et al., 2013; Olofsson et al., 2008), and this has been brought forward as one more argument for letting the client organisations drive the BIM implementation. However, the extent of the benefits following BIM implementation is discussed and has been questioned (Gustavsson et al., 2012; Jung & Joo, 2011; Fox, 2014).

The link between implementation of new information and communication technology (ICT) and increased productivity has been described in many different contexts. How investments in ICT influence the productivity of an organisation has been described as the “productivity paradox”, where these investments generate little or no increases in productivity (Brynjolfsson, 1993). This paradoxical connection has been suggested to stem from several different reasons for example, difficulties to measure influences of ICT and mismanagement of implementation and use of new systems (Brynjolfsson, 1993). In later studies Brynjolfsson and Hitt (1998) problematizes the concept of the “productivity paradox”. They argue that the use of ICT does not increase productivity by itself; rather, it is an essential part of a wider context of organisational changes which in turn influences productivity positively. A major part in the value of ICT is its ability to enable further investments in the organisational layout adapting business processes and work practices to the new possibilities (Brynjolfsson & Hitt, 2000). There can be found similarities between the earlier ambiguities in the link between ICT and productivity and the interest for BIM in the construction industry of today. Many potential benefits with BIM implementation have been presented and several studies presenting case-studies indicating positive outcomes of BIM-use in projects (Eastman et al., 2011). However there is still ambiguity in how this BIM use influences the productivity of the industry. The implementation and use of BIM is currently tentative within the industry and its promised benefits have not yet been shown (Gustavsson et al., 2012; Jung, & Joo, 2011). It has been argued that there is currently hype around the concept of BIM, further that this hype can lead to suboptimal decisions throughout implementation projects (Fox, 2014).

3.3 Casual structure – information technology and organisational change

The connection between information technology and organisational change has been of interest for many decades. Markus and Robey (1988) describe how there are several different theories describing the link between information technology and organisational change, but these theories are argued to have problems with reliable generalisations regarding this relationship. Further their study describes the causal structure of these theories as composing of three dimensions: Casual agency, logical structure and level of analysis.

Casual Agency:	Logical Structure:	Level of Analysis:
· Technological Imperative · Organisational Imperative · Emergant perspective	· Variance Theory · Process Theory	· Macro · Micro

Figure 1: Dimensions of Causal Structure (Markus and Robey, 1988)

Causal agency – describes the assumptions about the causal agent and the direction of influence of this agent. The 'technological imperative' views technology as the causal agent which determines the behaviours of individuals in the organisation. The 'organisational imperative' views the human individuals within the organisation as agents of change. The 'emergent perspective' finds causality in complex interactions between technology and human actors within the organisation.

Logical structure – describes the relationship between elements identified as precursors and those identified as outcomes. 'Variance theory' views specific precursors as essential and sufficient to achieve outcomes. 'Process theory' however, assumes that the precursors necessary to achieve certain outcomes, but insufficient to cause them.

Level of analysis – describes the level at which theories describes the impact of information technology, and is generally either: individuals, organisations or society.

Depending on the casual agency of how information technology is predicted to generate change different strategies of how to manage the change in an organisation follow. With the ‘technological imperative’ implementers focus on the choice of information technology and its technical requirements. When the correct technology is in place and working organisational change is expected to follow. Following the ‘organisational imperative’ focus tend to be on the allocation of resources and improving implementation strategies while the results of the implementation is perceived to stem from the behaviour of managers and system designers. The ‘emergent perspective’ finds predictions of implementation impossible and to support changes extensive participation of the analysis, design and implementation by the people involved can be advised. (Markus and Robey, 1988)

4. Results

The Swedish Transport Administration is the public actor responsible for long term construction, operation and maintenance of roads and railways in Sweden. The organisation is also designated to, in its role as client, to work towards increasing productivity both for its own investments and also in the branch on the construction industry related to infrastructure (SFS 2010:185). The interest for BIM by the Swedish Transport Administration was initially brought forth in a strategy document by the Swedish government emphasising the possibilities with the use of ICT. This document was presented in late 2011 and presented the government’s aim to establish Sweden at the forefront in regards to taking advantage of the possibilities with digitalization. In a Swedish government official report in 2012, these ambitions were concretized in regard to the infrastructure sector (SOU 2012:39). This report explored ways of increasing productivity and innovation in this sector. Building information modelling takes up a large part of this report and it is expressed that BIM has large potential to increase performance for the Swedish Transport Administration. In 2013 the Swedish Transport Administration initiated a project to begin structured implementation of BIM in their organization, the ‘BIM initiation project’. According to the project specification, this project is an answer to the guidelines given by the Swedish government and to increase productivity and innovation both for the client organisation but also for the industry as a whole. At the time, BIM was explored and used by an unstructured network of projects managers at the Swedish Transport Administration. The initiatives were driven by interested project managers and not coordinated by the mother organisation. The ‘BIM initiation project’ was the first coordinated step towards BIM by this actor.

4.1 The BIM initiation project

According to the project specification the ‘BIM initiation project’ was initiated 2013, with the following goals:

- All new projects in the ‘investment’ department uses BIM to some extent from 2015 and onwards. These projects make an active choice concerning BIM based on predefined levels.

- Make the work processes more efficient and thereby saving approximately 150M SEK to the end of 2015

- Make the Swedish Transport administration a client with an obvious demand for BIM both in design and construction.

The project aimed to address the possibilities and suggestions presented in the governmental official report, but also the organizations ongoing assignment to lead innovation within the infrastructure industry. The project was scheduled to end in 2015 and at that time introduce BIM-supported work practices in all projects initiated thereafter. According to the ‘strategy for BIM implementation’ presented by The Swedish Transport Administration within the ‘BIM implementation project’, BIM is described as: “the use of information models in a continuous flow through the main processes connected with a constructed facility”. Further it is expressed that the information produced in these processes could be used for multiple purposes, for example: clash control, analysis of different design alternatives, cost calculations and time scheduling. Combined, these benefits are expected to result in a more efficient work process. The BIM concept is described as being related to three different aspects: *Product* – The planned and constructed project, *Organisation* – The actors, planning constructing and maintaining the facility and *Process* – The work process which the organisation follows in their work.

4.2 Pilot projects

Within the ’BIM initiation project’ there were planned a total of 28 pilot projects. These projects were of varying size and complexity and were supposed to reconnect to the BIM initiation project and transfer knowledge of experiences of how BIM had been used in these pilot projects. According to interviews with several of the project managers in some of these projects, there are large differences in how BIM was used. The extent by these pilot projects influenced the ‘BIM initiation project’ also varies a lot. These pilot projects can be divided into three different groups:

- Projects using BIM extensively. These projects began their BIM use before the ‘BIM initiation project’ was started. Generally large projects with large interest for BIM within the project organization.
- Projects using BIM to some extent following the BIM initiation project.
- Projects not using BIM at all.

Among these projects the first category has been the most influential in regard to impacting the results of the BIM initiation project. In this category there are mainly two very large projects that distinguish themselves. According to the technical manager in one of these projects, much of the material presented by the ‘BIM initiation project’ was based entirely on documents produced in this project.

4.3 Results from the BIM implementation project

At its finish the ‘BIM initiation project’ resulted in a total of 32 documents, these documents contained changes to guidance documents and templates for e.g. meeting agendas. Most of these documents manly changed the templates to include ‘BIM’ and ‘models’ rather than ‘drawings’.

In addition to these documents there are three documents describing the use of BIM within the organization. All these documents went through a referral process within the organisation before they were reworked, resolved and incorporated in the project process by this actor.

General guidelines for BIM in projects – This document seeks to manage and support the use of BIM in new projects and ensure that BIM satisfies the goals presented in earlier visions. Within this document, changing roles and responsibilities following BIM implementation is described. The project manager in every project will be responsible for: (1) assuring that BIM will be used in a current extent to ensure efficient information management (2) ensure that the project organization reserves education regarding BIM and (3) to define BIM in relation to the specific project. This document also describes a ‘base level of BIM’ that should be fulfilled in all construction projects. There are however room to increase this level and use BIM at a larger extent in projects where it is deemed suitable.

Tutorial document for BIM-use in projects – This document is supposed to provide guidance for the actor responsible for BIM-use in the project (BIM-coordinator for example). It provides recommendations and descriptions of BIM and how it can be used in relation to process, organization and product. The document supports BIM-users and is supposed to be used as a compliment to other guiding documents.

Requirements on object oriented information – This document defines how information should be generated and managed to ensure use of object-oriented information in projects in a life cycle perspective. The document contains demands on technical aspects of the generation of object-oriented information and is supposed to be used in procurement processes. These are demands that should be used both in-house but also in contracts with external contractors. The document defines the file formats for exchange of model based information between actors to be DWG (AutoCAD) or DGN (MircroStation). Information should be classified according to BSAB 96 (Swedish standard).

Among the documents presented by the ‘BIM initiation project’ there is a focus on the technical aspects. How models should be produced and shared and what types of file-formats that can be used are well described. The documents regarding this information is categorised as requirements. On the other hand, the work practices when using these models are described more vaguely, with large degrees of freedom for the project managers in the actual construction projects. These documents are categorised as general guidelines or tutorial documents.

4.4 ‘Base level’ of BIM

The ‘base level’ of BIM defined by the ‘BIM initiation project’ is supposed to be used in all projects. As the description of the BIM concept, this ‘base level’ of BIM relates to both: *Product*, *Organisation* and *Process.* This level of BIM is defined in a list of 17 points supposed to be fulfilled in all projects. This level of BIM emphasises on enabling the shift towards an object-oriented work-practice, the use of models to ensure the quality of information. The ‘base level’ of BIM is presented as changing the current practice of presenting project related information in drawings, lists and descriptions into an object-oriented practice. Information should be stored in one or multiple models instead of the traditional alternatives. The details of this lowest level of BIM is affected both by the technical limitations such as problems with interoperability as well as organisational preconditions both internally and externally where lack of experience with the new work-practices is argued to hinder the implementation. The Swedish Transport Administration describes BIM as a structured way of managing information of good quality related to a constructed facility. With BIM this will give an unbroken information flow throughout the whole lifecycle of the constructed facility. This holistic perspective is said to bring conditions to minimise costs and time in: planning, design, construction and maintenance of the facility.

According to the BIM-coordinator in one of the most influential pilot-projects this base level of BIM implementation is a compromise between what is possible to achieve in the industry with the current level of BIM experience and possible benefits with BIM use. This level is further presented as an enabler for actors, wanting to use the collaborative aspects of BIM. By demanding models as a client, models can be available for exchange between contractors and consultants, supporting BIM oriented work practices by these actors.

5. Analysis

Prior research argues that the main role of public client organisations is to demand BIM use in their projects, thereby forcing other actors in the construction industry to adopt BIM if they want to continue to work for these clients. The BIM initiative in Sweden very closely resembles what other studies have found governments and public clients are doing in other countries. In order to increase productivity and innovation the Swedish Transport Administration is promoting the use of BIM. Similar to for example the UK, the Swedish Transport Administration is developing demands stating that project related information should be delivered in object oriented formats, de-facto demanding BIM-use. There is a view within the 'BIM initiation project' that, by following these requirements contractors and consultants are enabled to work collaboratively with the new possibilities that BIM enables. As in some BIM related research the 'BIM initiation project' assumes that such BIM requirements will result in higher BIM use in the industry. However, as studies by Brynjolfsson and Hitt, (2000) have concluded, in order to achieve the full potential of new IS/IT solutions there are a need for organisational change. It has been described that changes to work practices, enabled by new technology, is generating the sought after increases in productivity, rather than the technology itself. These conclusions are in line with research on BIM implementation describing the guidelines for high level BIM implementation. For example, Khosrowshahi and Arayici (2012) described the need for an effective implementation strategy as BIM requires substantial changes to how construction business is conducted.

As described by Markus and Robey (1988) there are many different theories describing the relationship between implementation of new technology and organisational change. Depending on the causal structure of the theory chosen, different focus will be taken and different results are expected. The 'BIM initiation project' by the Swedish Transport Administration is described as a structured first step towards implementing BIM in all new projects initiated by the organization from 2015 and onwards. The main deliverable from this project is the documents with proposed changes to how projects should be conducted. These documents mainly focus on the technical preconditions needed in order to use BIM. The technical requirements for how ‘object based models’ should be produced and managed. This information is described in detail within the requirement document, defining formats etc. The requirement document (Requirements on object oriented information) is supposed to be referred in the tender templates used in all newly started projects. Thereby, this document influences how information is managed in projects. A ‘basic BIM’ level, which should be used in all projects, is defined. This ‘basic level’ mainly focuses on a shift from drawings to models in order to support object oriented work practices. However, how these models should influence changes to work practices in projects using BIM is not focused upon. Instead the responsibility for these changes is delegated to each responsible project manager in the respective projects.

The results from the ‘BIM initiation project’ are based extensively on input from the pilot projects connected to this BIM implementation project. These projects differ widely in extent of BIM use. Most of the smaller projects on the list do not use BIM at all or at a very limited extent. The two large projects used BIM even before the ‘BIM initiation project’ started and it is mainly experiences from these projects that have influenced the referral material produced in the ‘BIM initiation project’. The individuals responsible for BIM in these projects have an extensive insight and knowledge in how BIM is and can be used as well as how it can influence work practices. This is however not defined and stored in the documents presented by the ‘BIM initiation project’. The importance of training in relation to BIM implementation presented by e.g. Khosrowshahi and Arayici (2012) is not addressed in this implementation project.

6. Conclusions

With the opinion that governments and public actors should drive BIM implementation it becomes relevant to study how these actors organise the implementation processes. Based on the study of the ‘BIM initiation project’ by the Swedish Transport Administration, it can be argued that this actor organises their BIM implementation based on the ‘technological imperative’. The technology is viewed as a causal agent for organisational change; in this case the use of object oriented models is expected to act as a driving force towards change in work practices. Following this view of BIM, the focus in this implementation process has been on ensuring the right preconditions for enabling a shift towards using object oriented models to store and manage information. The use of a ‘basic BIM level’ which should be used in all projects is expected to act as driving force for changing work practices. The project manager in infrastructure projects is given the role of change agent, responsible for ensuring the use of BIM within their projects. The ‘technological imperative’ view of BIM implementation addresses some of the barriers described in research in regards to the slow implementation of BIM. For example the issue of BIM training is not as well discussed in this stage of the BIM implementation by this actor. By demanding models as deliverables in construction projects there will have to be a shift towards producing models. However, this view does not address many other barriers in relation to BIM implementation. In order to evaluate which ‘causal structure' is most suitable in relation to BIM implementation, further research should study the results BIM implementation initiatives and relate them to the implementing actor's view of BIM in terms of causal structure.

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A Predictive Semantic Inference System Using BIM Collaboration Format (BCF) Cases and Machine Learning

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Abstract

Building Information Modelling (BIM) has been hailed as an artefact of collaboration, where all project participants are able to create, modify and implement design/construction configurations within the same virtual environment codified by International Foundation Classes (IFC). To facilitate communication between human participants during project development, the BIM Collaboration Format (BCF) was developed, enabling users of BIM applications to communicate issues and refer those to specific objects. A single BCF entity holds a textual description of the issue, a status, links to a BIM IFC model and objects, a picture of the issue, and a camera orientation. Therefore, BCF poses a rich repository of complex fuzzy semantic knowledge concerning design risks, such as change requests and rework proposals, in a readily accessible format based in the XML schema. This research investigates how data in BCF files can be extracted, and processed using a linear algebra method known as singular value decomposition (SVD). SVD is extensively used, along with dimensionality reduction, for pattern recognition applications and has been shown to infer semantic correlations amidst a variety of different unstructured data (e.g. texts, images, signals etc.), comparable to that of human cognitive associations. Consequently, a dynamic knowledge-base is established of past BCF cases, whereby designers can flexibly query and systematically retrieve most relevant past issues and related objects, given any known current parameter – reminiscent of how a human may recall past experiences upon inquiry or design review. This paper introduces the BCF structure, describes the machine learning steps taken to extract and process BCF data, and presents the conceptual framework of a queryable knowledge-discovery system. This allows for relevant past issues to be recalled and the knowledge integrated in future designs as problem- and change-prediction. It is of particular pertinence for users of BIM, in sight of the ever-growing masses of BCF data generated from project to project.

Keywords: BIM collaboration format, singular value decomposition, latent semantic analysis, change management, knowledge management.

1. Introduction

Design changes are very common in the building industry, where dynamic feedback, due to iterative cycles, are ubiquitous (Lyneis, Cooper, & Els, 2001). Change is a major cause of delay, disruption, and disputes (Motawa, Anumba, Lee, & Peña-Mora, 2007). Furthermore, it is hard to predict changes in construction projects, given the uniqueness of each project and the limited resources (Hanna, Camlic, Peterson, & Lee, 2004). There is thus an obvious need to better manage change, as well as to garner competence to predict and avoid unnecessary changes early during the design stage. The one-off nature of construction projects have often been used to justify unpredictable changes, however, even in such contexts many repetitive issues occur from project to project. Many of such potential change issues could well have been anticipated in advance and thus avoided given the tacit knowledge of experienced designers, and close collaboration between different design parties.

In the advent and increasing adoption of Building Information Modelling (BIM), the design reviews and change issue prediction are often done in the BIM environment. BIM is used to produce building models of different aspects of the building: architecture, structures, plumbing, heating, air-conditioning, and so on (Eastman, Teicholz, Sacks, & Liston, 2011). Therefore during the design, multiple interrelated models are produced in individual design tasks by different disciplines/parties. This creates great a challenge for the management of change across different models, in sight of change prompts and requests for information (RFIs) from both designers and contractors on site.

In recent years, the introduction of the BIM Collaboration Format (BCF) into the BIM ecosystem has enabled an additional layer of semantically rich communication between different project participants. It introduces a workflow communication capability connected to models based in the International Foundation Classes (IFC). The idea is to separate the "communication" aspects from the actual model. In particular, it was envisioned to enable the conveyance of RFIs, proposals, change prompts, or other queries/requests related to the model, collectively referred to as *issues*. It was also to allow such issues to be exchanged in collaborative work without the need to transfer the whole BIM-model as bulk data, as in the past. The BCF is an Open BIM standard format developed by BIM companies Solibri and Tekla in 2010 as "bcfXML v1", and later "bcfXML v2" became released in October 2014 and adopted by BuildingSMART (BuildingSmart, n.d.).

The BCF presents a repository of semantically rich issues of change-related knowledge. Alluding to knowledge management concepts of Nonaka & Takeuchi (1995), the BCF presents a codified form of, otherwise tacit, knowledge, which can then be *internalized* by the designers to be applied in value creating work, as part of the knowledge management lifecycle. However, *internalizing* these issues as human practitioners currently requires much time and effort as it occurs organically through the acquisition of experience dealing with such change cases from project to project. In order to aid this process, this study proposes the mining/extraction of textual natural language descriptions in BCF issues and process the dataset using the machine learning textual processing technique known as latent semantic analysis (LSA). LSA is based on a linear algebra operation called singular value decomposition (SVD) and has been shown to infer conceptual links amid natural language texts comparable to human semantic intuition (Landauer, McNamara, Dennis, & Kintsch, 2007) and similar techniques have been used in a variety of other pattern recognition problems (Deerwester, Dumais, Furnas, Landauer, & Harshman, 1990). This allows the matching of texts on semantic/conceptual level rather than explicit string matching used in word search-functions, where semantic relationships between texts are not involved. This ability of LSA is cardinal in managing and retrieving possible future change cases, where different building elements may be related to each other through different types of issues qualified by a variety of parameters. Consequently, this enables change cases to be automatically captured and stored in such a way that future designers are able to effectively query the system for past similar and/or related issues. This helps to enhance the designers' capacity to learn or *internalize* historical change-related knowledge and thus improves future design decisions in avoiding change.

In the Section 2 we cover some preliminaries regarding the background and mathematical basis of the latent semantic analysis method. Section 3 describes the methodology applied in our particular case, the nature of the textual *issue* descriptors extracted from the BCF of a specific project, and the pre-processing steps taken before the analysis. We then discuss the results in Section 4 with reference to other potential developments. Section 5 concludes by drawing up a brief summary and reiterating the value of our proposal in the BIM-based design change management context.

2. Theoretical preliminaries of LSA and SVD

Latent semantic analysis (LSA) is a techniques for creating vector-based representations of texts, which are claimed to capture their semantic content. The primary function of LSA is to compute the similarity of text pairs by comparing their vector representations, and has been shown to closely match human capabilities on a variety of tasks. It extends the vector-based approach by using Singular Value Decomposition (SVD) to reconfigure the data.

2.1 Pre-processing

LSA starts with a text quantification method based on what is known as Vector Space Model (VSM) (Salton, Wong, & Yang, 1975), where a corpus of d documents using a vocabulary of t terms is used to compile a t x d matrix **A**, containing the number of times each term appears in each document (term frequencies). Some trivial terms such as "the", "of", etc. (the stopwords) are excluded, and some others are consolidated, because they share a common stem (Porter, 1980) or some other lexical quality. The frequency counts in **A** typically undergo some transformation (term weighting) known as TF-IDF that penalizes common terms and promotes rare ones. After weighting, the term frequencies are also normalized so that the sum of squared weighted term occurrences within each document is equal to one (Salton, 1989). Subsequently, **A** is subjected to Singular Value Decomposition (SVD).

2.2 Singular Value Decomposition

Matrix **A** of dimensions *t* x *d* is decomposed into the product of three other component matrices **U** (*t* x *t*), **S** (*t* x *d*) and $\mathbf{V}^{\mathbf{T}}$ (*d* x *d*), that is, $\mathbf{A} = \mathbf{USV}^{\mathbf{T}}$. **U** columns consist of the *term* eigenvectors, and **V** columns are the *document* eigenvectors, and **S** is a diagonal matrix of singular values (i.e. square roots of common eigenvalues between terms and documents). In other words, matrix **U** describes the original **A** row entities as vectors of derived orthogonal factor values, matrix **V** describes the original **A** column entities in the same way, and the middle **S** matrix is a singular diagonal matrix containing scaling values in descending order along the diagonal of the matrix. When the three component matrices are multiplied the original **A** matrix can be reconstructed. The **U** and **V** matrices are thus regarded as all the constituent patterns that determine the original matrix **A**. The columns in **U** and **V** are orthonormal vectors that describe these patterns and are arranged in descending order of significance.

2.3 Dimensionality reduction

Dimensionality reduction is carried out in order to remove noise (small irrelevant patterns) inherent in natural language. This step is done by removing column vectors from **U** and **V** starting from the least significant, and retaining the most significant vectors. This corresponds also to the same number of diagonal singular values retained in the **S** matrix. The reconstruction of the truncated/reduced component matrices produces another matrix (essentially an approximation of matrix **A**), which exhibits latent semantic relationship between words and documents not evident in the original matrix **A**. The number of dimensions to keep is a difficult question as it depends on how much of the original variance is desired to be kept without loss of relevant data. In linguistic terms, it is difficult to interpret intuitively. However, many case-specific guidelines are given within different contexts. A very common technique is to plot the square of singular values of the **S** matrix against the number of dimensions (Sidorova, Evangelopoulos, Valacich, & Ramakrishnan, 2008). One may choose the number of dimensions corresponding to where the singular values decrease substantially (elbow of the graph) indicating the point where the patterns become insignificant. Generally, the more noise is removed (dimensions reduced), the clearer will the semantic relationships be revealed in the reconstructed approximate matrix.

2.4 Cosine similarity

The reduced **U** and **V** row vectors represent the semantic space of the words and documents. Thus a similarity function can be used to measure semantic correlations between term-term, document-document, and term-document relationships. The cosine similarity function tends to work well empirically (Landauer et al., 2007) and is widely used for vector matching in many applications. Cosine similarity is denoted by the cosine of the angle between two vectors (suppose vectors *a* and *b*) and can be calculated by dividing the dot product of *a* and *b* by the product of their magnitudes, that is, $a \,.\, b \,/\, (\, \|a\| \, \|b\| \,)$.

3. Methodology

Broadly, this study involves the automatic extraction of natural language information from BCF issues and processing it using latent semantic analysis. This is used to demonstrate how higher level semantics and linked data may be inferred automatically from existing data or documentation embodying some level of professional knowledge. The semantics inferred can then be fed back to the workflow to augment the knowledge of practitioners for future work. The BIM data acquired for this study is from a large renovation project of a heritage complex in downtown Helsinki, and the BCF issues thus reflect the nature of changes accordingly - predominantly related to mechanical, electrical, and plumbing (MEP) services. The steps of this study are covered in the subsections below.

3.1 Extract issues from XML schema of BCF

As described in Paasiala et al. (2015) a BIM Collaboration Format v2.0 formatted bcfzip file contains a folder for each issue. The issues correspond to proposals and change requests in BIM-data-models (BuildingSmart, n.d.). Each folder contains a markup.bcf file that embodies textual information about the issue, a viewpoint.bcfv file that specifies the related elements, the viewpoint, and the camera angle, and snapshot.png pictures describes the issue.

Only markup.bcf files contain human written sentences. In that XML file, although title and description tags can contain clauses, in practice, only comment tags had any content. A small program was written in the Java programming language to extract the comments from the files. The full source code of the program is available in (Oraskari, 2015). When extracting the bcfzip file, the program follows the first steps that was presented in (BIMServer, 2015). However, instead of marshalling the XML documents into Java objects, we parse the files using a JDOM XML parser (Hunter & Lear, 2015). The XML document tree of the markup.bcf is traversed recursively. Whenever there is a comment tag in the graph, the content is copied. A total of 71 passages of text from BCF issues were extracted as natural language descriptions for each issue logged by human project participants.

3.2 Textual parsing and term-document matrix

The extracted text passages (documents) are then parsed into words. The words are filtered in order to remove stopwords – such as “the”, “a”, “an”, “is”, “in” etc. – that supposedly do not contribute to the semantic value of each document. A standard “stoplist” is used for the English language. The words then undergo morphological stemming, where the words with different morphological conjugations would be reduced to the root of the word. For instance, “ventilate”, “ventilating”, “ventilated” etc, would be reduced to be the same stem or root of the words. As an example, the document “Office area: Electric duct location? Radiators hot water piping penetrates electric duct” are parsed into the following terms: “are”, “duct”, “electr”, “hot”, “locat”, “office”, “penetr”, “pipe”, “radiat”, “water”. The resulting words are now considered the terms in the term-document matrix (t x d), consisting of the occurrences of term t in document d.

The term-document matrix is transformed through TF-IDF (term-frequency, inverse document frequency) weighting to enhance the discrimination between documents, by discounting the weight of very common terms and promoting the weight of less occurring terms (Salton, 1989). The term-document matrix's raw occurrence values are replaced by the product, $\boldsymbol{w_{td} = tf_{td} * idf_t}$, where $\boldsymbol{tf_{td}}$ is the normalized term occurrence in each document *d*; and $\boldsymbol{idf_t = \log(N/df_t)}$, where **N** is the total number of documents in the collection, and $\boldsymbol{df_t}$ is the number of documents that contains term *t*. After TF-IDF weighting, the document vectors are normalized to remove the advantage that longer documents have over the short documents. Cosine normalization is an effective normalization technique and is computed, by dividing the TF-IDF weights by the Euclidean length of the respective document vector (Salton, 1989).

3.3 SVD, dimensionality reduction, cosine similarity, and query

The term-document matrix (*t* x *d*) undergoes singular value decomposition to yield the **U**, **S** and **V** matrices. Effectively, the terms and documents are vectorised and transformed or mapped to the same vector-space through dimensionality reduction. To choose how many dimensions to retain, the squares of the diagonal values of the singular **S** matrix are plotted against the number of dimensions (the number of singular values to retain) as shown in Figure 1. The number of dimensions to retain is chosen to be 13, after which the graph starts to flatten out, indicating that the patterns before dimension 13 contributes most to the variance of the original matrix **A**. Singular values after dimension 13 is therefore assumed to constitute "noise".

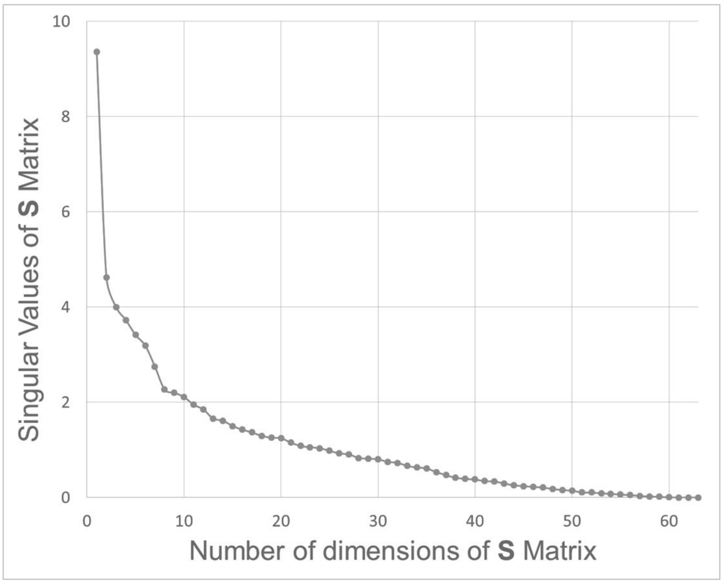

Figure 1: Plot of squares of singular values against the number of dimensions

3.4 Cosine similarity and query

The terms and documents can now be represented as vectors of 13 dimensions, as the rows of the reduced **U** and **V** matrices respectively. The similarity between any two vectors can thus be computed (through cosine similarity as earlier explained). If the two vectors are identical, the cosine similarity is 1 since the angle between them is 0°. Vectors that are totally uncorrelated has a cosine similarity of 0 (angle 90°), while cosine similarity of -1 implies that the two vectors are total opposites (angle 180°) or inversely proportional intuitively. The cosine similarity between vectors of the reduced **U** and **V** matrices equates to semantic similarity between them. Since this process is automated, it allows the system to calculate similarities upon query and recommend similar terms or documents from the database. The query is achieved by creating a pseudo-document consisting of a set of terms as query input. This pseudo-document can be represented as an explicit vector (q) of term occurrences, which can be mapped to the semantic space. The semantic query vector (q_s) can be obtained, through a simple algebraic manipulation following $\mathbf{A}=\mathbf{USV}^{\mathbf{T}}$, to be $q_s = q^{\mathrm{T}}\mathbf{US}^{-1}$. Cosine similarity can then be applied to gauge the similarity between the query vector q_s and all the other semantic term and document vectors represented by the dimensionality reduced rows of **U** and **V** matrices.

4. Discussions

In principle, the cosine similarity values between term and document vectors depends on the degree of correlations between the row and column spaces of the original **A** matrix, in particular, how co-occurrence of terms within the same documents indicates some level of relationships between these terms. The fundamental concept of semantic inference in human text is that similar/related terms would have much higher co-occurrence within documents than unrelated terms. For instance, considering the hypothetical corpora consisting of all of human literature, it is understandable that the terms "pear" and "apple" would have a much higher chance of occurring together in the same sentence, than "pear" and, for instance, "radiochemistry", to name an arbitrary example. The semantic meaning of certain terms, and their potentially numerous metaphorical or ambiguous nuances in natural language, can be qualified by other terms that occur together with it. In the same way, a semantic space can be established for domain knowledge, such as design change issues in this case, and co-relationships between the constituents of these issues can be automatically inferred, even to reveal non-apparent associations. To demonstrate the logic, some results of the analysis are shown with more specific detailed discussions covering the interpretation of the output of the proposed data extraction and latent semantic method on change issue management, integrated in BIM.

4.1 Interpretation of query and matching

Queries can be made to the system by inputting any number of terms. Some arbitrary query and results are shown in Figure 2. One- and two-term queries are shown and the top 10 semantically related documents (issues) are tabulated. One can very quickly use simple data visualizations to gain an overview of the nature of the spectrum of issues with relation to specific concepts. For instance, issues related to "corridor" are high in similarity though not as spread out as say "window", which seems to have one very similar issue, while the rest are spread out. Issues related to "electric cable" and "ventilation ducts" do not have as high semantic similarities as others, implying that even though the issues related to both concepts are widespread, they are not very specific. "Ablution area" has quite a few issues that are very semantically relevant, but not as widespread as the others. Such a table gives a strategic view about the how common certain issues occur with respect to specific concepts queried by the user, as well as how much semantic similarity there is between the issues and the queried concepts. This poses a suggestive function for the user to gauge the likelihood that certain change issues may arise in a new project given certain parameters as concepts to query the historical knowledge.

"Electric cable"		"Ventilation ducts"		"Ablution area"		"Windows"		"Corridor"	
Issue24	0.664	Issue54	0.747	Issue57	0.909	Issue53	0.851	Issue1	0.857
Issue62	0.618	Issue33	0.697	Issue68	0.902	Issue50	0.657	Issue27	0.805
Issue63	0.588	Issue11	0.683	Issue67	0.775	Issue44	0.617	Issue28	0.777
Issue38	0.544	Issue65	0.643	Issue60	0.767	Issue54	0.591	Issue7	0.682
Issue39	0.538	Issue70	0.603	Issue16	0.648	Issue30	0.575	Issue36	0.607
Issue8	0.532	Issue53	0.560	Issue14	0.353	Issue14	0.540	Issue20	0.576
Issue57	0.424	Issue50	0.545	Issue44	0.302	Issue11	0.493	Issue49	0.454
Issue32	0.400	Issue71	0.540	Issue17	0.290	Issue65	0.446	Issue18	0.315
Issue20	0.334	Issue15	0.527	Issue49	0.226	Issue67	0.431	Issue11	0.296
Issue2	0.318	Issue38	0.480	Issue19	0.195	Issue70	0.320	Issue59	0.275

Figure 2: Top 10 semantically related document/issues with respect to specific concept queries

"Electric cable"		
Issue24	0.664	Technical area: Electric cable tray through ventilation duct
Issue62	0.618	Technical area: Electrical box through ventilation pipe and ventilation pipe through cable tray
Issue63	0.588	Technical area: Cable tray through sewage pipe
Issue38	0.544	Business area: Electric cable tray through ventilation duct
Issue39	0.538	Business area: Electric cable tray location
Issue8	0.532	Technical area: Electric cable tray penetrates inside ventilation pipes
Issue57	0.424	Ablution area: Electric cable tray underneath the ceiling
Issue32	0.400	Sewage drain through electric cable tray?
Issue20	0.334	Corridor area: Electric cable tray through the hot water pipe
Issue2	0.318	Office area: Electric duct location? Radiators hot water piping penetrates electric duct

"Windows"		
Issue53	0.851	Window and ceiling height? Architect model space object is missing
Issue50	0.657	Social area: ventilation duct door and water drain are at the same point. Floor is missing.
Issue44	0.617	Lobby area: ventilation piping in the same place as the front surface of the ceiling
Issue54	0.591	Ventilation duct and ventilation terminal clashes with electric duct and cooling pipes. Space object is missing
Issue30	0.575	Display area: Radiators in front of windows and door
Issue14	0.540	Stairwell: modelled staircase elevations dimensions?
Issue11	0.493	Drainage pipe penetrates ventilation ducts.
Issue65	0.446	Utility area: Cooling coil penetrates ventilation duct and electric cable tray
Issue67	0.431	Stairwell: ventilation duct is underneath the ceiling and goes through the building structure
Issue70	0.320	Technical area: Cooling pipe and electric cable tray penetrate the ventilation duct

Figure 3: Full issues semantically similar to queries: "electric cable" and "windows"

Figure 3 tabulates more detail about the "electric cable" and "windows" queries for further interpretation. For "electric cable" the top 10 semantically similar issues all contain some form of the terms "electric" or "cable", but it doesn't necessarily need to be the case, as the system uses "concept matching" rather than "string matching". Nevertheless, it is of course expected that issues explicitly containing the query terms would have high semantic similarity. A few explanations need to be given for how the issues are ranked for "electric cable". One sees that cases to do with clashes with ventilation related elements seem to be placed higher than other issues related to electric cables. This is due to the terms being weighted differently. "Ventilation" related terms appear many times in the corpus, so much so that the weight of those terms have been reduced as they are deemed non-unique (through TF-IDF and normalization). Therefore the contribution of "ventilation" to the semantic value of the issue is low, thus leaving the semantic weights of the electric cable to be prominent in that specific issue. A bit lower down (Issue57, 32, and 20 for instance) all contain "electric cable", but because of the contributing semantic weight of the other related elements, the share of the weight of "electric cable" is reduced with respect to the issue. Therefore, as one can see, the method is able to cater for different semantic weights of terms and aggregation of terms to match whole issues to a concept, and not merely wherever a term appears within an issue. This is the property of LSA that allows latent semantic traits of passages of texts to be identified and mapped to other passages of text, as concepts denoted by the aggregation of semantic vectors.

The results for "windows" (Figure 3) can be interpreted in a similar way. However, one sees that only Issue53 contain "window" and is expectedly semantically significant, while the rest is somehow related even though "window" doesn't occur explicitly. Issue 50 for instance is matched, because Issue53 (where "window" is evident) also is related to some object being "missing", while Issue50 has similar (i.e. floor is "missing"). This co-occurrence of concepts has created a link between "window" and some problem related to "missing" objects or information. Issue44 is linked probably due to the relation to "ceiling" which also occurs in Issue53. LSA has the ability to take into account the complex second order relationships of concepts, in fact, all latent relationships identified are based on aggregates of multiple orders of semantic associations across all the issues in the corpus.

Of course, it is also possible for the system to return the most semantically related terms rather than issues as shown above. However, in this particular exercise, the terms by themselves (being out of context) are difficult to infer meaning. It is therefore more meaningful for this particular renovation orientated context to retrieve the issues. Other cases, for instance, colloquial discourse within large corpora of literature, term retrievals usually reveal synonymy – multiple terms describing similar concepts.

"in the conference area, the hot water pipe is below the ceiling"		
Issue20	0.734	Corridor area: Electric cable tray through the hot water pipe
Issue7	0.677	Corridor area: Hot water pipes penetrates through the electric cable tray.
Issue41	0.567	Office area: Lighting rail clashes with ventilation terminal. Electric cable tray clashes with ventilation pipe and hot water pipe.
Issue42	0.474	Office area: Electric duct and radiator clash
Issue59	0.465	Corridor: Level and the stair in the same place? Cable tray and water pipe clash

Figure 4: Example of a natural language query

Due to the limited length of the paper, more detailed discussions and interpretations will be reserved. However, it is worth mentioning that given the nature of how query vectors are established, the queries can be indeed done in natural language. An example in Figure 4 shows the most semantically related issues returned given the arbitrary natural language query. Such queries will be much more accurate and valuable when the training corpus is big. In our case, we only have 71 issues (for one change review cycle) consisting of 78 terms. If, for instance, the BCF knowledge regarding change management is extracted from 10 projects, each having just 100 change issues, 1000 issues could be processed and vectorised semantically in the database, and used as suggestive knowledge augmentation for future engineers' decisions. The benefit is that the system can handle datasets of change cases that are ever growing from project to project and the latent semantic structure of the data also updates accordingly. This is comparable to how a human engineer may accumulate experience over time through experience, and apply the lessons learnt to new decisions and predictions to avoid problems.

Currently, with only 71 issues, consisting of 78 terms (4430 characters, thus supposedly 4.3 kB of data), it is remarkable how intuitive semantic relationships between terms and documents can be inferred through the proposed semantic system. This is noteworthy in sight of the association of machine learning techniques with “big data”, where large datasets (in the order of Gigabytes) apparently needs to be mined to train algorithms. Our proposed technique demonstrates effective results even given small sets of data, available in all segments of the construction context.

4.2 Extended BIM possibilities

It is useful to enrich the textual comments used in this study with some further explicit contextual information. They can be added in the sentences in the form of “keywords” or even include ontological entities from IFC schema. The sample sentences would contain not only more information, but also it would allow the learning algorithm to use the information that is available in the BIM models.

The BCF specification makes it possible to obtain a list of identifiers of entities that are related to a BCF issue. In principle, those identifiers can be used to fetch information from the relevant BIM models. This can be done either manually using a BIM tool or using a program to automate the task. In practice, the relevant identifiers are listed in the viewpoint.bcfv files, the corresponding entities can be marked visible or selected using tags. The viewpoint.bcfv files further specify a camera view inside a BIM model. That makes it possible to use standard 3D graphics processing to calculate which parts of the model are visible for the camera. For example, ray tracing (Glassner, 1989) can be used. The parts could be used to infer the affected BIM entities. They could, in turn, be used to enrich the issue descriptions, so as to allow these BIM entities to be included in the latent semantic analysis.

Additionally, if we had a series of changes in the model that has taken place after the BCF is time stamped, and possibly before the next BCF prompt, the series can automatically convey information of the actual changes that were imposed upon the BIM model, following the requests in the previous BCF issues. In principle, BIM tools could keep track of changes in the model, which is possible if the BIM tool can be changed. Otherwise, a more generic way is to export the model versions into IFC/RDF representation (Pauwels & van Deursen, 2012) and use algorithms presented in Oraskari and Törmä (2015) to provide change sets of added and removed RDF triples. The triples include identifiers of entities in the model and they have location in the graph. It makes it possible to deduce the affected entities in the BIM model and the triples express the changes made. The change description could be used as a context for a BCF issue comment. In other words, these change events identified can be attached to the change requests in BCF issues, therefore establishing the possibility for the semantic retrieval of not only change requests, but as well as the change actions taken in response. For instance, the natural language query in Figure 4 may be used to retrieve similar past issues, and if the past issues also include the following change events, it poses a suggestive function to respond to future change requests/prompts, be it in BCF or otherwise. This is especially useful for a novice engineer who may query possible change risks, and the system adds an additional layer to suggest the possible actions to be taken in response to the risk, thus catering both for the prediction (change avoidance), as well as mitigation (change cost alleviation) functions.

5. Conclusions

Design change management poses a huge challenge in any civil engineering project. This study sets out to investigate how to better manage design changes in a BIM integrated environment, in sight of the growing adoption of BIM in typical workflows. In particular, this study demonstrates how data from existing BCF files in the BIM environment can be extracted and semantic inferences made to predict future changes given natural language queries by the user. Natural language is particularly interesting as it is able to capture specifics, as well as fuzzy semantic dimensions, required to describe complex change prompts and issues. The proposed method uses data extraction techniques to obtain textual data from BCF issues, processes the texts via latent semantic analysis and establishes a semantic knowledge repository, which can be flexibly queried by future users. The types of semantic inference is shown and discussions are made on how retrieval results can be interpreted to illustrate the reasoning of the technique. This semantic knowledge repository, in the form of vectorised terms and issues, is to some extent an analogy for how human tacit experience in change prediction and mitigation can be captured and presented in an intuitive manner, that is also both scalable in size and flexible for multiple domains. The computational technique thus simplifies the complexity of knowledge/information modelling, by harnessing the properties of linear algebra decomposition, thus enabling an inductive logic to be applied to complex, unstructured data. It is remarkable that with as little as 4.43kB of training data in this exercise, intuitive semantic associations can be inferred and thus used for matching intuitive concepts, otherwise tacit in expert reasoning. On a fundamental level, the simplicity and effectiveness of the prototype democratizes artificial intelligence for construction contexts, and shows the possibilities beyond natural language texts to include specific BIM or IFC entities, made possible by innovations in linked-data and ontology-related research. Ultimately, the effectiveness of the system can be enhanced given more data over time, which also caters for the adaptability of the system by considering the shifting trends of the industry or domain with respect to how design changes are managed.

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Construction Supply Chain Coordination Leveraging 4D BIM and GIS Integration

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Abstract

Construction supply chain management (CSCM) is challenging and information demanding due to the fragmentation of project participants and one-of-a-kind nature of construction projects. Construction supply chain coordination is the core issue to improve the performance of CSCM. Coordination of construction supply chains requires tracking of construction activities, an integrated platform, and certain coordination mechanisms. Some researchers have suggested the use of building information modeling (BIM) to monitor construction activities and manage construction supply chains. However, since material warehousing and delivery are mostly performed outside construction sites, a single BIM model is not sufficient to coordinate the entire construction supply chains over a wide region. In this research, an integrated framework was developed based on 4D BIM and geographic information sciences (GIS) for coordination of construction supply chains between the construction site and other project related locations, such as supplier sites and material consolidation centers. The integrated platform was used to solve three critical problems in CSCM, namely selection of supplier sites, number of deliveries, and the location-allocation of consolidation centers for multiple sites using information from BIM and GIS. The framework will be demonstrated using scenario examples in San Francisco.

Keywords: Construction supply chain management, Building information modeling, GIS, Coordination mechanism, Lean construction

1. Introduction

The construction supply chain is a converging supply chain directing all materials to the construction site where objects are assembled from incoming materials. Moreover, the construction supply chain is a temporary supply chain producing one-off construction projects. As a result, the construction supply chain is typified by instability, fragmentation, and especially by the separation between the design and construction of built objects. A closer look at the construction industry shows that a considerable amount of waste produced is rooted in poor management of the material supply chain (e.g. delivery services, inventory, communications). Therefore, since the end of the 1980s, the construction industry has seen the launch of a number of CSCM initiatives.

While there is abundant literature on the design, application and evaluation of construction supply chains, the effective use of geographic data in CSCM has not been fully explored. Jadid and Idrees (2013) argued that traditional SCM had no effective mechanism for locating the nearest suppliers for particular materials. Li et al. (2003) pointed out that location-related information plays an essential role in all kinds of business activities, including an E-commerce system for construction activities. GIS is potentially applicable in construction supply chain management to manage spatial information, and provides an ideal solution to manage costs of transportation and market analysis in the overall E-commercial activities. Irizarry et al. (2013) revealed that the traditional way of managing the supply chain with a focus on the site activities (e.g. to reduce costs or the duration of site activities) or on the supply chain itself (e.g. to reduce logistics costs, lead time and inventory) are not adequate anymore and the processing of information for any other section of the supply network using a BIM and GIS integration framework should be clearly studied.

In this research, three problems are identified as only solvable when considering geographic data in the CSCM system. The first problem is the selection of supplier, when the supplier with the lowest cost may not be the nearest supplier. The second problem is to determine the number of deliveries, as there is an adverse relationship between the number of deliveries and inventory cost. Increasing the number of material deliveries will decrease the need for onsite inventory, but it will increase the fees for delivery. The third problem is the location allocation problems for consolidation centers (CC) for construction material for multiple sites. an integrated framework was developed based on four-dimensional BIM (4D BIM) and GIS for the coordination of construction supply chains between the construction site and other project-related locations, such as supplier sites and material consolidation centers. 4D BIM provides schedule information for pull-based CSCM and material demand information, while GIS provides related geospatial data such as delivery distance estimation, material tracking and consolidation center information. The objective of the integrated framework is to minimize costs in construction supply chains by generating optimized solutions for selecting supplier sites, determining the number of deliveries and allocating consolidation centers. Information from 4D BIM is used to determine the construction activities and their material demands. A bidding and requisition module is developed based on GIS to allow suppliers to bid for material orders. Based on the actual travel distances from the supplier sites to the construction sites, the integrated framework calculates the delivery fees that are used to optimize three solutions, namely the supplier selection, the number of deliveries and the allocation of consolidation centers.

2. Literature Review

The study of supplier selection is an important part of SCM research. The information in 4D BIM can be used to determine the products and quantities to be ordered. There are extensive studies on supplier selection and inventory lot sizing. Kasilingam and Lee (1996) examined the development of a chance-constrained integer programming formulation to address the vendor selection problem and the determination of order quantities to be placed. However, in their model, the unit cost of each item already includes the transportation cost and does not change according to delivery distance. Jayaraman et al. (1999) presented a mixed integer programming formulation of the supplier selection problem. The model could help an organization choose an optimal set of suppliers, taking into account quality requirements, restrictions in storage and production capacity, and production lead time. However, this study did not consider the delivery fees of products while it is estimated that transportation costs account for 10-20% of construction costs (Shakantu et al., 2003). In this regard, the locations of suppliers and construction sites and transportation distances should be retrieved. Thus, a GIS should be introduced in the CSCM process to support the wide range of network/spatial analysis used in the supply chain coordination process.

The setting up and allocation of consolidation centers are seldom studied in CSCM. Kasim (2008) reported the setting up of consolidation centers in an airport terminal and airfield modification project. The implementation of the consolidation center ensured that the correct construction materials were efficiently delivered to the correct construction site at the required time. In this method all materials are transported to the consolidation center before distribution to the construction site, in order to avoid the congestion of materials at the site loading area. The implementation of the consolidation center also solves the problem of lack of storage space at the construction site. However, to our knowledge there is no more literature concerning the design and allocation of consolidation centers in the construction industry. In the area of SCM for the manufacturing industry, there is a rich body of literature focusing on the design and operations of consolidation centers. Song et al. (2008) developed coordination mechanisms for shipments while considering the product release times at the source locations, the latest arrival times at the destinations, the routes and options used for the transportation, the storage cost at the consolidation center, and the consolidation policies (as early as possible or as late as possible). The objective of the study was to minimize the sum of the transportation cost and the storage cost through optimizing shipment coordination. While there are a lot of studies on the coordination mechanisms in consolidation centers, the allocation of consolidation centers has not been studied. Specifically, we will show that consolidation centers are cost-effective when onsite inventory is limited. Thus the problem remaining is that given project information and supply chain network, how is it possible to determine the location of consolidation centers so that the cost for inventory and delivery is minimized. In this regard, the project information can be retrieved from BIM, and the allocation problem can be solved using network analysis functions in GIS.

3. Construction Supply Chain Management Problems

3.1 Supplier selection and finding the optimal number of deliveries

By introducing GIS in the problem setting, we added one more constraint to the CSCM problem, which is delivery distance from different suppliers to construction sites. With this new setting, we first formulate the CSCM problem in mathematical form and then discuss solutions to the problem.

Some notations used in the problem formulation (capital letter plus subscript) are introduced here:

Construction Sites: CS [CS_a,CS_b,CS_c]

Activities in construction retrieved from BIM: A[A_{ai},A_{aj},A_{ak}]

Starting time of activity A_{ai}: ST[ST_{ai},ST_{aj},ST_{ak}]

End time of activity A_{ai}: ET[ET_{ai},ET_{aj},ET_{ak}]

Task duration retrieved from BIM: D[D_{ai}, D_{aj}, D_{ak}]

$$D_{ai}= ET_{ai} - ST_{ai} \tag{1}$$

Quantity of required material used in each task: Q[Q_{ail}, Q_{aim}, Q_{ain}]

Supplier Sites SS[SS_l,SS_m,SS_n]

Onsite inventory for each material I [I_l,I_m,I_n]

We assume that all the materials are delivered right on time in the ordered amount, so in a case where only one order is needed, the normal ordering time will be related to the lead time of material delivery. For each construction activity, at the beginning of material purchasing, based on information from BIM (material demand and scheduling information) and GIS (geolocations, true travel distances), we want to find an arrangement of ordering of material that aims to:

Find the supplier site SS_l for activity A_{ai} (as ordering cost OC (Irizarry et al., 2013), material price and delivery cost may vary according to supply and the location of suppliers)

Compute the optimal number of orders N for each activity A_{ai} considering inventory cost, delivery cost and ordering cost

Following the principle of Just-In-Time, the ordering cost can be calculated as:

$$OC = OCR \times Q_{ail} \tag{2}$$

where OC is Ordering Cost, and OCR is ordering cost rate proportional to the quantity of material ordered.

The delivery cost can be calculated as:

$$DC_N = \begin{cases} N \times DD_{al} \times DFT_l \\ DD_{al} \times DFT_l \end{cases} \tag{3}$$

where N is the number of deliveries, $N >= Q_{al} / CP_l$, CP_l is the capacity of one delivery (i.e. number of material l that can be delivered each time)

The material cost can be calculated as:

$$MC = Q_{ail} \times P_{Sl} \tag{4}$$

In an ideal case, the onsite inventory is reloaded when the inventory level hits zero. In this case, the inventory cost can be calculated as:

$$IC_N = \begin{cases} \dfrac{QD_{ai}}{2N} \times ICR \\ \dfrac{I_{ai} D_{ai}}{2} \times ICR \end{cases} \tag{5}$$

Where ICR is the inventory cost rate, proportional to the inventory level.

So the problem of selecting supplier site and finding the optimal number of deliveries becomes finding S and N to:

$$Min(OC + DC + MC + IC_N) \tag{6}$$

Subject to constraints of onsite inventory and the delivery capacity of suppliers.

$$Q_{ail} / \mathrm{N} \le \mathrm{I}_\mathrm{l} \tag{7}$$

$$Q_{ail} / \mathrm{N} \le DC_\mathrm{l} \tag{8}$$

Since only a finite number of potential suppliers and finite discrete number of orders are considered in the solution, to find the solution for (6), a Monte-Carlo simulation is used to find the value of S and N.

3.2 Allocation of consolidation centers using BIM-GIS integration

Kasim (2008) investigated two construction projects involving the use of consolidation centers. It is revealed in this study that the implementation of consolidation solved the problem of a lack of storage space at the construction site, provided a solution for improvement of site security and safety, reduced congestion from construction traffic within the airport perimeter, improved delivery reliability, and there was an associated environmental benefit, improved workforce efficiency, and reduced materials losses. However, Kasim (2008) did not provide details as to why consolidation centers should be set up and how to allocate them. In this study, we first show how consolidation centers can reduce the cost of inventory and delivery, and solve the allocation problem of consolidation centers using GIS.

In Equation (6), since Ordering Cost and Material Cost are fixed for a given amount of material, the flexible part of costs related to geolocations of facilities are:

$$LoationSensitiveCost = DC + IC_N \tag{9}$$

which can be further elaborated as:

$$LoationSensitiveCost = N \times DD_{al} \times DFT_l + \frac{QD_{ai}}{2N} \times ICR \tag{10}$$

In a congested site (when *I* is small), we assume:

$$I_{ail} = Q_{ail} / \mathrm{N} \tag{11}$$

Then:

$$LoationSensitiveCost = \frac{Q_{ail}}{I_{ail}} \times DD_{al} \times DFT_l + \frac{I_{ail} D_{ai}}{2} \times ICR \tag{12}$$

The tipping point where cost is at minimum is:

$$I_{ail}' = \sqrt[4]{\frac{8 \times Q_{ail} \times DD_{al} \times DFT_l}{D_{ai} \times ICR}} \tag{13}$$

This equation reveals the relationship between inventory space and project conditions. I_{ail}' can be seen as a critical inventory value. If onsite inventory $I_{ail} < I_{ail}'$, the total cost will increase rapidly. In a construction market where *DFT* is small, this critical value I_{ail}' is small as well. This implies that if contractors can find suppliers nearby, the inventory level on construction sites could be smaller. However, if some suppliers for some materials are far away, then I_{ail}' is large, which implies that site inventory must be large as well; otherwise cost will increase dramatically. Therefore, the setting up of consolidation centers is essential.

Finding the optimal location for a consolidation center is challenging, as this problem is affected by the location of construction sites, supplier sites and the traffic network itself. Assume that we set up a consolidation center Z, with distance to site *a* as D_{Za}, to supplier *S* as D_{ZS} (distance as actual travel distance calculated from GIS). The capacity of inventory of Z for material *l* is I_{Zl}.

It is reasonable to assume that:

$$I_{Zl} > I_{ail} \tag{14}$$

With a buffer zone, the total cost of delivery and inventory can be calculated as:

$$\begin{aligned} TotalCost &= \left(\frac{Q_{ail}}{I_{ail}} \times DD_{al} \times DFT_l + \frac{I_{ail} D_{ai}}{2} \times ICR\right) \\ &+ \left(\frac{Q_{ail}}{I_{Zl}} \times DD_{Zl} \times DFT_l + \frac{I_{Zl} D_{ai}}{2} \times ICR\right) + ZC \end{aligned} \tag{15}$$

where ZC is the cost to set up the consolidation center.

Denote

$$F_{aiZ} = \frac{Q_{ail}}{I_{ail}} \times DFT_l \tag{16}$$

$$F_{SiZ} = \frac{Q_{ail}}{I_{Zl}} \times DFT_l \tag{17}$$

$$F_Z = \frac{I_{ail} D_{ai}}{2} \times ICR + \frac{I_{Zl} D_{ai}}{2} \times ICR + ZC \tag{18}$$

Then

$$TotalCost = F_{aZ} \times DD_{al} + F_{SZ} \times DD_{Zl} + F_Z \tag{19}$$

Since F_Z is fixed, F_{aZ} and F_{SZ} are cost ratios proportional to the distance between a consolidation center and site and supplier. F_{aZ} and F_{SZ} are only affected by project parameters. Consider a consolidation center serving different construction projects. For a project, the total cost ratio factor is:

$$F_a = \sum_{i=1}^{m} F_{aiZ} \tag{20}$$

where *m* is the total number of activities

For multiple projects, the total cost for setting up a consolidation center is:

$$TotalCost = \sum_{a=1}^{n} F_{aZ} \times DD_{al} + \sum_{S=1}^{k} F_{SZ} \times DD_{Zl} + F_{Z} \tag{21}$$

So the problem of finding an optimized location for a consolidation center becomes:

$$\min\left(\sum_{a=1}^{n} F_{aZ} \times DD_{al} + \sum_{S=1}^{k} F_{SZ} \times DD_{Zl} + F_{ZZ}\right) \tag{22}$$

We can use Equation (21) to evaluate different candidate locations for setting up consolidation centers. Or, if certain areas are considered for consolidation centers, we can turn it into a discrete simulation problem using point sampling in the given area. Later we use a case study to show the work flow for finding the optimal location of consolidation centers.

4. Framework Development and Validation

4.1 Framework Description

The construction supply chain management process requires massive data input as well as reliable analytical functions to provide management decision-making. Therefore, a CSCM framework should at least have three layers: the data retrieval and storage layer, the analysis layer, and management interface. The use of 4D BIM and GIS provides opportunities to minimize the manual efforts for data input, and all data can be stored in the geodatabases in GIS with customized analytical functions. A comprehensive 4D BIM model stores the full range of information about activities with associated material demand and duration. In the proposed BIM-GIS integration CSCM framework, a detailed quantity takeoff of the construction project is executed at the early stage of procurements from BIM, and GIS is used to support the wide range of analysis functions to provide decision-making in the CSCM process. The data from BIM are exported to databases linked to GIS, which will be used for analysis. The manually input data are mostly related to the quotations for material from multiple suppliers and changes in current project plans. It is possible that some of the construction activities, for example scaffolding, are not present in the 4D BIM. In this case, manual inputs of such activities along with their material demand and time duration are needed. In the proposed CSCM framework, the data storage, analysis and decision-making are performed in a GIS system. GIS has the capacity to store massive amounts of data and the ability to access fundamental analysis tools such as route finding for delivery cost analysis.

The architecture of the proposed CSCM framework is shown in Figure 1. The data input layer consists of data sources (BIM, GIS and user input) and data retrieval functions. The retrieved data are used by various analysis functions such as cost analysis and network analysis to support solutions of CSCM problems.

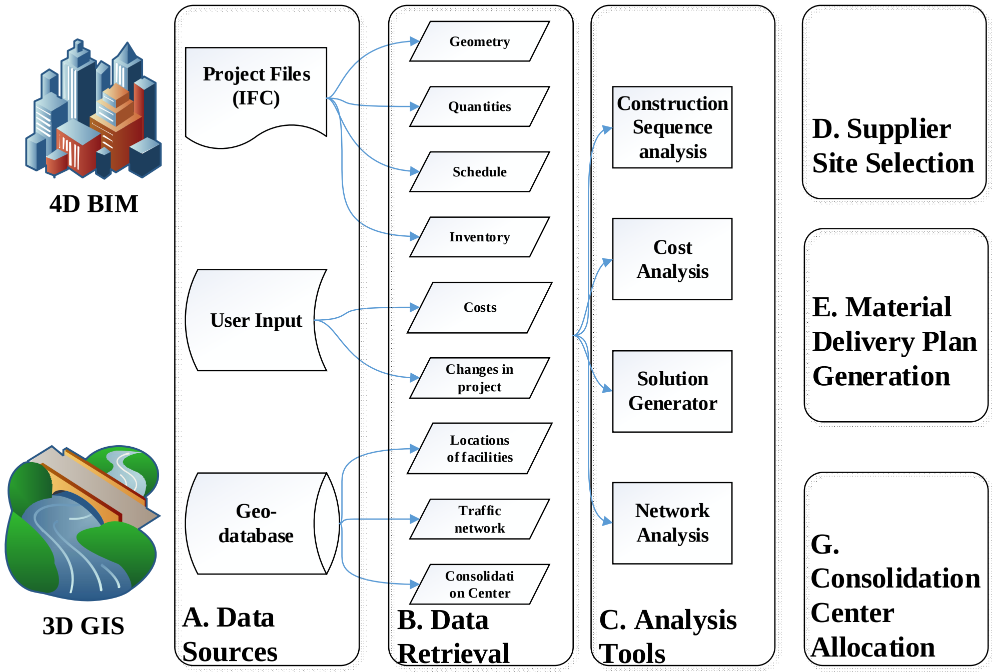

Figure 1 Framework Overview

4.2 Validation of Framework

In order to demonstrate the BIM-GIS integration CSCM framework, we use the road network data in San Francisco, USA as a base map. A five-storey building construction project is used to demonstrate the problem of the selection of suppliers and number of deliveries. Specifically, we show that the delivery fees and inventory fees are critical in calculating the total cost incurred in the supply chain. Selection of material supplier cannot only rely on the unit prices or nearest delivery distances. We use another supply network with five construction sites and 15 suppliers to demonstrate the location-allocation problem of setting up consolidation centers.

We first validate the effeteness of BIM and GIS integration in supplier selection and number of order optimization, In the design phase, a 3D model of the building was created using BIM software Autodesk Revit. The schedule information was added to the BIM later by linking to project databases using Navisworks. The generated 4D model was exported to IFC format, which was then parsed by our developed parser. All the relevant information for CSCM was finally exported to data tables in the GIS system, which is based on ArcGIS.

We used the material Brick (230 mm) in Level 1: Interior wall construction to demonstrate the material selection process. The potential suppliers that are willing to supply this material and their location along with the location of the construction site is shown in **Figure 2**. The GIS network analysis function allows route finding with the shortest distance, which is used for delivery fee estimation. The route finding results are also shown in **Figure 2**. The manual input function is used to enter the information of different potential suppliers. The delivery distances are obtained from the network work analysis to represent the actual delivery distance. The cost analysis function in the framework computes the delivery cost and onsite inventory cost for every potential supplier considering different numbers of deliveries. In order to find the suppler with the lowest cost, the total costs were analyzed. The results are shown in Figure 3.

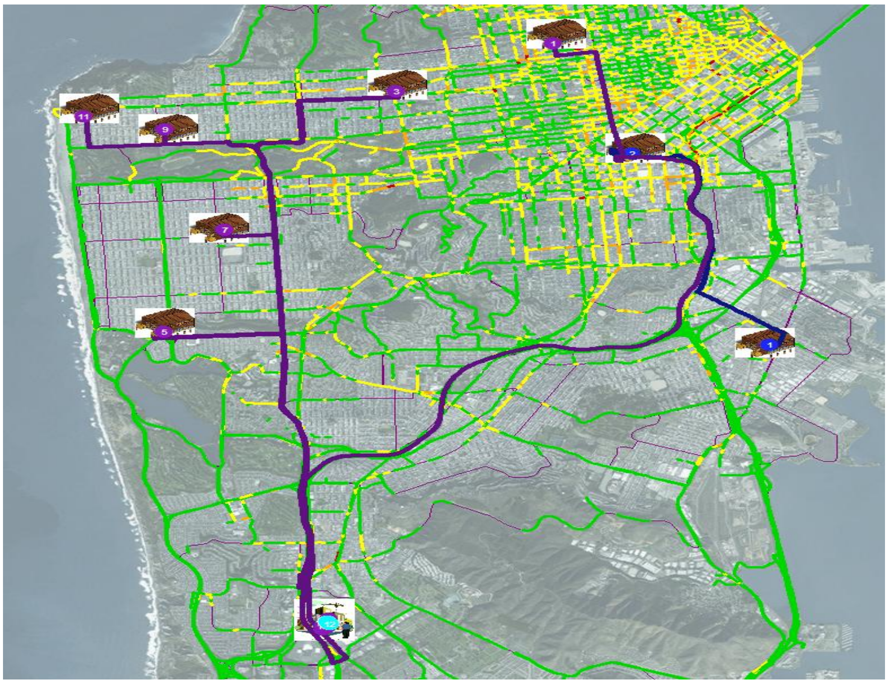

Figure 2 The route finding to calculate delivery fees

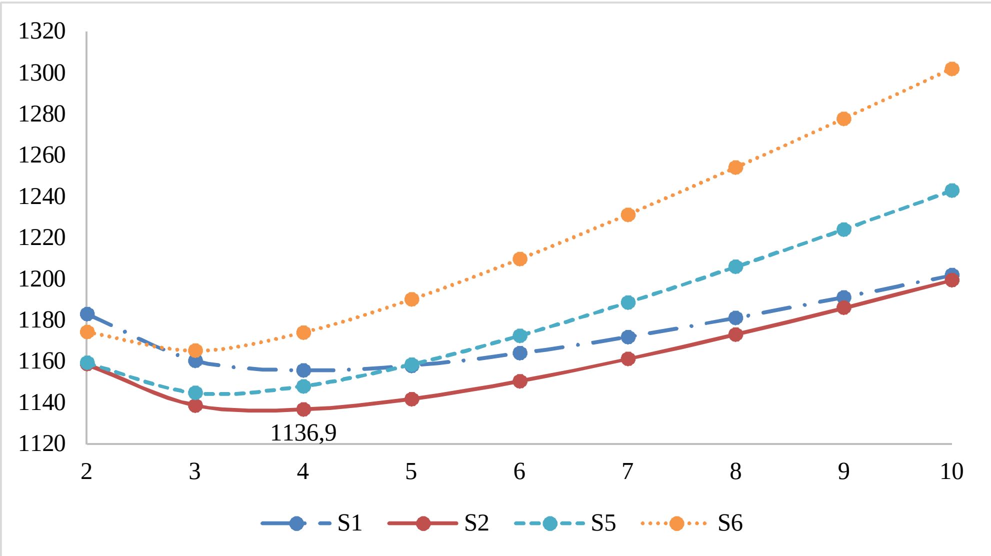

Figure 3 Total cost analysis for different suppliers and different number of deliveries

The second case study considers a supply chain network consisting of five construction sites and 15 suppliers in different locations supplying different material. The road network data in San Francisco are used here to calculate delivery costs. The first step of the consolidation allocation problem is to determine the cost ratio F_{aZ} and F_{sZ} using Equations (16) and (17) with data from these five projects.. With the calculation of F_{aZ} and F_{SZ} from project data, the allocation problem of consolidation centers has been transformed to a location-allocation problem in GIS. The process of consolidation center allocation starts from generating unified distributed sample points on the base map. Here we set the resolution of sample points to 100 meters. After acquiring the sample points, the cost for each sample point is calculated using Equation (21). After calculation of each sample point, it is possible to generate a cost map which represents the cost of setting up a consolidation center in a given location, as shown in *Figure 4*. The location with the lowest cost after setting up the consolidation center is shown by a star symbol. *Figure 4* also provides guidelines for project managers to find an optimal location for setting up consolidation centers. It is noticeable that near the optimal location in *Figure 4*, there is a zone with a consolidation center cost. The reason is that in this area the traffic network becomes less dense, and the transportation cost will increase dramatically in this area. This is more evidence that GIS network analysis should be used in calculating delivery costs.

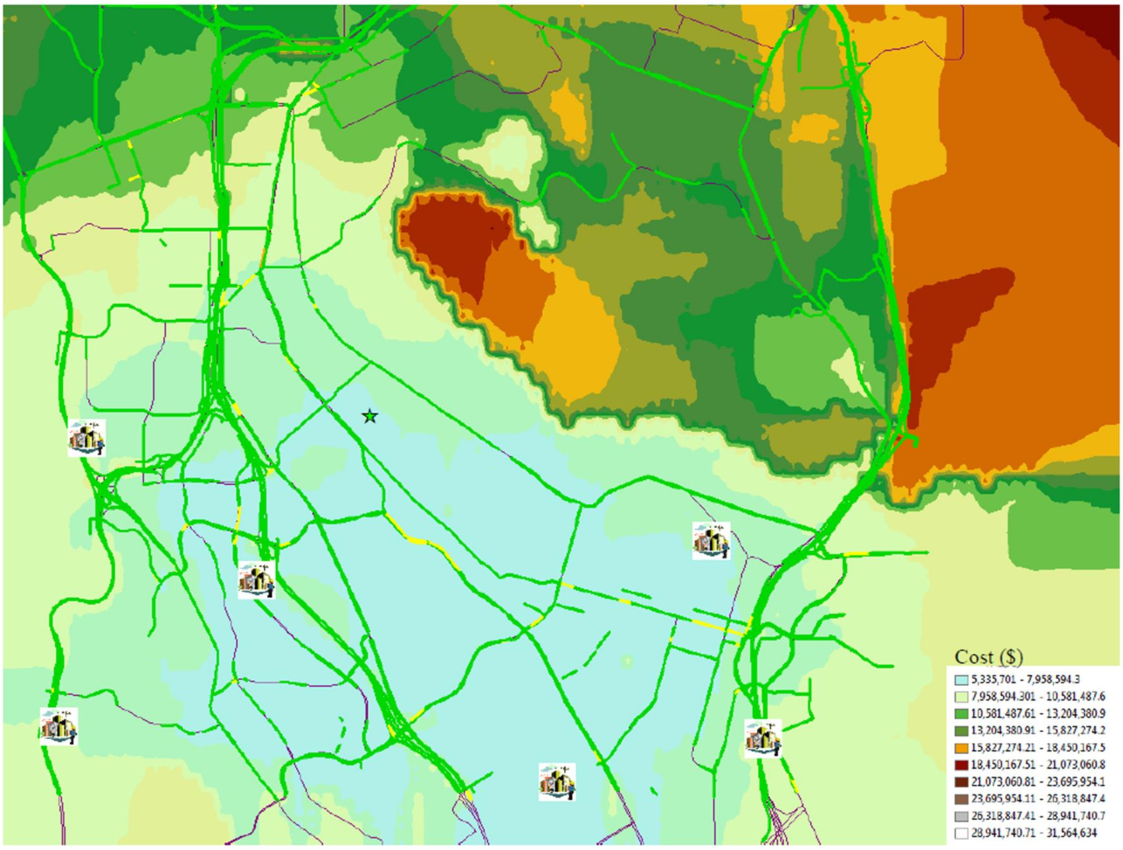

Figure 4 Finding an optimal consolidation center location

5. Conclusion

By using data from BIM and GIS, we formulate the three problems in mathematical form and provide solutions to these problems. Specifically, we make the following contributions to these three problems: firstly, we prove that selection of suppliers should not only consider factors such as delivery distance or unit price solely. Secondly, we should understand that the number of material deliveries has impacts on the total invoice cost of the supply chain, and we provide a Monte-Carlo Simulation solution to this problem. Thirdly, we prove the necessity of setting up of consolidation centers given the congested sites and long delivery distances using mathematical modelling. And finally, we provide a solution to the location-allocation problem of the setting up of consolidation centers. It is noticeable that all the contributions could not be made without the data inputs and analysis functions in BIM and GIS.

Acknowledgements

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Knowledge Acquisition to Address Skills Challenges in UK Construction Industry

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Abstract

The successful implementation of new technologies plays a major role in the economic growth of the country. Building Information Modelling (BIM) is considered to be one of the most recent technologies introduced within the Architecture, Engineering and Construction (AEC) industry. However people who are involved in BIM based construction projects are struggling to achieve their project outcomes due to not having enough knowledge and skills to work with this new technology. The main aim of the paper is to explore how knowledge can be distributed among the project participants to acquire the appropriate knowledge and skills during the implementation of new technologies. Connectivism theory has been adopted in this study to understand the distribution of knowledge and the learning process in the BIM construction projects. Following that, data was obtained through conducting the interviews with the professionals who have used BIM in their construction projects. The collected data focused on the knowledge acquisition in the implementation of BIM technology. In addition the learning process within BIM construction projects was also looked in terms of achieving the knowledge and appropriate skills which is essential to support the various stakeholders to efficiently use BIM technology.

Keywords: Building information Modelling (BIM), Connectivism, Construction, Learning, Skills, Knowledge.

1. Introduction

Productivity in a country influences in determining the competitiveness for the businesses and wages for people at work (UKCES, 2015). According to HM Treasury (1988) productivity is ‘a fundamental yardstick of economic performance’ however the UK significantly lags the best performing OECD countries due to poor productivity records (Allen, 2015). The construction industry has been one of the main engines of UK economic growth nevertheless still UK’s productivity gap is driven back due to skills challenges faced in the construction industry. One of the reasons for the construction industry to face these skills challenges is due to its resistance to adopt new technologies. However, the purpose of introducing these new technologies is to improve productivity (UKCES, 2015) which also leads to alter and create quicker ways to deliver goods and services (Corney, 1997), high performance work practices (Bresnahan *et al*, 2002) and economic well-being (Hansushek and Woessmann, 2008). The studies in construction industry highlight the skills challenges as a major barrier in improving productivity (UKCES, 2015). Supporting this construction skills report (CITB, 2004) suggests that employer's skills requirements need to be taken into consideration to enhance efficiency of the construction projects to cope up with continuous changes in construction industry. Even though skills challenges have been highlighted in many construction studies lack of knowledge is the key factor that leads to these skills issues in the construction. Therefore distribution of knowledge is important within the project participants to acquire the appropriate skills to achieve the project outcomes. Therefore the aim of the study is to explore how knowledge can be distributed to acquire the appropriate skills during the implementation of new technologies within the construction industry.

2. Literature Review

2.1 Importance of skills and knowledge in construction industry

Acquiring appropriate skills encourages economic performance (O'mahoney and de Boer, 2002), innovation and flexibility (Leiponen, 2005). Moreover it helps to determine individual's employability to productivity (HM Treasury, 2006) and business profitability (Bosworth, 2013). This has been highlighted in Sami's (2008) study where he claimed more attention is needed to reskill, multi-skill or upskill professionals in construction industry to successfully achieve project targets. However, skills must be grounded and the meaning might differ according to its reference to context (Spencer, 1990) as shown below.

Table 1: A summary of the skills definition

Author/s	*Year*	*Definition*
Becker	*1964*	*Capabilities of workers that they acquire outside the work place and the job on and the capabilities have meaning only when they translate into productivity and job rewards, such as earning.*
Mangham and Silver	*1986*	*Dexterity and knowledge of the workforce.*
Wood	*1988*	*Expertise that describes the quality of overt behaviour in a particular job.*
Odusami	*2002*	*Ability to perform the task well or better than average. Skills can also be described as the ability to translate knowledge into action.*
Boyatzis et al	*2002*	*Emotional intelligence which includes both self-awareness of one's emotional reaction to specific events, situations and unexpected circumstances and the coping strategies that may be developed to handle those feelings and concomitant reactions effectively.*
HM Treasury	*2006*	*Capabilities and expertise in a particular occupation or activity.*

These definitions state that skills are centred on various different factors such as capabilities, people, physical and practical activities. However, Odusami's (2002) definition is adopted in this study which states that skills are not only about completing the task better than average but also translating the knowledge into action. The UK Commission's Employer Skills Survey 2013 (UKCESS 2013) and CITB (2015) have discussed about the skill deficiencies and highlighted the need for people with appropriate skills and knowledge. Moreover these studies show that knowledge should be developed along the process to acquire the appropriate skills to complete the task. Therefore to resolve this current situation there is a need for people who are capable, agile and able to respond to the challenges presented by new technologies.

2.1.1 Skills gaps, Skills shortages and Latent Skills shortages

Current skills challenges within the construction industry are mainly due to skill gaps, skills shortage and latent skills shortages. Skills gap happens due to employees in workplace not having appropriate skills to achieve the organisation's objectives (Campbell *et al*., 2001). On the other hand skills shortages also occur when there is shortage of skilled people in labour market to fill in the vacancies (Barnes and Hogarth, 2001).Campbell *et al* (2001) argued that there are more skills gaps in construction industry and Bloom *et al* (2004) believed skills shortage plays a significant role towards the economic growth. Apart from this, latent skills shortage is also an issue, which is a situation where establishment fall short of what might be considered good or best practice. This might be the reflection of low skills or poor business performance, even though there is no report of recruited problem or skills gap (Hogarth, 2001). Generally this occurs when the organisation starts to manage a project with existing skills without being aware of necessary skills. Chan and Cooper (2006) claimed that this situation is more frequent in construction industry because construction practitioners often do not know what skills they need to produce to achieve their project outcomes. Therefore skills challenges are problematic to move towards the digital world. Building Information Modelling (BIM) is a recent technological development introduced within the AEC industry to integrate processes throughout the entire project lifecycle (Aouad and Arayici, 2010). Moreover BIM also helps to drive a step-change to increase the productivity of the construction process, tangible quality improvement in the end product and associated reduction in true cost (O'Rourke, 2015). Recently the UK government has mandated to use BIM in public sector projects since 2016 (Cabinet Office, 2011) therefore construction companies have slowly started to adopt BIM in their construction projects.

2.2 Building Information Modelling (BIM)

There are many ways of looking at BIM as shown in below in Table-2; this study has adopted the National BIM Standard (2014) definition that looks from a knowledge point of view. Here BIM is about unlocking knowledge and insight, creating the platform for more efficient and sustainable solutions through sharing the information. While the information is shared through BIM, knowledge needs to be distributed among the project participants for the decision making to achieve the project targets. Therefore this paper is looking at how knowledge is shared and distributed among the project participants using BIM in construction projects. Furthermore Connectivism theory has been adopted in this paper to study the knowledge distribution and learning process to achieve the project outcomes.

Table 2: A summary of the BIM definition

Author/s	*Year*	*Definition*
Autodesk	*2007*	*A building design and documentation methodology characterized by the creation and use of coordinated, internally consistent computable information about a building project in design and construction.*
Eastman et al	*2008*	*A computer aided modelling technology for managing and generating building information, with the related processes of producing, communicating, and analysing building information models.*
Vanlande et al	*2008*	*The process of generating, storing, managing, exchanging, and sharing building information in interoperable and usable way.*
McGraw Hill	*2009*	*The process of creating and using digital models for design, construction and or operations of projects.*
Nisbet and Dinesen	*2010*	*A digital model of a building in which information about a project is stored. It can be 3D, 4D (integrating time) or even 5D (including cost) – right up to 'nD' (a term that covers any other information).*
National BIM Standard (NBIMS)	*2014*	*A digital representation of physical and functional characteristics of a facility and a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition.*

The impact of technology on humanity continues to grow in greater prominence which allows entering into a new form of 'knowledge society'. Moreover Bloom *et al* (2004) claimed that even though new technologies are out there, significant amount of knowledge and skills are not there to work with those new technologies. Therefore, there is a need for a suitable learning theory to increase human cognitive functioning to cope with this changing society. Connectivism is a theory introduced by Siemens and Downes (2009) for the digital world.

2.3 Connectivisim

Connectivism is an application of network premises that define both knowledge and process of learning. In this, knowledge is defined as a particular pattern of relationship whereas learning is defined as the creation of new connections and patterns along with the ability to maneuver around existing networks/ patterns. Moreover Connectivism focuses on the presence of technology as a part of cognition and knowledge. Previously philosophers and theorist had different views of learning where they failed to address the learning that occurs outside the individual and to discuss the learning process that happens among the group of people or organisation. According to Sieman (2004) Connectivism is an intriguing development where learning happens with the knowledge and perception gained through the additional personal network. Even though it is impossible to experience everything, there is an opportunity to develop the knowledge through sharing and collaboration. In this digitalised world there is a necessity for further knowledge to understand the amount of the data available to complete specific tasks. Therefore Connectivism which is an actionable knowledge can be considered as a learning theory, where understanding of where to find the knowledge is more important instead of answering how and what the knowledge incorporates. According to Siemens (2005) and Downes (2005) Connectivisim theory is appropriate to handle this digital world where its main principle is linking ideas and connecting people and information sources. However opposing this Duke *et al* (2013) state that in comparison to existing learning theories there is an overlap of ideas and therefore this cannot be accepted as new learning theory.

Learning process in Connectivism is not entirely focused on the control of the individual and more focused on connecting the specialised information sets and enable people to learn more than their current status of knowing. In this process information flow is a key factor where new information will be continuously acquired. In Connectivism, the starting point for learning occurs when knowledge is actuated through the process of learners and then connecting and feeding information into learning community. This begins with an individual and the personal knowledge is included of a network which feed into organisations and institutions, which in turn feed back into the network, and then continue to provide learning to individual. This cycle of knowledge development allows the leaners to be up to date in their field through the connections they have formed. Therefore the fundamental idea of this is about 'Distribution of knowledge'. This means a property of one entity must lead to or become a property of another entity in order for them to be connected; the knowledge that results from such connections is referred as connective knowledge.

The Diagram-1 generated by García (2008) shows the Connectivist view of learning as a network creation process that impacts the way learning is designed and developed. Diagram-1 emphasis the central principle of Connectivism which is the creations with usual nodes (element connected to any vertices, elements, or entities) supports and strengthens existing large effort activities. The integration of learning, knowledge and understanding through the personal extension of a personal network is the key of Connectivism.

Diagram 1: Connectivism: Process of creating network (García, 2008)

Supporting the Connectivism theory several studies have highlighted the importance of the knowledge to successfully complete the tasks. Hutchins (1993) in his study emphasised that knowledge is necessary and it should be distributed among the team to carry out a certain task. Moreover Lave (1988) suggested that relationships between human thoughts, human action and the environment is so tightly interwoven that the mind cannot be studied independently of the culturally organised settings within which people function. On the other hand Nonaka and Takeuchi (1995) believe that the knowledge is created and expanded through social interaction between tacit knowledge and explicit knowledge. Therefore these previous studies have highlighted the important to view the knowledge as composed of connections and network entities to encourage the interaction within these complex systems. This will then lead to the acquisition of appropriate skills to complete a task in an efficient way. From this discussion it is clear that initially knowledge needs to be acquired to gain the appropriate skills to work with the new technologies to achieve the project outcomes. However in this study the knowledge acquisition and learning process is viewed through Connectivism which is appropriate to tackle the rapid technological changes.

3. Methodology

The purpose of this research is to explore how knowledge can be distributed to acquire the appropriate skills when new technologies are introduced to achieve the project outcomes. The situations were analysed through interacting with BIM professionals by asking about their experience and their beliefs. Therefore, qualitative research is adopted as a method best suited to explore the new area. Qualitative research is ‘‘Multi-method in focus, involving an interpretive, naturalistic approach to its subject matter’’ (Denzin and Lincoln, 1994). Moreover this method explores and understands the meaning where individuals or groups ascribe to a social or human problem (Creswell, 2008). The purpose of this qualitative method study is to understand how construction project participants gain their knowledge and acquire skills during technology change within the construction industry.

Data for qualitative study analysis is collected through conducting 10 semi structured interviews with BIM professionals working in the UK construction industry. Firstly BIM professional’s personal opinion about BIM and their BIM experiences were collected. Secondly gaps within BIM learning and their causes were discussed. Finally their learning experience to work with BIM and recommendations for future BIM professionals were discussed. These interviews were conducted to understand the significant of skills challenges and to explore the skills issues in BIM construction projects. Moreover this is also to understand how project participants within the construction projects learn and acquire the appropriate skills to work with the new technologies. During these interviews professionals engaged with BIM construction projects shared their experience and individual perception about the skills related issues faced in BIM construction projects. Two pilot studies were conducted with the construction professionals working with BIM before conducting the interviews. This has assisted to refine some of the questions with appropriate wordings and made the questions clear to the interviewees. This semi structured interviews were conducted across the UK, open-ended questions were employed to get a wider view of the situation and interpretation was done along the way. The data collected through the semi structured interviews explained how knowledge is distributed among the project participants which have then led to the skills acquisition to work with the new technologies introduced in the construction industry.

4. Discussion

The data collected from the interviews clearly show that the way of gaining knowledge has been changed from old days. In the beginning knowledge acquisition is more focused on individual and their influences on the organisation or community. This is supported through one of the interviewee saying ‘‘learning the new software in BIM with the multidisciplinary team helped us to know the difficulties the other employees face’’. Moreover another interview stated that ‘‘Learning process with other project team members provide us a wider knowledge of the new software’’. Therefore it is evident that currently knowledge is not about focusing on the individual but also gaining the knowledge outside the primary knowledge.

As discussed in the literature, skills challenges can be viewed from the point of skills gap, skills shortage and latent skills shortages. BIM professionals indicated that they had to face several skills gaps such as detailing elements in BIM applications and using software , lack of understanding about family creation and detailed understanding, lack of knowledge about in putting the data into the objects and extracting it, process and standard gaps and lack of engineering. This is due to lack of knowledge within the internal workforce. On the other hand latent shortage is also a problem where skills gaps are unrecognised because project organisations have simply coped operationally without the necessary knowledge and skills. In BIM projects latent skills shortages are derived from lack of defined project process, lack of understanding of role and responsibilities and frequent change of software to work with BIM. In addition this happens more often in BIM construction projects due to lack of communications between the project team members. In other words the problems faced by the project team members are rarely discussed among them and in most situations doesn’t not get reported to the top management. This clearly shows that skills gap, skills shortages and latent skills shortages are significant constraints to achieve the project outcomes. Interviewees believe that adopting a new way of gaining knowledge which will then invest in skills acquisition could produce a radical shift in employees’ perception of working which can lead to achieve the project outcomes quickly.

From the interview results a similar situation is observed in BIM construction projects. In BIM construction projects individuals gained their fundamental knowledge through different learning methods such as degree programs/ education, self-learning, basic software training, attending meeting, conference and workshops. However most of them expressed that they were reluctant to use BIM due to lack of understanding of fundamental aspects of BIM enabled technologies. This involved in understanding what BIM is and some of the benefits associated with it. Therefore interviewees suggested that old learning theories that focused only on the individuals needs to be replaced to tackle the new digital world.

After the individuals have gained the fundamental knowledge BIM models were used to share the information among the project participants. In this situation knowledge needs to be distributed among the project participants to complete the necessary tasks through decision making. Therefore after connecting the information resources and people within the BIM construction projects the property of one entity leads to become a property of another entity in order for them to connect and finally connected knowledge will be generated. This will allow all the project participants involved in the project to gain the knowledge and also to understand the current situation of the project. The connections and knowledge gained allow individuals to work effectively and help to avoid mistakes during the projects. While an individual keeps repeating this process again in different BIM projects he/she is expected to become a skilled person with ability to deal with BIM issues in any project setting. However it is important to notice that every project is unique and has its own BIM related skills challenges. Therefore as interviewees suggested more training, engaging with other BIM projects, following BIM courses, getting constant feedbacks about software from the newsletters, understanding the standards and setting out the project goals in the beginning of the project needs to done to achieve better project outcomes.

Therefore this current situation in the construction industry has confirmed that new technology such as BIM has created a new culture and it has reshaped the way of learning. In early days learning theories were only concerned of individual learning whereas currently learning as a function is not under control of learner therefore learning needs to be redesign as two-way process (García, 2008). Actuate known knowledge at the point of application is vital in a learning theory. When the knowledge is needed and not known; it is important to have the ability to plug in the sources to meet the requirements. Connectivism theory is suitable to adapt these circumstances and these interview results highlight the importance of distribution of knowledge within the construction team during the implementation of new technology. Diagram-2 explains the learning ecology in BIM construction projects. Understanding this learning process helps to improve the knowledge as well as makes the individual as a skilled person.

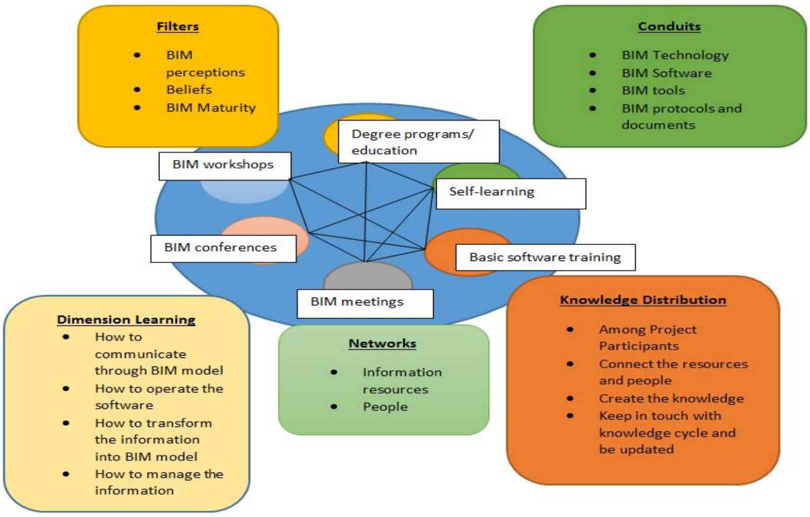

Diagram 2: Knowledge acquisition and learning process in BIM Construction projects

5. Conclusions

The construction industry has been one of the main engines of UK economic growth. Therefore several new technologies are introduced to improve productivity. BIM is one of the recently introduced technologies in the UK construction industry however it is not fully utilised due to the skills challenges. Therefore it is ever more important to focus on knowledge and skills acquisition during the technological change. The study conducted with BIM professionals working in the UK construction industry articulate that a new way of learning and knowledge acquisition needs to be introduced among the project participants to gain the appropriate skills to work with new technologies. Connectivism theory has been identified as a suitable approach to develop knowledge among project participants during the implementation of new technologies. The main principle of this theory is to distribute the knowledge through forming the connections between nodes. Therefore in this situation the knowledge acquired will be both individual learning and the learning outside the primary knowledge. This would help the project participants to achieve the project outcomes efficiently. Since a project participant keeps on accessing back to the knowledge cycle he/ she not only becomes a skilled person but also knows about the up-to date situation of their field. Therefore Connectivism theory is beneficial to understand the use of new technology and to improve the distribution of knowledge among project participants.

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Big Data in Construction Management Research

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Abstract

The paper is a literature review on Big Data in project management of construction projects. The literature shows practical examples of use and potential use of Big Data in construction management research. Big Data has become common as a business term in most businesses. However there is little published management scholarship that tackles the challenges of using Big Data, or even that explores the opportunities for new theories and practices that Big Data might bring about. There is a need for further discussion of the possible implications Big Data can have for construction management research.

The construction process can be studied in a number of dimensions. We structure documented and potential use of Big Data related to construction projects in the time perspective of a typical construction project, from concept preparation and brief, through design and construction to use.

We have identified studies describing Big Data applications and theory. Thematically they fall into three broad categories: 1) New construction equipment; generating, sharing and storing data about use. 2) Data from internal IT systems; such as planning, procurement and Building Information Modelling (BIM) can be utilised. Lastly, 3) people generate an increasing flow of information, which can be useful if handled with care. In combination this addresses the life-cycle from concept to decommissioning. We find that the construction phase appear to have received most attention from researches. We also find that several studies are applicable to more than one phase of a construction project. We find a potential for increased use of Big Data methods and applications within construction. While some data and applications have been analysed in isolation previously, there is a potential to combine different types of data.

Keywords: Big Data, Construction management, Construction projects.

1. Introduction

Big Data has become common as a business term in many industries, like manufacturing, transportation, retail, finance and IT. However, according to George et al. (2014), there is little published literature in management scholarship that deals with the challenges of using big data or even explores the opportunities for new theories and practices that Big Data might bring about. Olsson et al. (2015) discuss how Big Data can be applied in project evaluation and in project management research. But there is a need for further discussion of the possible implications Big Data can have for construction management research.

1.1 More quantitative data available

On a worldwide basis, the total amount of digital data created and replicated each year is expected to increase exponentially up to 2020 (Tien, 2013). This is also the case for data that can be applied in construction projects and management. The principles used in Big Data can also be applied on smaller quantitative data sets. This include data stored in company internal IT-systems.

The definition of Big Data is shifting as software tools become more powerful. Big Data was first defined as data sets whose sizes are too large for commonly used software tools to capture, manage and process within a tolerable elapsed time (Manyika et al., 2011; Tien, 2013; Waller & Fawcett, 2013). However, other definitions will probably be needed, as Big Data is becoming a part of commonly used software tools. The uniqueness of Big Data is the volume, velocity and variety, the three V's (Courtney, 2012; Russom, 2011). The volume refers to the size of data sets, containing a few terabytes to many petabytes. But it is the variety and velocity of the generated data that makes the data sets so big. Variety refers to the variety of sources. In addition, the data are measured and captured in more detail, such a location, time and metadata, giving both structured and unstructured data sets (Russom, 2011; Waller & Fawcett, 2013). The velocity of data refers to the speed at which the data is generated, from being recorded, updated or measured monthly and weekly to more frequent updates such as daily, hourly or continuously (Courtney, 2012). The access to real time or almost real time information makes it possible for a company to be much more agile than its competitors (McAfee & Brynjolfsson, 2012).

Courtney (2012) mentions veracity and value when describing Big Data. Veracity refers to a quality of the data sets, while value is reference to the goal from using the data sets. Veracity is a description of how the measures are reliable, referring to the accuracy and the quality of the generated data. Value refers to turning the Big Data-sets into value for the business. Size does not need to be the only defining part of Big Data, and data can be discussed along more than the mentioned three dimensions. George et al. (2014) points out that there are discussions among practitioners that "big" is no longer the defining parameter, but rather "smart", including a fine-grained nature of the data. The data available to companies are often unstructured (Davenport et al., 2012). The sources of digital data can include retail transactions, security cameras, internally registered data in the organisation, time-stamps, GPS-tracking, sensor-data from instrumented machinery and metavalues of documents.

The main reason to carry out data analysis is to derive information from data, knowledge from information, and wisdom from knowledge (Tien, 2013). And this is the purpose of Big Data. Big Data can give new information and knowledge for decision-making. For instance, Big Data can be used to make more precise predictions, and it follows that better predictions yields better decisions (Jagadish, 2015). McAfee and Brynjolfsson (2012) found that the more companies characterized themselves as data-driven, the better they performed on objective measures of financial and operational results. More and more business activity is digitized, and new sources of information are available (McAfee & Brynjolfsson, 2012). This also applies to the construction industry.

1.2 Use of new quantitative data in construction management

Technology has always been a part of construction management, both in research and practice, but there are new technological demands. This means that new data can support the trend towards an intelligent built environment, covering the whole lifecycle of facilities. Big Data has a potential to generate new insights into the costs, designs and processes of construction management. The aim is to develop tools and approaches for intelligent, efficient and sustainable construction management. Such strategies need to be sufficiently flexible to meet requirements resulting from changes in user-demands, technology and other framework conditions, while at the same time increase efficiency. It is a potential to integrate areas such as Computer Aided Facility Management (CAFM), Building Information Modelling (BIM), and Integrated Building Control and Monitoring Systems (BCMS). Such knowledge can later be utilized in decision making support, innovation of technical systems and in the education and training of project managers.

Monitoring activity across a large, complex construction site is particularly difficult because there are so many moving parts, and because the jobs being performed change frequently. In contrast to production industry, most construction sites are also temporary by nature, often challenging the investment in production infrastructure. Several reports document (including Egan, 1998; Lo et al., 2006; Durdyev & Mbachu, 2011) that construction lags behind other industries such as manufacturing in terms of productivity, and blamed the situation on problems with planning, coordination, and communication.

Modern construction equipment also generates data through usage. Producers of equipment such as trains have for some time utilised equipment life-cycle management data, which are generated in large scales through the period of production, operation, and maintenance. There is broad recognition of value of data and information obtained through analysing it. This type of data is also possible to generate from construction equipment. The exponential growth in this type of data means that new measures are needed for data management, analysis and accessibility. MIT Technology Review (2015) reports on the use of drones to monitor construction progress. Once per day, drones automatically patrol the work site, collecting video footage. The footage is then converted into a three-dimensional picture of the site, which is fed into software that compares it to computerized architectural plans as well as the construction work plan showing when each element should be finished. The software can show managers how the project is progressing, and can automatically highlight parts that may be falling behind schedule.

A discussion has emerged about use of Big Data and performance measurement for micro management and continuous monitoring of employees. Using drones to monitor activity continually can be controversial. Such controversies have occurred related to monitoring of employees in other sectors. As reported by the New York Times (2015), the company Amazon monitor employees in warehouses using sophisticated electronic systems to ensure they are packing enough boxes every hour. In a similar way, the Amazon also uses a self-reinforcing set of management, data and psychological tools to spur its tens of thousands of white-collar employees to do more and more.

1.3 Purpose and research questions

There is a need for broader discussions of Big Data in society and its implications for management research in general, including construction and project management. George et al. (2014) points out that even though "Big Data" has become commonplace as a business term, there is little published management scholarship that tackles the challenges of using such tools, or that explores the opportunities for new theories and practices that Big Data might bring about. The purpose of this paper is to investigate different use and potential use of Big Data in construction management research. The construction process can be studied in a number of dimensions. We structure documented and potential use of Big Data related to construction project along a time axis of a typical construction project, from concept preparation and brief, through design and construction to use.

Our research questions addressed in this paper are:

- Which applications of Big Data in construction project management have been published in recent years, based on the defined literature search criteria?
- Which time phases of a construction project are recent Big Data research relevant to?

2. Method

We review previous research and structure the papers based on the time perspective of a typical project. Several approaches were used to identify relevant literature. Searches in the Norwegian library database (Bibsys) were conducted, covering both books and academic journals. Searches were made using several search engines on the Internet, such as Emerald, Science Direct, Wiley Online Library, and Google Scholar. During the database searches, both titles and keywords were examined. In the searches in Google Scholar the entire texts are searched, consequently providing more search results of both relevant and irrelevant papers. Exclusion keywords were provided in the search, to exclude papers from non-relevant research fields. The collected material was subsequently examined in more detail. The main keywords used in the search were «big data», «construction project/industry», and (construction/project) management. Relevant literature was also found in the journal for automation in construction, as this is relevant technology and data source even though the papers do not use the phrase "big data".

Searches were also made with capital projects and engineering projects as search keywords, but with limited additional search results. Exclusion keywords used were psychology, ecology, biology, constructionism, health, and network construction. The overview of search keywords, databases and number of results is given in Table 1.

In the search results, there are several papers that are not available or do not deal with construction industry. Most of these were excluded by the excluding keywords. However, several papers are within the areas of software development, data management, construction of data centre facilities, Big Data project etc. but are not directly related to the construction industry. The papers where excluded by the search keywords, based on headings, abstracts, or a quick search for construction, management, and Big Data within the main text. Exclusion criteria were used to exclude studies that are not relevant to answer the research questions. Only papers that give a clear contribution or are of clear relevance to Big Data in construction projects or management are of interest. The papers are limited to 2014 and 2015, and Table 1 show that most research contribution has been published these last couple of years.

*Table 1: Overview of search keywords, databases and results. (*Year 2005-2015, **Year 2011-2015, ***Year 2014-2015)*

Keyword	*Search engine /data-base*	*No. of papers*
«big data» AND construction AND management	*Oria*	*121* (95)****
«big data» AND «construction project OR industry» AND management	*Google Scholar*	*(591)** (462)****
«big data» AND «construction project OR industry» AND management –psychology –ecology -constructionism	*Google Scholar*	*(418)** (319)****
«big data» AND construction AND «project management» -health, -ecology, -constructionism, -"network construction", -psychology	*Google Scholar*	*838 (581)* (553)***
«big data» AND «construction project OR industry» AND «project management» –psychology –ecology –constructionism -biology	*Google Scholar*	*168 (142)** (103)****

The literature that we found to be relevant to our research questions, where structured into the time perspective of a typical construction project inspired by the phases in the RIBA (The Royal Institute of British Architects) model. The RIBA Plan of Work is the definite UK model for the building design and construction process (RIBA Plan of Work 2013). The RIBA model has served as an inspiration to a recently presented Norwegian phase model for construction (bygg.no, 2015). The Norwegian model uses a time frame similar to the RIBA model, but highlights the perspectives of owner, user, supplier and society. The Norwegian model has the following phases: Strategic definition; Concept development; Concept design; Detailed design; Construction; Handover; Use and facility management and finally, Disposal. The selected literature is categorised based on this life cycle perspective. In addition to the time perspective, we found need for adding a second dimension, and discuss a number of alternatives.

3. Literature

As mentioned in the previous section, the construction phases that we structured the literature based on, are; Strategic definition; Concept development; Concept design; Detailed design; Construction; Handover; Use and facility management; and Disposal. The result of the structuring of the literature that we found to be relevant is given in Table 1.

A significant portion of Big Data is geospatial data, generated from sources such as mobile devices and RFID sensors. Geospatial Big Data gives both opportunities and challenges, as discussed by Lee and Kang (2015). Related to the construction industry, location aware data can give useful information into urban planning, by providing information in the early project phases on how people use public spaces and infrastructure.

Caron (2015) focus on the importance of an early engagement of stakeholders to improve the forecasting/planning process and manage the project. Engagement of stakeholders from the stage of the project life cycle, in which they may be involved in or be impacted by the project, can significantly increase the available amount of both explicit and tacit knowledge. Managing stakeholders is critical in large construction projects, and in infrastructure major projects this is especially difficult due to the diversity of stakeholders and interests. A study by Bakht et al. (2014) evaluate stakeholders' impact on infrastructure megaprojects through analysis of Big Data captured from online social media.

During the project phases, from early preparation to handover and the liability period, a project produces a lot of documents. Kähkönen et al. (2015) study content and characteristics of current practice of Electronic data/document management systems (EDMS) in building construction projects. This includes project cost, number of files and file accessing actions (open, view, download). They looked at 15 building development projects, which used the same data system.

According to Naderpajouh et al. (2015), effective frameworks to facilitate data-driven decision-making are noticeably lacking in the construction industry. They developed a hierarchical definition for health of the construction industry that was used to propose a framework to benchmark, interpret and analyse data associated with the status of the health of the industry. The dimensions of the framework include; positive financial performance; stability and resilience to shocks, pleasant working atmosphere, applying the best expertise, science, and technology in the production process, and producing high quality products.

Collection of new data and analytical approaches has potential to develop new insights in project management maturity, as examined by Williams et al. (2014). In particular two Big Data analytical techniques is highlighted to have potential to develop understanding of maturity in organisations. These are social network analysis and text analysis. The study by Whyte (2015) analysed change management practices in three separate organizations, including a large construction project, who all deliver complex projects, rely on digital technologies to manage large data-sets, and use configuration management to establish and maintain integrity. The organisations use for instance configuration management in the concept, product identification and definition stages, and as control at the "as-built" stage before handover. The authors conclude that the unstructured, uncontrolled nature of Big Data presents challenges to complex projects that deliver assets. Martínez-Rojas et al. (2015) demonstrate that suitable data handling facilitates and improves the decision-making process and helps to carry out successful project management. They analysed what the main information and communication technologies are, and reviewed the proposals that exist in the literature that focused on the management of information and knowledge from a general point of view in the field of project management.

Barista (2014) presents some early successful applications of data-driven design and planning applications, and how Building Teams can benefit from this. For instance, designers can capture and analyse data from key building performance metrics, such as energy use intensity, to optimize early prototypes. Based on feedback data from building occupants, firms can evaluate design concepts against the real world, and help the building team to understand how people interact with spaces. Redmond et al. (2015) studied how social network analysis and energy usage analyses can be a source to create integrated models for green building design. The main objective was to highlight green building technologies, while at the same time engaging end-users and harnessing their collective knowledge in building design. Several papers also treat opportunities and challenges in combining BIM and Big Data (e.g. Chen et al., 2015).

Several of the papers cover the construction phase. Akhavian et al. (2015) investigate the prospect of using built-in smartphone sensors as data collection and transmission nodes in order to detect detailed construction equipment activities. The method demonstrated a perfect success in recognizing the engine off, idle, and busy states of construction equipment. The work by Teizer (2015) outlines early results for vision-based sensing technology for tracking of temporary assets on infrastructure construction sites. Research and practical industry applications demonstrate promising work towards automated visual recording and progressing of temporary construction resources. Guo et al. (2015) show that Big Data can be used for behaviour observation in China metro construction. The suggested framework was verified in an example to be able to analyse semantic information contained in images effectively, extract worker's unsafe behaviour knowledge automatically.

Automation is a field in construction that uses new data sources and technologies. Machine-to-machine (M2M) installed on construction machines could be used to recommend overhauls to end users at the optimum timing according to Vanzulli et al. (2014). To track the progress of earthwork processes at underground construction sites, Bügler et al. (2014) suggests a novel method that combines two technologies based on computer vision, photogrammetry and video analysis. Combining these data sources allows exact measurement of the productivity of the machinery and determining site-specific performance factors. The construction quality of the material roller-compacted concrete, used in construction of storehouse surfaces, is affected by factors such as the roller compaction, concrete temperature and construction climate. Liu et al. (2015) proposes a real-time construction quality monitoring method, to provide the construction operations on site with timely collection and comprehensive analysis of construction data from the construction process. Wang et al. (2015) presents a method for automatic object recognition and rapid 3D surface modelling, including point cloud data collected from a construction jobsite. Yang et al. (2015) reviews state-of-the-art vision-based construction performance monitoring methods. According to Skibniewski et al. (2015), the construction and operation of infrastructure systems have opportunities for improvement through research on robotics and automation. Automated equipment could cut waste, improve job safety and the overall quality of construction projects. Performance monitoring can be made more effective with tools that better characterize the extent to which construction plan are being followed and the extent to which workers and equipment are being fully utilized.

Table 2: Categorisation of literature in the time perspective of a construction project.

<table>
<tr><th>Strategic definition</th><th>Concept dev.</th><th>Concept design</th><th>Detailed design</th><th>Construction</th><th>Hand -over</th><th>Use</th><th>Dis-posal</th></tr>
<tr><td colspan="3">Lee et al. (2015)</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="4">Caron (2015), Bakht et al. (2014)</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="6">Kähkönen et al. (2015), Naderpajouh et al. (2015)</td><td></td><td></td></tr>
<tr><td></td><td colspan="3">Redmond et al. (2015)</td><td colspan="4"></td></tr>
<tr><td></td><td colspan="5">Williams et al. (2014), Whyte (2015)</td><td></td><td></td></tr>
<tr><td></td><td></td><td colspan="5">Martinez-Rojas et al (2015)</td><td></td></tr>
<tr><td></td><td></td><td colspan="2">Barista (2014)</td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td colspan="2">Chen et al. (2015)</td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td>Akhavian et al. (2015), Teizer (2015), Guo et al (2105), Vanzulli et al, 2014, Bügler et al. (2014), Liu et al. (2015), Yang et al. (2015), Wang et al. (2015)</td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td colspan="3">Skibniewski et al. (2015)</td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td colspan="4">Lu et al. (2015)</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td>Hong et al. (2015), Ioannidis et al (2015), Isikdag (2015)</td><td></td></tr>
</table>

Lu et al. (2015) study the performance of construction waste management for the construction categories building, civil engineering, demolition, foundation, and maintenance and renovation. The study develops a set of key performance indicators (KPIs)/waste generation rates using an available Big Data set on construction waste management in Hong Kong. Demolition was found to be the most wasteful works that generate both non-inert and inert construction waste.

There have been published several examples of evaluation of buildings in use, using quantitative methods based on Big Data approaches. The study by Hong et al. (2015) reviews the state-of-the-art in the major phases for a building's dynamic energy performance, focusing on the operation and maintenance phase. Ioannidis (2015) presents Big Data and visual analytics techniques for comparing building performance under different scenarios and design. Data that provide useful information is energy consumption, building geometry, and space occupancy. Isikdag (2015) provides a method for facilitating the geographic information system (GIS) based fusion of information residing in digital building "Models" and information acquired from the city objects. The virtual BIM sensors in the proposed design pattern will provide geometric and semantic information together with information related to the state of the building elements, and the information can be used to represent the building within a GIS environment, and city monitoring/management.

4. Concluding discussion

Our first research question was related to which applications of Big Data in construction project management that have been published in recent years, based on the defined literature search criteria. We have identified studies describing Big Data applications and theory. Thematically they fall into three broad categories: 1) New construction equipment; generating, sharing and storing data about use. 2) Data from internal IT systems; such as planning, procurement and BIM can be utilised. Lastly, 3) people generate an increasing flow of information, which can be useful if handled with care. In combination this addresses the life-cycle from concept to decommissioning. We find that Big Data have been used in energy management. Data from internal IT systems, such as planning, procurement and BIM can be utilised. People generate an information flow, which can be useful but also treated with care to safeguard personal integrity. Heating, ventilation, and air conditioning (HVAC) and electricity management systems generate large volumes of data that can be applied for life-cycle management of the equipment, but also for describing the use of the building. None of the capabilities described in this study are entirely novel in inception nor unique to the construction industry, producers of major equipment such as train rolling stock have for some time utilised equipment life-cycle management data, which are generated in large scales through the period of production, operation, and maintenance.

Other categorisations of Big Data could have been applied. One alternative is to use a hierarchy of increasing aggregation; raw sensor data, databases of sensor data, reports from such systems, and different forms of presentations and reports based on input from several systems. Other alternative dimensions include different stakeholders involved in the project, type of data sources or different types of use of the data.

Our second research question was which time phases of a construction project that recent Big Data research is relevant to. The literature is presented based on a project phase perspective. We find that the construction phase appear to have received most attention from researches. We also find that several studies are applicable to more than one phase of a construction project.

We find a potential for increased use of Big Data methods and applications within construction. Typically, the power of data integration is hard to demonstrate in limited and small pilots, but requires critical mass before providing return. Big Data can be used to make more precise predictions, which can lead to better decisions. While data and applications related to different engineering disciplines, such as energy, have been analysed in isolation previously, there is a potential to combine different types of data. This creates opportunities, but also challenges related to personal privacy. Big Data appear to have a potential to generate new insights into the costs, designs and processes in project management. The aim is to develop tools and approaches for intelligent, efficient and sustainable construction project management. This research addressed Big Data. It is not necessarily the “big” part of Big Data that is key in construction applications. A possible development is that concepts from Big Data are applied on smaller datasets. Focus will then be on new data, or expanded use of existing data.

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The Implementation of Building Information Modelling within an Integrated Public Procurement Approach: The Main Contractor's Perspective

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Abstract

The purpose of this paper is to explore the impact of an Integrated Public Procurement Approach on the main contractor's attitude and to investigate how Building Information Modelling (BIM) can support emerging needs. Innovative Procurement Approaches that promote collaboration and sharing of risks among counter parties are spreading in the Public Construction Sector. However, there is still limited knowledge on what types of changes are required when these procurement models are applied. The research is based on a case study involving active participation. The Procurement Approach used is Leasing Costruendo, where a financial institution gives the money to the contractor to build public project and, only at the end of the construction phase, public administration pays the financial institution. The design team and the main contractor should work together to develop the project. Moreover, for a fixed period the main contractor carries out the facility management on an agreed bid price. The findings indicate the main contractor had to change work practices and processes and the implementation of BIM was very useful to manage emerging needs. The Procurement Approach forced the main contractor to collaborate with the designers and the suppliers, paying more attention to the quality of the building as well as to the schedule. The main contractor had to control design and construction phases in order to minimise future costs related to the facility management. Moreover, tight deadlines were respected to get money by the financial institution. Thus, higher quality public buildings have been delivered to the society. Results can be used to understand implication of an Integrated Public Procurement Approach and the role of BIM in helping the main contractor.

Keywords: Integrated Public Procurement Approach, Building Information Modelling, Leasing Costruendo, Public Construction Sector

1. Introduction

Recently, the Construction Industry has been asked to introduce some changes due to the economic crisis. Moreover, the construction activity has been reduced in the last years especially in European Countries such as Italy. This situation generates problems not only for construction companies, but also for public clients. On one hand, there are fewer projects for construction companies and, on the other hand, public clients have fewer possibilities to invest on public services and finance construction works for the community. In order to mitigate this trend, new procurement methods have been developed such as Public-Private Partnership (PPP) (Osei-Kyei and Chan, 2015). Osei-Kyei and Chan (2015) have identified the principal critical success factors of PPP in several Countries as appropriate risk allocation and sharing, strong private consortium, political support, community/public support and transparent procurement. *Leasing Costruendo* falls into the PPP category. One of the major innovation in *Leasing Costruendo* deals with the involvement of financial institutions, such as banks, to realise buildings and infrastructures. Meantime, these innovative procurement methods introduce new requirements and responsibilities for the parties involved in the process (Love et al., 2015), especially for the main contractor. Thus, new approaches are required to deal with new challenges in procurement (Love et al., 2015). However, there is still limited knowledge on what types of changes are required when these procurement models are applied. The proposed paper explores the impact of the *Leasing Costruendo* procurement method on the involvement of main contractors in design processes and how Building Information Modelling (BIM) can support emerging needs.

2. Methodology

The research approach is based on a single case study where an Integrated Public Procurement approach (*Leasing Costruendo)* has been used together with Building Information Modelling (BIM). An Italian case study has been selected to investigate main contractor's perspective. The author's team actively participated in the case study and followed the progression of the projects taking part into meetings and supporting the introduction of BIM in the workflow.

The use of a BIM methodology was not included in the tender documentation. However, the main contractor decided to implement it in order to better manage risks associated to this procurement method. The main contractor selected a design firm and a financial institution to bid together for a public tender. The object of the tender concerned the construction and the twenty-year maintenance of two new pre-primary schools (four-class and eight-class), an auditorium and a food service building. After the awarding of the tender, the main contractor, a small-to-medium enterprise (SME), started to concern on risks related to the contractual agreement with the financial institution (a bank) as well as on problems due to the maintenance activity. The main contractor, in fact, did not have any previous experience on facility management tasks. For that reason, it agreed to embrace an innovative approach that could have helped them to take into account the entire life-cycle of assets. Some years before the awarding of the tender, the main contractor attended training courses related to BIM benefits for construction companies. Even if it did not have any direct past experience on BIM projects, the construction company decided to contact the authors' team to implement a BIM-based process. The first aim of the main contractor dealt with the realisation of a Building Information Model through which to effectively support facility management activities. After some meetings, the chair decided to involve the authors' team in the design process, that was still ongoing at the detailed design phase, in order to create a parametric model from the traditional 2D drawings. Thanks to the Building Information Model, several clashes and omissions were identified in advance and the entire process was optimised.

Research results are based on a single case study, for this reason, they cannot be generalised to the entire construction sector. In addition, the authors' team was actively involved in the decision-making process: weekly meetings were arranged in order to present and discuss critical issues with designers, main contractor and sub-contractors. The authors are aware of weaknesses of being involved in the process due to the contractual agreement with the construction company. However, this approach allowed the authors to better understand the construction company's 'way of thinking'. An active participation in the process was crucial to understand the main contractor's needs and to study the constant evolution of the project from design to construction.

3. BIM and Procurement

3.1 Overview on building procurement systems

The construction sector has a long experience in using traditional procurement methods such as Design-Bid-Build (DBB), Design-Build (DB), and Construction Management (CM) (Lahdenperä, 2008). Starting from 1990s a growing interest in Public-Private Partnership (PPP) has emerged, especially after 2007-2008 global financial crises (Osei-Kyei and Chan, 2015). Public institutions seek to use private sector's knowledge and capital to minimize their deficit and, in the same time, maximise taxpayers with value for money (Osei-Kyei and Chan, 2015). In addition, in order to reduce risks and costs associated to procurement, new procedures are spreading in the AEC industry as discussed by Bolpagni (2013). Some of them are Cost Led Procurement (CLP), Integrated Project Insurance (IPI), Two Stage Open Book, Integrated Project Delivery (IPD) and Project Alliancing (PA) (Bolpagni, 2013).

Within the UK Construction Strategy (Cabinet Office, 2012), three innovative procurement methods CLP, IPI and Two Stage Open Book, have been developed in 2011. The new procurement models are based on early contractor involvement, independent assurance and higher levels of integration and transparency (Cabinet Office, 2012). The client plays a crucial role as driver in order to promote innovation, identify waste, secure knowledge transfer and corresponding growth opportunities (Cabinet Office, 2012). Integrated Project Delivery (IPD) and Project Alliancing, also called Alliance Contracting (Petäjäniemi and Lahdenperä, 2012), are relational project delivery arrangements where all the stakeholders are committed to a mutual objective and are involved from the very beginning of the project (Halttula et al., 2015).. It is important to underline that, even if it is possible to achieve IPD without BIM, its adoption is essential to efficiently achieve the collaboration required for IPD (AIA, 2007; Eastman et al., 2011).

3.2 Role of BIM in building procurement systems

Despite significant differences on the management of these innovative procurement procedures, all of them encourage the early involvement of counterparties and a collaborative behaviour, trying to move from an 'everyone against everyone' approach to 'we are all in the same boat' (Ciribini et. al., 2015). This is the reason why Building Information Modelling can be used to achieve these goals, as it allows cooperation and transparency (Eastman et al., 2011; Bolpagni, 2013, Halttula et. al., 2015).

Building Information Modelling can be implemented in several procurement methods, from traditional to innovative ones (Bolpagni, 2013). However, when BIM is used in traditional procurement methods full potential cannot be expressed (Salmon, 2012). According to Dave et al. (2013) traditional procurement routes and forms, such as DBB, can be the 'biggest hindrance to a proper Lean/BIM implementation (or even individual Lean or BIM implementation)'. Actually, the maximisation of value and the minimisation of waste is difficult when the contractual structure inhibits coordination, stifles collaboration and innovation, but incentives individual goals at the expense of others (Mathews and Howell, 2005). A partnering approach, as supported by the new form of contracts (*e.g.* ConsensusDOCS, 2015), can support principles required for Lean/BIM implementation such as collaboration and integration (Dave et al., 2013). Relational contracts enable commercial relationships between the parties that not only stimulate 'mutual trust, but also facilitate the sharing of knowledge and information to generate innovation and value' for the parties involved (Colledge, 2005). The approach is generally 'people oriented' and, thanks to it, time, cost and quality risks are managed collectively focusing on the achievement of wider, shared values or purposes such as a successful outcome for a client (Colledge, 2005). Moreover, relational contracts often provide team-based incentives or reward mechanisms, placing value on successful outcomes, rather than in cost or individual performance (Colledge, 2005). Thus, relational contracts can better support co-location of teams, early contractor involvement, joint development of design and other such crucial requirements, rather than traditional contracting methods (Dave et al., 2013).

There are already contractual forms suitable for a BIM environment (McAdam, 2011). In the UK there is a long experience of collaborative procurement and currently Government is fostering it (McAdam, 2011). NEC3, PPC2000 and JCT Constructing Excellence promote working in a 'spirit of trust and co-operation' (McAdam, 2011). Thus, even if they have not been developed on purpose of BIM, they can be appropriate for use as part of a successful BIM process (McAdam, 2011). On the other hand, Document E202 and ConsensusDOCS 301 have been set in the US to be incorporated in a BIM project (McAdam, 2011).

Relational contracting principles are more difficult to be applied in the public sector rather than in the private one due to several limitations such as legal constraints, cultural clashes and lack of skills (Ke et al., 2011). Thus, more attention is needed dealing with public sector in order to achieve successful results.

Nowadays, there is not an Italian governmental strategy to guide the growing implementation of information-based technologies. Thus, several Italian public calls for tender have required the use of BIM ‘tools’ without a proper change in the working process. The Legislative Decree on public work is currently being updated to include the European Directive (European Parliament, 2014). For the first time the European Directive stated that ‘for public works contracts and design competitive bids, Member States may require the use of specific electronic tools, such as of building information electronic modelling tools or similar’ (European Parliament, 2014). Thus, also the European Directive explicitly refers to the use of BIM ‘tools’ instead of a BIM-based methodology. The Italian legislator is carefully dealing with this topic to avoid the use of BIM just as a technological change.

4. Case Study

4.1 Introduction of *Leasing Costruendo*

The leasing is a financial method mainly used in the private sector. Recently, it has been used also in the public sector. It mainly involved three parties: a public administration (*e.g.* a town council), a financial institution (*e.g.* a bank) and a construction company. During the tender phase the financial institution and the construction company bid together in order to award the project. After the awarding, the public administration periodically sends the money to the financial institution and the bank gives it to the main contractor in order to build the asset (Figure 1). The construction company must respect the schedule in order to be paid by the leasing company during the construction phase. After the construction phase, the construction company is in charge of the maintenance for an agreed period (Figure 2). That is one of the reasons why the construction company has to provide a high quality building to reduce future maintenance works and organise all the information in an efficient way in order to easily access them if needed.
When the agreed maintenance period ends (in the proposed case study it lasts twenty years), the construction company has to give back the property to the public administration (Figure 3)

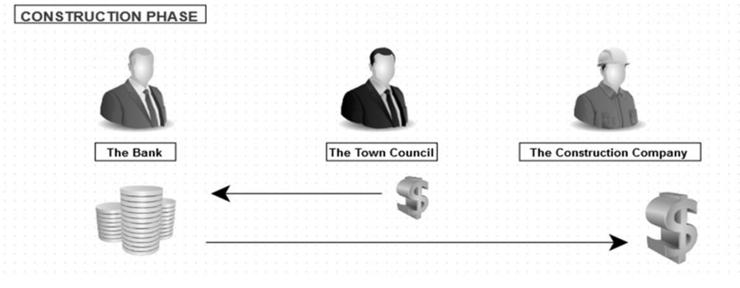

Figure 1: Leasing Costruendo - Phase 1

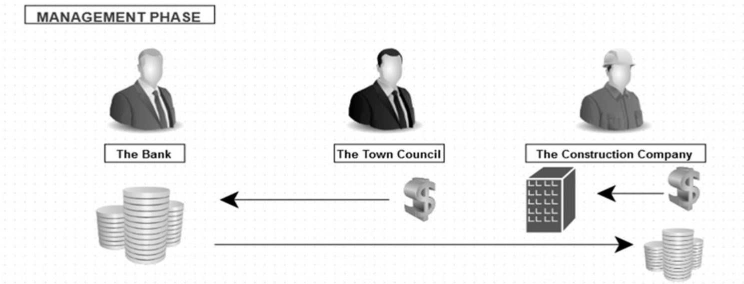

Figure 2: Leasing Costruendo - Phase 2

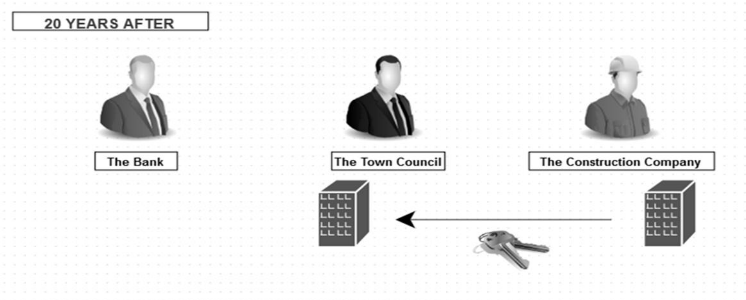

Figure 3: Leasing Costruendo - Phase 3

In the presented case study, the public administration developed the first phases of the design process and it asked bidders to present a detailed design. After the awarding phase, the public administration was in charge of monitoring the construction phase. In this procurement method the financial institution assumes all the financial risks related to the investment. On the other hand, the construction company assumes all the non-financial risks related to the construction and maintenance of assets, such as supply management and maintenance costs. *Leasing Costruendo* is a beneficial financial method for the public administration, because it can promote the realisation of high quality buildings and payments can be divided in several quotes. Moreover, usually the schedule is respected because the financial institution can receive payments only on the base of previously defined construction percentage progress. During an economic crisis as the current one, with a large number of Italian public administrations not having financial capabilities to promote new projects, the use of *Leasing Costruendo* is growing.

Leasing Costruendo could be considered as an innovative procurement method that forces the parties involved to collaborate in order to reduce risks. The main contractor, in fact, has to establish integrated and collaborative workflows with designers, subcontractors and the public client in order to define efficient solutions. *Leasing Costruendo* falls into the PPP category of procurement. A BIM approach could be beneficial to support a collaborative and a life-cycle approach as also discussed by Love et al. (2015).

4.2 Description of the project

The proposed case study is related to the construction and the twenty-year maintenance of two new pre-primary schools (four-class and eight-class), an auditorium and a food service building.

The public client divided the tender in two parcels with a different delivery deadline. The first parcel includes three buildings, two new constructions (four-class pre-primary school and food service building) and the renovation of an existing auditorium. This first parcel had to be completed in a time span of 240 consecutive days. The construction activities within the second parcel could start only once the first parcel had been completed, in accordance with some constraints such as the start of the new academic year and the necessary time to move the educational activities from the existing school to the new one. The second parcel includes the new construction of an eight-class pre-primary school. Because of this schedule, the main contractor had to carefully organise its construction activities in order to avoid penalties and delays on the starting date scheduled for the second parcel. A lack of production, in fact, would have led a payment postponement according to the construction percentage progress and, at the same time, resources that could not be relocated on other construction sites.

The four-class pre-primary school is a one-floor new construction building and it has an area of 1200 m^2. The structure is composed of a reinforced concrete foundation (thickness 40 cm), supporting precast wooden vertical structures. In accordance with architectural and structural designs, the MEP systems are collocated within the ventilated under-floor cavity; ducts and pipes are supposed to climb only in specific points. The construction company needed a detailed planning of the sewerage and ventilation systems installed in the ventilated under-floor cavity to be coordinated with the design of the precast vertical structures in order to optimise coordination and construction sequences on site.

The first parcel also contains an auditorium, an existing building of 1000 m^2 built in the nineties with a precast concrete structure. This building needed to be renovated with new architectural and MEP systems parts, including the ventilation and electrical ones. A critical issue was the coordination between architectural design and ventilation systems. In the first parcel there is also a food service building, a new construction of 1250 m^2 to be built next to an existing one. The structure is in cast-in-place reinforced concrete. MEP systems are mainly installed above suspended false ceilings. Finally, in the second parcel there is the eight-class pre-primary school. It is a two-floor new construction building with an area of approximately 2900 m^2. The structure is entirely in cast-in-place reinforced concrete and MEP systems are allocated above suspended false ceilings.

4.3 The BIM implementation

In the proposed case study, the bid was related not only to the construction phase, but also to the maintenance one and the construction company had to include costs related to both phases in the offer. Moreover, the tender selection criteria was the lowest-price one, a very common criteria in Italian public procurements. The evaluation of construction costs was a well-known activity for the main contractor; on the other hand, it was not familiar with facility management activities. For the first time, it had to consider a twenty-year maintenance project, taking into account facility management issues. Moreover, usually traditional practises do not effectively integrate different phases, such as the design, construction, operation and maintenance ones, leading lack of knowledge and inefficiencies (Eastman et al., 2011). In the proposed case study, the required integration of design, construction and maintenance phases was a new challenge for the SME. For that reason, the main contractor thought that Building Information Modelling could have been a valuable support. Therefore, the principal needs of the construction company were related to a constructability review of the designed buildings, optimising the construction phase, and to the definition of optimal solutions for an efficient facility management in order to reduce possible future costs.

A small group of Civil and Building Engineers with competences in Information Modelling and Management (IMM) was organised in order to coordinate a BIM-based approach between designers, the main contractor and the subcontractors. Unfortunately, the use of a BIM approach started only in the final phase of the design process, between the technical design phase and the construction one. At first, in order to set up a successful process, it was necessary to answer to the following questions:

- According to the defined BIM uses of constructability review and facility management, what is the Level of Development (LOD) (AIA, 2013) required for the informative content of the Building Information Model? Which kind of geometric accuracy is needed?
  For example, it was decided that a high degree of geometric accuracy was essential in order to avoid intersections and to identify and correct any problems that, otherwise, might have arisen during the installation of MEP systems (COBIM, Series 6, 2012). Moreover, the Building Information Model was managed in order to visualise construction sequences and support the installation phase, as suggested by Rischmoller et al. (2001). Facility management parameters were embedded in BIM objects according to the Construction Operations Building Information Exchange (COBie) standard (Eastman et al, 2011) and the contractor's requirements. A shared calendar between the main contractor and the suppliers was also organised in order to remind maintenance scheduled dates by means of an automatic alert e-mail system.
- Which would be the best procedure in order to exchange information among the stakeholders involved?
  An iterative process of Model Checking allowed the main contractor to effectively implement the BIM methodology for improving the construction phase (AGC, 2010). Model checking was used to detect clashes and validate coordination and collaboration

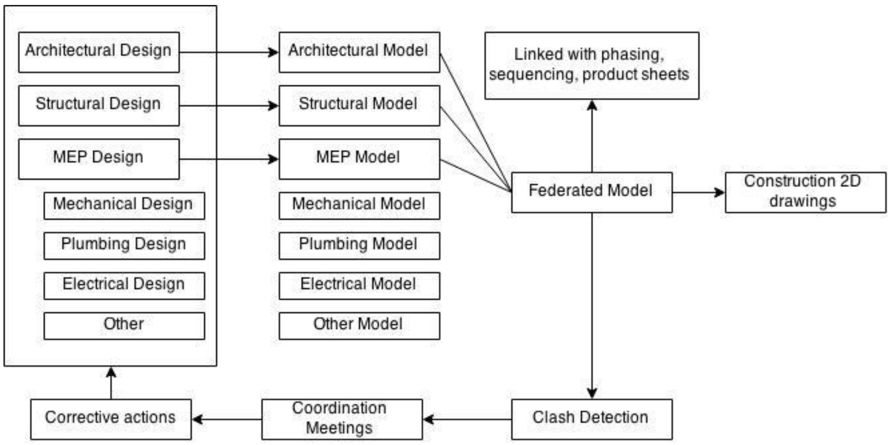

Figure 4 Ongoing discipline and multi-discipline clash detection to support the decision-making process and the constructability review (Caratozzolo et al., 2015)

between designers, main contractor and subcontractors (COBIM, Series 13, 2012). This approach allowed the optimisation of the design phase according to constructability and maintenance needs. Building Information Models of each discipline were produced based on traditional 2D designs and merged into a federated model. Clash detection results were exported in clear and effective coordination reports and documentation to be used during interdisciplinary meetings between designers, main contractor and subcontractors. After that, corrective actions were taken and the optimisation process started again (Figure 4).

5. Results and Discussion

The iterative and collaborative validation process, was essential for construction and the maintenance phases. It was strictly connected to a high level of coordination and responsibility for all the actors involved, from designers to suppliers. Subcontractors actively participated to all the coordination meetings during the constructability review process and they had the opportunity to clearly visualise what would have been realised on site. Moreover, subcontractors had an active role in the decision-making process integrating their knowledge to designers' and main contractor's. An example of the coordination achieved is related to the construction of the pre-primary school 'four-class': here the position of the ventilation vertical ducts influenced the design of the precast wooden walls. The subcontractor of the wooden structure had the opportunity to exactly know where MEP systems would have been located and their actual dimensions, so it was decided to optimise the design and the installation process by customising the precast wooden panels.

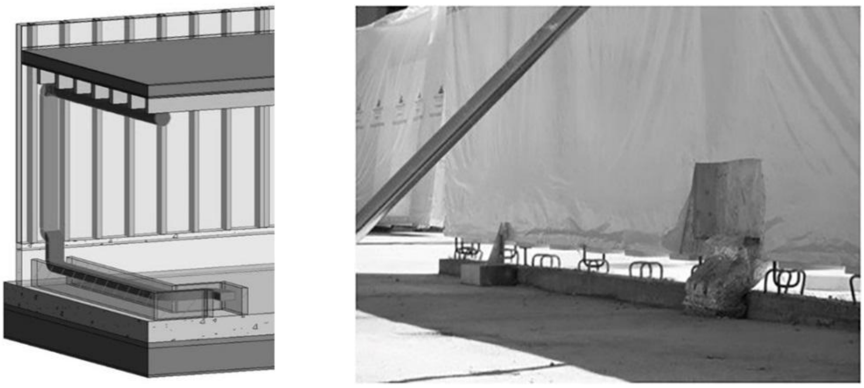

Figure 5 Customised precast wooden walls based on the BIM Model (Caratozzolo et al., 2015)

A special area to host the climbing vertical ducts within wooden panels was added (Figure 5). In this way, the energy efficiency of the wooden panels was controlled. Indeed, on site some climbing ducts in the wooden panels could have modified the dimension of the insulation layer and the final energy efficiency of the system. Moreover, MEP geometric accuracy was such that the installation of MEP components could have been conducted based on the Building Information Model. From the beginning, in fact, the main contractor understood the potentialities of this BIM-based approach, and it decided to use the Building Information Model as the unique source of data to review the project and extract shop drawings. In this way, a high level of coordination was guaranteed and the merged model was the reference point that everyone had strictly to follow. This approach allowed subcontractors to work at the same time on different tasks, reducing construction time and costs. This result was very important to respect schedule deadlines with the bank required in *Leasing Costruendo*. Moreover, the improved collaboration between parties favoured trust in the decision-making process.

This approach is still not common in Italy, especially for SME, which traditionally use 2D drawings. The Italian law does not require the use of BIM procedures and Building Information Models are rarely considered effective due to lack of skills and trust in new approaches. *Leasing Costruendo* is an innovative procurement method and contractors are still not used to integrate design, construction and facility management phases. Finally, they are not used to work with a financial institution and respect deadline to receive the money.

6. Conclusions and Future Works

Leasing Costruendo is a quite new procurement method that creates emerging needs for construction companies such as a project life-cycle approach and respect of the schedule. In this procurement method, contractors have to deal with facility management issues that usually are not part of their business (Love et al., 2015). Moreover, even if the construction site of the proposed case study did not have large dimensions, realisation times were tightened and the different types of buildings required different skills, construction procedures and maintenance solutions to be defined. In order to meet these new needs, the implementation of the BIM methodology was crucial.

In this case study the effectiveness of the BIM implementation was limited because it was implemented in a traditional design process and required by the main contractor. More benefits would have been reached if the public owner had asked for such an integrated process since the beginning, including Employer's Information Requirements (EIRs) (BSI, 2013) in the tender documentation. The public client has to be an intelligent driver, anticipating and solving possible issues during the entire project life-cycle. Moreover, clients need to work within a single source of digital information, defined as Common Data Environment (CDE) (BSI, 2013), with the entire supply chain in order to manage a fully effective BIM process. With regard to the use of BIM, in fact, general issues depend on the level of collaboration within the project team since the early beginning. The public client has to learn how to effectively formalise the EIRs to outline issues and then collaboratively work with the entire supply chain. Thus, it is important to explore several possible solutions, taking into account issues of constructability and facility management from the design phase. In this way, clients become co-author of the process.

Moreover, information modelling is based on the management of an integrated knowledge; but today traditional procurement methods tend to put the various parties one against each other (Eastman et al., 2011; Bolpagni, 2013). For this reason, the implementation of the BIM methodology is an opportunity to improve procurement processes, promoting the digitalisation of the entire supply chain. Integration Project Delivery (IPD) and other collaborative procurement methods such as *Leasing Costruendo* allow the early involvement of contractors in the design process increasing benefits of using BIM.

Finally, the implementation of the information-based technologies needs to be consistent with an effective BIM-oriented strategy. If the awareness on the change of the entire process is not fully developed, the tendency is to use new tools of information modelling and management only to emulate traditional processes and to provide traditional documentation. This practice, however, leads to data fragmentation, invalidating the potential innovative aspect of the Information Management and Modelling (IMM) methodology. In Italy a government BIM mandate seems to be necessary for an effective implementation of new digitalised practises and integrated methodology, together with the development of standards and guidelines to support all the parties involved in the process according to their specific needs.

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The European Client's Attitude Towards the Quasi-Automation of the Procurement Processes within a Digital Environment

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Abstract

The paper shows the client's attitude towards the quasi-automation of the procurement processes in the backdrop of a digital environment in some European countries. The construction industry is increasingly competing on new bases, implementing a digital approach. The client plays a key role in defining digital requirements and controlling the entire supply chain in the very early phases. Indeed, first, an 'intelligent' digital built environment needs an 'intelligent' driver. In this scenario, clients should set digital requirements able to control the compliance of offers in a quasi-automated way during tendering and awarding stages. However, the current implementation and understanding on this new attitude is not very clear and there is a gap in literature. For this reason, a deductive approach based on an online questionnaire delivered to a sample of leading European clients has been used to investigate the state of the art. Results indicate that a large number of clients use digital tools to set digital requirements and include digital deliverables in the contract (such as Building Information Models). However, the adoption of e-Procurement platforms and the evaluation of the entire supply chain during the tendering and awarding stages are still limited. Moreover, most of the clients perceive that the quasi-automation of the procurement process can generate benefits and favour risk mitigation for banks and insurances. The results can be used to get a better understanding of the current situation and to define fields where a digital approach can be further implemented.

Keywords: Procurement Process, Digitalization, Tendering, Quasi-Automation, Building Information Modelling

1. Introduction

Several European Countries, such as the UK, Germany, France and Spain are actively working on the digitalisation of the construction sector implementing Building Information Modelling (BIM). By now, there is not an univocal definition of BIM; Eastman et al. (2011) define it as '*a verb or adjective phrase to describe tools, processes, and technologies that are facilitated by digital machine-readable documentation about a building, its performance, its planning, its construction, and later its operation*'. It is important to underline that BIM is not just a technology change, but also a process change focused on a life-cycle approach (Eastman et al., 2011). Moreover, it promotes a high level of collaboration among project participants (Eastman et al., 2011). In the last year, several reports have been published on the impact of BIM (e.g. Dodge Data & Analytics, 2015). Even if there are still limitations on its full implementation, BIM can improve the overall process (Bolpagni, 2013). For this reason, the European Parliament (2014) incorporated it in the new Directive on public procurement and several European Countries have decided to include it in their construction strategies.

In 2011 the UK Cabinet Office published a Government Construction Strategy followed by an Industry Strategy for 2025 (HM Government, 2013), a report on the digital future of the Built Environment 2050 (Philp and Thompson, 2014) and the *Digital Built Britain* initiative (HM Government, 2015). The Government will require level 2 of BIM on its projects by 2016 and it is working to promote an industry that is 'efficient and technologically advanced' (HM Government, 2013). Moreover, in 2015, the German Federal Ministry of Transport and Digital Infrastructure declared the creation of a Digital Building Platform and it announced an initiative for the digitalisation of the construction industry. Indeed, BIM will be applied to all new projects from 2020 onwards. In addition, the French Ministry of Territorial Equality and Housing is promoting the modernisation and innovation within the construction sector and a BIM Task Group has been established in 2015. Moreover, in the same year, the Spanish Ministry of Public Works has established a national BIM strategy and it is working to include BIM as a mandatory requirement on public projects. In addition, Scandinavian Countries, such as Finland and Norway, have developed national BIM Guidelines to support the use of BIM in public works.

These initiatives demonstrate that the Construction Industry is increasingly competing on new principles, implementing a digital approach. More and more the client plays a key role in defining digital requirements and controlling the entire supply chain in order to achieve an effective process. Indeed, first, an 'Intelligent' built environment needs an 'Intelligent' driver. However, the current implementation and understanding on this new attitude is not very clear and few published data is available in literature. Thus, the aim of the paper is to show the client's attitude towards the quasi-automation of the procurement processes in the backdrop of a digital environment in some European Countries. Nowadays, it is not possible to fully automate the procurement process, especially the creation of digital requirements and the evaluation of offers (e.g. due to the presence of subjective requirements that cannot be translated into machine-readable rules) (Ciribini et al., 2015). Thus, expression 'quasi-automation' is used in the paper.

1.1 Overview of the digitalisation of the Procurement process

The digitalisation of the procurement process is not a new concept and in literature there are several publications on the use of e-Procurement and e-Business indicating the state of art, benefits and barriers both in the public and private sectors (Chaffey, 2009; Eadie et al., 2010; Ronchi et al., 2010; Costa et al., 2013). As showed by Eadie et al. (2010) the principal drivers deal with reduction of costs and time together with improvement of quality. On the other hand, the principal barriers are related to cultural, infrastructure, security, legal and compatibility limitations (Eadie et al., 2010).

In the public sector, the European Commission has promoted several initiatives. In 2010 the European Commission delivered a document to define objectives of the European Digital Agenda. The principal aim is to promote 'sustainable economic and social benefits from a digital single market based on fast and ultra fast internet and interoperable applications'. One of the key elements deals with the digitalisation of public services for citizen and business (e-Government) (European Commission, 2010a). In the same year, several documents have been published such as the 'The European eGovernment Action Plan 2011-2015. Harnessing ICT to promote smart, sustainable & innovative Government' (2010b). Today the EU is working on a new e-Government Action Plan 2016-2020 to complete the Digital Single Market (European Commission, 2015b). Moreover, the Green paper on expanding the use of e-Procurement in the EU (European Commission, 2010c) explained the importance of e-Procurement, the current state of art, challenges and actions to be taken. The principal challenges deal with the overcoming inertia and fears on the part of contracting authorities and suppliers, lack of standards, absence of means to facilitate mutual recognition of national electronic solutions, onerous technical requirements and the management of multi-speed transition to e-Procurement (European Commission, 2010c). The last topic has been clearly described also in the IDC report (2013). The new Directive on public procurement (European Parliament, 2014) makes the use of e-Procurement progressively mandatory and by October 2018 Member States are required to use e-Submission. Despite several initiatives to promote e-Procurement in EU, such as the PEPPOL project, there are still several barriers (2012, 2015).

It is important to underline that usually e-Procurement is associated with the use of electronic processes to procure supplies and services (European Commission, 2010c). Instead, e-Procurement is often used to procure works due to its greater complexity (Bolpagni, 2013).

As previously discussed, Building Information Modelling is more and more becoming a key element of the digitalisation of the construction sector. However, there is not a large number of e-Procurement platforms able to manage a BIM-based process. In Portugal, several research activities have been developed to integrate BIM within e-Procurement platforms during the PLAGE project (Jardim-Goncalves and Grilo 2010a, 2010b; Grilo and Jardim-Goncalves 2011, 2013; Costa and Grilo, 2015). However, a functional platform is not yet available. Moreover, Costa and Grilo' s approach (2015) is focused on e-tendering using a Building Information Model to purchase a specific product for a building, but it does not discuss procurement processes where a Building Information Model is not yet available in tendering.

Some platforms (e.g. Viewpoint For Projects™, Asite™, Aconex© and Conject©) are emerging in the market in order to manage a collaborative BIM-based process and some procurement tools are available. For example, Viewpoint For Projects™ allows setting an invitation to tender attaching a Building Information Model. However, effective data analytics tools are not available and e-Procurement platforms cannot fully take advance from a BIM-based approach.

2. Methodology

A deductive approach based on an online questionnaire has been used. The empirical data was gathered via an online SurveyMonkey® questionnaire. SurveyMonkey® is an online survey programme that allows the user to create and manage the survey from a web-interface. A sample of leading European clients has been chosen to investigate the state of the art on the digitalisation of the procurement process. Three European Countries, the UK, Finland and Germany, have been selected. The clients were chosen for their active participation in national working groups for the innovation of the AEC sector. In the paper, they are both defined as 'clients' or 'European clients' due to their belonging to Countries where European directives on Procurement are adopted, especially for the public sector. Initially, 46 clients were selected and each of them was contacted by email, telephone or direct contact. A presentation was sent to all contacts by email to get an introduction of the research topic and to better explain the purpose of the survey. Moreover, the same email included a web link to access the online survey.

The survey was a structured questionnaire where questions were listed in a pre-arranged order and all questions required answers. The survey contained 19 questions: 14 closed-ended and 5 open. The survey was divided in three parts: a) general questions to investigate the type of clients b) questions related to the management of tendering and c) questions related to the use of a digital procurement process. The survey covered the following main topics:

- use of information requirements
- evaluation of the entire supply chain in tendering
- digital requirement in tendering
- use of e-Procurement platforms
- benefits and limitation of a quasi-automated procurement process

The online questionnaire has been accessible for three weeks starting from January 2015 and responses were received from 14 contacts, all of them were full completed. First, results were analysed using SurveyMonkey®. The tool provides an automatic visualisation of results in graphics as well as in tables. Later, data were exported in Excel in order to create different graphs. In addition, the free tool Wordle™ was used to create world clouds to analyse results coming from open questions. Finally, results were shared among interviewees and a workshop was organised to present findings. It is important to underline that the number of received responses is very limited; thus, findings cannot be generalised to the entire construction industry. Moreover, interviewees were selected from groups that are actively engaged in digitalisation processes of their respective countries. Therefore, findings are especially addressed to the leading edge of the industry.

3. Survey Findings

The paragraph reports findings of the survey divided in three consecutive sections: general questions, management of tendering and the use of a digital procurement process. Later, results will be discussed in paragraph four.

3.1 General questions

The first part of the survey investigates client's general information to better understand if they work in the public or private sector and which is their type of business.

The interviewees are mainly public clients (64,29%) followed by developer private clients. Most of them are involved in infrastructure works (42,86%), some only in vertical assets (35,71%) and only few have a mixed portfolio (21,43%). As clients, most of them usually buy capital projects (64,29%) and only few both capital and operational expenditure (35,71%).

3.2 Management of tendering

The second part of the survey explores if clients usually provide information requirements in tendering. In the UK, such requirements have been defined as Employers Information Requirements (EIRs) (The British Standards Institution, 2013). EIRs are pre-tender documentation '*setting out the information to be delivered, and the standards and processes to be adopted by the supplier as part of the project delivery process*' (The British Standards Institution, 2013). The use of client's information requirements in an early phase of the process, forces clients to reason about their needs and provide more information to bidders. The survey investigates also if clients have standard organisational and asset requirements. In addition, other questions explore how clients usually evaluate the supply chain, especially on BIM capabilities. Indeed, BIM is more and more mandatory in tendering, but in literature there are not standard evaluation criteria and it is not clear if and how clients evaluate this requirement.

Most of interviewees (78,57%) affirmed that they determine and issue client's information requirements as part of the tender process. Most of interviewees do not have standard set of organisational and asset requirements (42,86%), others develop them uniquely for each project (35,71%) and only few have such requirements (21,43%). Moreover, the survey reveals that most of the interviews evaluate only the tier 1 design team and main contractor (78,57%) on BIM capabilities. On the other hand, only few (21,43%) evaluate the tier 1 plus their proposed supply chain. In addition, interviewees were asked to express how they usually assess capabilities of the supply chain ticking all options that applied. A large number of clients use BIM pre-qualification questionnaires (92,86%) followed by pre-contract BIM Execution Plans (BEP) (64,29%), interviews (42,86%) and capabilities assessments tools (35,71%). Finally, most of clients use standard criteria to measure capabilities of the supply chain (50,00%), others apply tailored project specific criteria (35,71%) and only few do not measure them (14,29%).

3.3 The use of a digital procurement process

The third part of the survey shows client's feedback on the adoption of a digital approach for the procurement process. Questions examine client's use of digital deliverables as well as electronic procurement (e-Procurement) platforms. Moreover, interviewees express their opinion on the main benefits, risks and cultural barriers related to the implementation of a quasi-automated procurement process, especially in tendering and awarding phases. The survey also investigates potentialities of gamification in procurement. It is a quite new concept and it deals with the paradigm of anticipation. For example, during the tender phase a gamified approach could force the main contractor to simulate its relations with perspective suppliers in front of a specific situation. Finally, interviewees were asked to evaluate clients' and supply chain's current level of competence on the digitalisation of the procurement process.

Most of clients (50,00%) usually include digital deliverables such as 3D parametric domain models plus federated models as part of the contract. Other clients ask also for non-graphical data exchanges such as Construction Operations Building Information Exchange (COBie) (35,71%) and only few do not include any digital deliverables (14,29%). Moreover, the survey reveals that still a large number of clients do not use e-Procurement Platforms as part of their business process (57,14%). Most of interviewees (85,71%) perceive benefits from the quasi-automation of the procurement process and a large number (71,43%) believe that a quasi-automated approach can favour risk mitigation for banks and insurances through the validation process. In addition, interviewees were asked to express how ready are clients in their Country to deploy a computer-readable bidding process through an open question. Most of them said that by now clients are not ready and they are only at the starting point. Furthermore, most of clients answered that they will be ready to automatically generate client's information requirements from a digital brief within one year.

The survey shows that the main risks related to the quasi-automation of the bidding process are the loss of control, poor client's requirements, poor supply chain's skills, technology limitations, the structure of the public sector procurement itself and poor briefing culture change. As previously said, the gamification applied in the procurement process is a quite new concept. Most of clients think that the gamification could not help the awarding stage of a contract. Others believe that it will add costs for clients or interviewees do not have a precise opinion on this topic. On the other hand, other clients think it will be helpful to better understand the scenarios and to promote a dynamic intelligent evaluation of offers. Thus, it will support a more transparent process. Moreover, results on supply chain's readiness for a quasi-automated procurement process are included in Table 1. Tier 1 project managers and technical adviser and main contractors are mainly self-confident; designers, tier 2 specialist sub-contractors and tier 3 product manufacturers, instead, are mainly beginners in managing a quasi-automated process. On the other hand, most of interviewees believe that tier 1 facility managers have less experience.

Table 1: Supply Chain's readiness for a Quasi-Automated Process

Tier / *Evaluation scale*	*No experience*	*Beginner*	*Self-confident*	*Expert*
Tier 1 Project Managers and Technical Advisers	14.29%	14.29%	57.14%	14.29%
Tier 1 Designers	35.71%	50.00%	14.29%	0.00%
Tier 1 Main Contractors	0.00%	21.43%	57.14%	21.43%
Tier 1 Facilities Managers	42.86%	42.86%	14.29%	0.00%
Tier 2 Specialist Sub-Contractors	21.43%	57.14%	21.43%	0.00%
Tier 3 Product Manufacturers	7.14%	57.14%	28.57%	7.14%

Finally, clients were asked which cultural barriers need to be overcome to move towards an automated bidding and awarding process using computer-readable data through an open question. Most of clients believe that trust is the biggest barrier followed by collaboration, inertia to change, security, confidence in data, quality assurance of information, share of risks and rewards and understand of benefits of such approach.

4. Discussion

This paragraph presents the principal implications of findings, taking into account the limited number of responses received.

The survey shows that only few interviewees have a standard set of organisational and asset requirement as well as standard benchmarks to evaluate offers. Such a trend could slow down the potentialities of a quasi-automated procurement process because, without clear standards, clients would have to spend more time in creating digital requirements and evaluation criteria. Moreover, it will be more difficult to compare results of different projects in order to create updated benchmarks. Thus, in order to promote an effective digital process, clients should establish clear standards.

In a digital procurement process, client's information requirements play an important role. Indeed, they can promote more transparent offers because bidders have a better comprehension of client's needs (The British Standards Institution, 2013). On the other hand, thanks to them, clients can speed the evaluation of offers checking the compliance between bids and initial requirements in a quasi-automated way. The UK has been the first Country to develop a digital tool, the NBS BIM toolkit, to set and manage digital client's information requirements (EIRs). Such requirements should be included in each UK public tender by 2016. The research findings reveal that several interviewees understand the importance of client's information requirements and include them as part of the tender process. However, most of interviewees are not ready to manage a computer-readable bidding process using clients' information requirements; even if they are working on this direction to be ready within one year. The results mirror the situation in Countries, such as the UK, when this practice will soon be mandatory. Different results could be identified in other European Countries without similar compulsory requirements. In addition, it is interesting to notice that interviewees believe that project managers, technical advisers and main contractors are self-confident in managing a quasi-automated procurement process. On the other hand, designers, tiers 2 and 3 should improve their skills, together with facility managers who received the lowest score. For this reason, an appropriate training and support should be provided to improve the overall process.

Recently, the use of Building Information Modelling has been increased and it is used in several phases of the overall process (Dodge Data & Analytics, 2015). Thus, more and more it has been used as selection criteria in tendering, especially in complex projects. Indeed, clients have to evaluate BIM capabilities in order to select tenders able to manage a BIM-based contract. Still a small number of interviewees evaluate the tier 1 players (design team and main contractor) together with their perspective supply chain. Such results could be due to the complexity in defining members of the supply chain in the very early phase of the process. However, the evaluation of the entire supply chain in tendering could be beneficial to better understand if all parties are capable to manage a collaborative BIM-based process. For this reason, the survey includes a question related to the use of gamification. Even if the gamification applied to tendering and awarding phases is a quite new concept, some clients believe that it could create a dynamic intelligent evaluation of offers. Indeed, the involvement of key players of the perspective supply chain in tendering could improve the reliability of bids, moving from evaluation of written promises to the evaluation of real capabilities. For example, a simulated and gamified approach could support the assessment of the supply chain's attitudes towards working in a collaborative environment. Such approach is being used in innovative procurement methods, such as Integrated Project Delivery (IPD) and Project Alliancing (PA), where, before the awarding phase, clients organise workshops and interviews with a selected number of bidders to assess their capabilities, attitudes and behaviours. After the awarding phase, contracts should ensure that the selected team will remain the same in order to take advance of the gamified approach.

Moreover, a large number of interviewees do not use e-Procurement platforms as part of their business process, even if the European Commission is strongly encouraging them as previously discussed in paragraph 1.1. This result confirms results of other published studies and could be linked to presence of several barriers (Chaffey, 2009; Eadie et al., 2010; Ronchi et al., 2010; Costa et al., 2013) and to the absence of mandatory requirements at national level (IDC, 2013).

It is interesting to notice that a large number of interviewees see benefits from the automation of the procurement process such as risk mitigation for banks and insurance companies. Thus, the digitalisation of the procurement process could be beneficial to better monitor, track and check data reducing possible claims and associated risks, as also discussed by Chaffey (2009). However, in order to reach this goal, an electronic platform is needed.

Finally, interviewees highlighted some risks related to technology limitations as well as others due to the structure of the current procurement process. There are still legal issues related to the implementation of BIM in the procurement process (Eadie et al, 2015) and it is difficult to change people's attitude. Such risks can be correlated to cultural barriers needed to be overcome, such as the lack of collaboration and trust among parties. For this reason, a change in the management of procurement process is needed, introducing innovative procurement processes that favour a collaborative approach (Bolpagni, 2013). Results are in line with cultural and legal barriers against the implementation of e-Business and e-Procurement identified in literature, as discussed in paragraph 1.1.

5. Conclusions and Future Works

The paper shows the attitude towards the quasi-automation of the procurement processes in the backdrop of a digital environment of a limited number of European Clients that are actively engaged in digitalisation processes of their respective Countries. Results indicate that a large number of interviewees use digital tools to set digital requirements and include digital deliverables in the contract (such as Building Information Models). However, the adoption of e-Procurement platforms and the evaluation of the entire supply chain during tendering and awarding stages are still limited. Moreover, today not all members of the supply chain are ready to manage a quasi-automated procurement process. On the other hand, most of interviewees perceive that such approach can generate benefits and favour risk mitigation for banks and insurances. The results can be used to get a better understanding of the current situation and to define fields where a digital approach can be further implemented, such as the integration between e-Procurement and BIM, as well as the definition of client’s standard set of organisational and asset requirements. However, due to the low response rate, results cannot be generalised to the entire construction industry, but only for the leading edge of the industry.

For this reason, in the future, the same survey could be submitted to other European Countries to get more data, especially from Countries with a specific governmental digital construction strategy. Moreover, it could be useful to interview the same group after one year and compare results to monitor client’s attitude.

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Steel Framing Construction with Augmented Reality Onsite

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Abstract

New approaches to prefabricated steel framing are proving popular in both first world and third world countries. A container can be packed with a steel section fabricator and all materials required to construct the steel framing for a range of client specified building designs. Such a container can be delivered to a building site in even the most extreme and isolated locations to enable a building to be erected. However, especially in third world environments with a poorly trained workforce, it is possible to assemble the framing incorrectly (e.g., back to front sections) which can have negative consequences on the building's ability to withstand design loads. Steel section fabrication machines have the ability to print onto the steel sections that they roll, which provides a potential for more sophisticated handling of the framing construction process. In this project the use of fiducial markers on the steel framing is investigated as a means of serving the construction process as well as for quality assurance processes. Fiducial markers allow a virtual connection to be established between the BIM design model and the rolled element such that an Augmented Reality (AR) application can be used onsite to support both the construction, and quality assurance, processes. Low cost tablets were investigated as the AR environment to support visualization of framing design on top of the steel framing and to develop a quality assurance application. The impact of accuracy of marker placement, types of fiducial marker, rendering accuracy, field of view of cameras in different tablets, and ease of use were explored for the developed application.

Keywords: Steel framing, augmented reality, quality control

1. Introduction

Mobile devices such as smartphones and tablets are becoming more and more prevalent and have ever increasing processing power as well as various different kinds of location sensors. With these new capabilities, there is an opportunity for these mobile devices to be used on construction sites. By making a connection between the real world and a virtual model of the building, useful real time information can be made available during the construction phase (Koch et al. 2007; Webster et al. 1996). In particular this information could relate to whether the building has been constructed correctly, i.e. provide quality control. This project investigates what problems could be solved in a steel framing application domain by such a mobile application and develops a prototype to demonstrate the feasibility of the solution.

1.1 Steel Framing

Mobile rollforming technology has increased in popularity in recent years with innovative approaches to delivering steel trusses to a building site. In particular, a number of companies manufacture mobile rollforming machinery which can be packed in a container, along with steel coils, and delivered to site for use in remote site construction projects, or in particular for third world settings where the transport infrastructure is not reliable or efficient. In New Zealand the National Association of Steel-framed Housing (NASH) identifies three companies who provide containerised rollforming solutions driven by virtual models developed in BIM-like design tools (i.e., FrameCAD Ltd, Howick Ltd, and Scottsdale Construction Systems Ltd).

While the rollforming machinery is capable of delivering perfectly sized steel framing with highly accurately placed dimples and notches, there is still a manual assembly process for frames and trusses which introduces the potential for human error. This is of greater concern in markets where there is a paucity of a trained workforce and the steel framed construction will be performed by low-skilled workers. This concern is exacerbated by steel frames and trusses appearing quite symmetrical, but in reality having a required installation alignment to ensure that design loads can be withstood.

To help address the assembly concerns the use of information technology to aid in correct assembly, and in the quality control checking of assemblies, is of interest. A vector of support in the context of this project is the fact that the rollforming machinery can print onto the steel sections as they are rolled, enabling a range of (currently low resolution) text or images to be placed on any section of rolled steel.

1.2 Augmented Reality (AR)

Augmented Reality (AR) has been seen as a promising technology for application in many industries, though not reaching its tipping point to date (Carmigniani et al. 2011; Furht 2011). In A/E/C it is mainly expected to benefit on-site processes where the ability to layer virtual model information (e.g., from a BIM) onto the actual site would augment, improve and speed up many current processes. AR can be delivered through many hardware platforms, from smartphones, through tablets, to specialised glasses and helmets. Providing a plethora of platforms upon which an AR platform can be developed. One of the major issues with AR, and of particular concern in A/E/C, is that of alignment between the virtual and real world (Azuma 1993). To support many processes the AR system needs to accurately locate the user of the system and to paint the virtual model accurately into the real world. Accurate location on site is an ongoing research issue with GPS approaches unsatisfactorily inaccurate in many urban environments and inside buildings, and the alternates of wifi, Bluetooth, inertial sensors, fiducial markers, etc all suffering a range of drawbacks along with their successful use scenarios (Watson et al. 2005; Zandbergen and Barbeau 2011). Establishing and maintaining accurate alignment between real world objects and virtual objects in real time also proves problematic in the majority of A/E/C scenarios, though rapid progress is being made to ameliorate these issues.

2. AR Approach

To develop an AR platform for steel framing erection a range of information inputs are required to feed into the on-site application. Figure 1 provides an overview of the information flows necessary for this type of application. Our solution uses a number of different components to generate an augmented reality view of a particular location at a building site. Using markers printed onto the steel framing, the application is able to precisely determine the position of the device in 3D space, which then enables the application to render an overlay of the building model onto a live feed from the device's camera. This allows the user to verify what has been constructed against the model of the building loaded into the application.

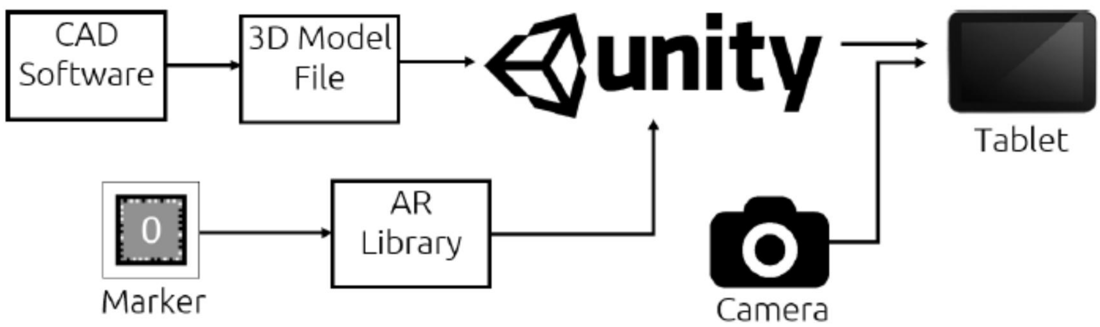

Figure 1: Information flows for an AR application

2.1 Unity

The Unity engine is a cross-platform graphics engine which can be used to visualize models in 3D on both desktop and mobile devices (Unity3D 2014). By using a cross platform engine such as Unity, it is possible to develop an application for both Android and iOS. This will be useful as the application is able to run on whatever type of device is available at the construction site. Unity is able to import 3D models from a range of common building modelling software packages. It also has a scripting engine which was used to develop the interactive components of the application, i.e. the quality assurance process and menu structure.

2.2 Vuforia

Vuforia (2014) is an augmented reality plugin which is compatible with Unity. Using Vuforia, it is possible to define markers and then link them to a position in Unity's 3D model. Through the Vuforia plugin, the application can detect the markers in the physical world using the device's camera, and then adjust the 3D model so it overlays the markers correctly. Vuforia is able to detect the position, rotation and scale of the marker and then adjust the 3D model so that it matches.

2.3 Markers

Developing markers that would be accurately and reliably detected by Vuforia in a range of lighting conditions was one of the major challenges for this project. After trialling a number of different configurations of marker, we found the marker shown in Figure 2 to be most reliable. Because of its large white border and contrasting background, Vuforia is able to detect it reliably at any size greater than 4cm. The black and white binary pattern allows Vuforia to differentiate between 512 different markers, enough for at least a significant portion of a building's framing.

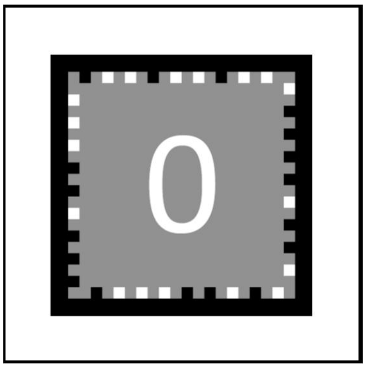

Figure 2: Effective AR marker

Another useful feature of these markers is the central space which is not actually used by the application. This space can be used for human readable text, for instance a joint number. This makes the markers useful even without the AR application.

We carried out an experiment with these markers to determine the relationship between marker size and maximum recognition distance. The larger the recognition distance, the more useful the application, as more of the structure will be visible on the screen.

Our results showed that, as would be expected, the larger the marker size, the better the recognition distance (see Figure 3). In particular, there was a significant jump in detection distance at 4cm, this is the minimum practical limit for marker size. Fortunately, steel framing is typically wide enough to accommodate markers of at least 4cm.

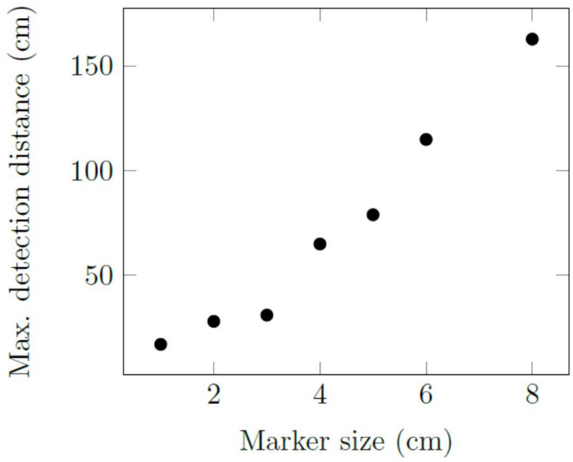

Figure 3: Impact of marker size on detection distance

2.4 Mobile Application

Combining Unity, Vuforia and the markers, we have developed a cohesive mobile application for framing verification. Starting from the home screen the user can select a particular scene they would like to view. Each scene defines a mapping between a set of markers and a 3D model.

Once a scene has been selected, a feed from the device's camera is shown on the screen (Figure 4). When a marker is detected from the camera feed, the corresponding 3D model is overlaid on the screen. The user can then tap on each segment of the model to verify that it is present. In a quality control mode unverified and verified segments are displayed in red and green respectively (see Figure 5). The ID number of the identified marker and the number of unverified segments remaining are displayed in the top left hand corner of the screen.

2.5 Server

To allow an off-site inspector to remotely verify the status of a structure, we have introduced a server component which communicates with the mobile application. The server component tracks the status of each piece of a truss, so that a mobile application can save the status (verified or unverified) of every object to the server. This status can also be loaded from the server by a mobile application, so that multiple devices can be used to verify the same building at the same time.

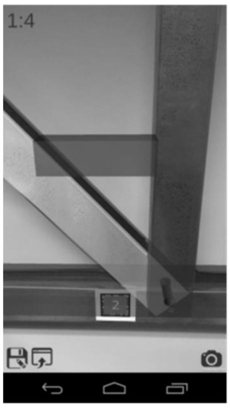

Figure 5: Truss with verified and unverified steel sections

In addition, the camera button in the application allows the user to upload screenshots (as seen in Figure 5) directly to the server. Each screenshot is associated with the marker currently in view. This allows a remotely-based inspector to view photos of each point of interest on the structure and manually verify that it is correct.

To allow information about the current status of the structure to be viewed remotely, there is also a web interface. This allows an expert at a remote location to login, view the overall progress of a building as well as details of every component tracked by the system.

2.6 Limitations

While this project demonstrates the potential usefulness of augmented reality in steel framing quality control, it is very much a proof of concept application. As such, there are a number of limitations in our implementation which would have to be addressed before this project could become practically useful.

Firstly, it would be difficult to print the markers with sufficient clarity for use in this project onto steel framing. Currently, the steel printers are only able to print black ink onto the framing (for labelling different sections), whereas our markers require three high contrast colours (black, white and blue) to be reliably detected. This could be addressed by improving the printing technology, or improving the marker recognition system.

Another interesting problem we encountered was the differing field of view (FoV) of different devices' cameras. When testing on a Nexus 5, for instance, the virtual model and the camera feed lined up perfectly. However, on an ASUS tablet the model did not line up well at all, as shown in Figure 6. This could be fixed by changing Unity's rendering settings depending on the device being used.

A side effect of the intensive image processing performed by the augmented reality engine is the high battery consumption when using the application. A typical mobile device depletes its battery after approximately one or two hours of running the application continuously. This is difficult to mitigate and could become a problem when checking a large building.

Figure 6: Truss with incorrect AR alignment

3. Evaluation

3.1 Quality Control

The main purpose of this application is to streamline the quality control process. We considered the different ways framing could be incorrectly assembled and evaluated how well the mobile application would detect these faults.

Component missing: If there is a component which is in the 3D model but not present at the building site, it would immediately be apparent to the user - when the user comes to check on that particular component, it will not match with any component in the physical world.

Extra component: If there is a component which should not be present, it should be obvious that it does not line up with any part of the 3D model. However this case is not as straightforward as the case of the missing component as the application cannot automatically identify and track these extra components.

Component in incorrect location: One of the specific problems tackled was symmetrical looking pieces of framing being inserted the wrong way around. If there are unique markers at each end of such a piece, it would be obvious when using the application that the framing has been assembled opposite to the expected model.

Component misaligned: Our application is also able to make small errors in alignment obvious to the user. In our testing we found that if a joint was as little as 5° different to the 3D model, it was very apparent that something was misaligned.

3.2 User Testing

To evaluate the ease-of-use of our application, we carried out user tests on Software Engineering students who had never used the application before. The testers were given a simple explanation of what the application does and then were asked to verify our example truss, upload the data to the server and then view their progress on the server. They were encouraged to think out loud and were asked for feedback after the task was completed.

Overall the feedback was positive, with users easily able to determine how the application worked, the meaning of the green and red components and the actions of the various buttons. The testers were all able to identify all the correctly assembled joints as well as a joint with a missing cross-section. However, the testers did highlight some interface issues in the menu system of the application, poor scrolling and confusing menus (which have since been addressed).

All of the testers agreed that this system would be helpful for verifying the correct construction of a building. While this feedback was helpful, more realistic user testing at a real building site with construction workers is needed to determine how useful the application would be in a practical context.

4. Conclusions

Combining architectural visualisation and augmented reality is a powerful way of addressing some of the real world problems experienced in the construction industry. While there are a number of limitations of our implementation, the prototype does demonstrate the feasibility of performing quality control of framing and truss assemblies using augmented reality. The markers developed, in combination with the mobile application, provide easy access to the building model. The checking-off process in the mobile application allows for effective quality control, and the server allows the verification process to be overseen remotely.

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Automated Extraction of Construction Collocations for Knowledge Discovery Based on Text Mining

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Abstract

Text data plays a critical role in construction project management and covers an overall project lifecycle from its beginning to completion. To be specific, project decision makers can take advantage of text data generated from previous projects, in order to solve similar project-related risks occurred while executing different projects. However, text data has usually been in an unstructured form and it was hard to utilize; tacit knowledge presented in documents turned out to be difficult to collect, analyze, evaluate and manage systematically throughout the project lifecycle. Thus, it is important to develop a text data management system not only to discover knowledge but also to keep abreast of accumulated data for a project team. This research developed a prototype system of UNI-Tacit and its modules for preliminary implementation. The primary objective of this study is to investigate text-specific characteristics of the construction industry, such as peculiar term usages or structures of phrases/documents, which can support the extraction of knowledge from text data. The research methodology to support automated knowledge discovery in UNI-Tacit, included (1) data pre-processing and (2) collocation analysis. The research analyzed approximately 30,000 documents on the web such as editorial articles, interviews, official correspondences, and journal papers to demonstrate the usefulness and practicality of the proposed system. Specifically, collocation techniques were uncovered and the most applicable method to overcome technical difficulties, mainly caused by the construction industry's distinct features during collocations, was determined. UNI-Tacit presents two main contributions. One is the automated keywords extraction, which can summarize original documents, and the other is multi-document summary visualization to provide meaningful insights for decision support relevant to keywords.

Keywords: Construction text data, text mining, collocation, knowledge discovery, UNI-Tacit

1. Introduction

A significant amount of text data has been accumulated over time in the construction industry (Hjelt and Björk, 2006; Zhu et al., 2007; Ma et al., 2011). It is so, because construction projects are unique, complex, and of long duration, and the stakeholders face numerous issues from the beginning until the conclusion of the project (e.g. Figure 1). Any problems that arise during the project lifecycle are commonly written in documents as text, which is the most natural form of storing information (Tan, 1999). Construction sites generate documents such as specifications, quality and safety reports, design change documents, and claim documents, as well as construction-related text data on the web such as news, editorials, reports, and journal articles (Rubin et al., 1999; Chun, 2001).

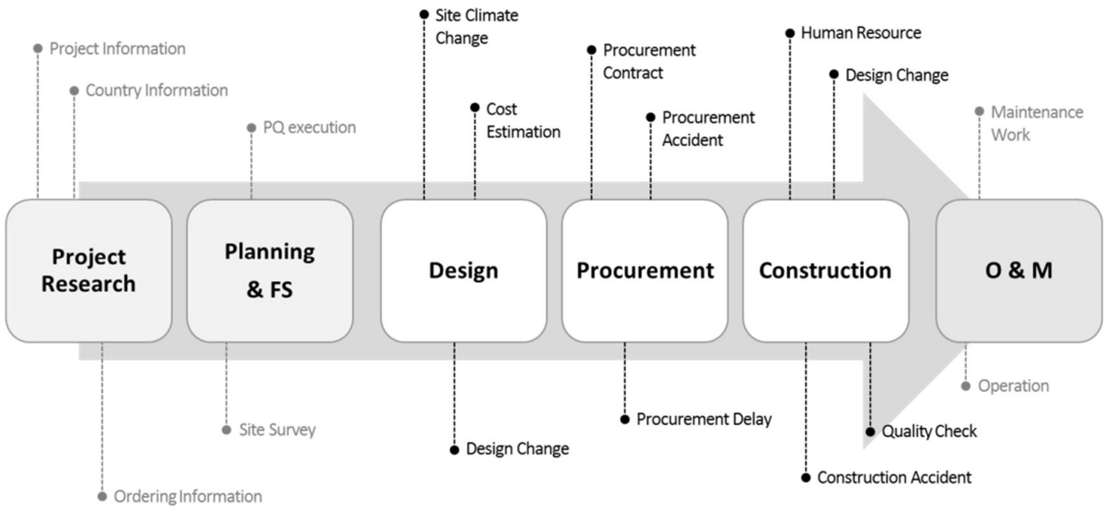

Figure 1: Various issues in a construction project

Text data is very useful to the construction industry, regarding project-related decision making. Nearly 80% of the information generated by companies is in document form (Cleveland, 1995; Gantz and Reinsel, 2012). Furthermore, important information collected from previous projects as experience, is mainly presented through documents (Pathirage et al., 2007; Soibelman et al., 2008). Such information can be reused in upcoming projects, delivering lessons learned for better risk management and project control. Thus, text-based information can play an important role in business strategy development in the highly competitive construction industry (Song et al., 2009; Qady and Kandil, 2010).

However, there are challenges in utilizing text data. Above all, text data needs to be pre-processed before being able to extract useful information from it, as most text data is unstructured (Akilan, 2015). The characteristics of natural language (e.g., non-standard expressions, segmentation issues, and tricky entity names) need to be investigated during the data processing. Complex and distinctive linguistic terms exist in numerous types and forms, in the construction industry (Soibelman, 2008). Moreover, the text data management system infrastructure is scarce in the construction field (Go, 2013). Such text management environments in the construction business, result in plenty of constraints when applying existing text mining techniques, used in other industries, to construction and construction-customized text mining techniques need to be developed.

In addition, problems to keep up with daily updated information and manage piled up construction documents, still exist. They are usually time consuming and require specific manual efforts. To deal with these setbacks, researchers have mainly focused on two fields of study: text analytics and information visualization (Liu et al., 2009). However, few researches that maximize the value of text analytics and information visualization for construction application, were studied (Liu et al., 2009).

To tackle these challenges, this research developed UNI(User Needed Information)-Tacit (Figure 2) prototype. The primary objective of this study is to investigate text-specific characteristics of the construction industry, such as peculiar term usages or structures of phrases/documents, which can support the extraction of knowledge from text data. This was achieved by data pre-processing and collocation analysis. These processes support two main contributions. One is the automatic extraction of the appropriate keywords, which leads to a brief summarization of documents, and the other is a practical visualized output, which provides meaningful insights to keywords in the construction industry.

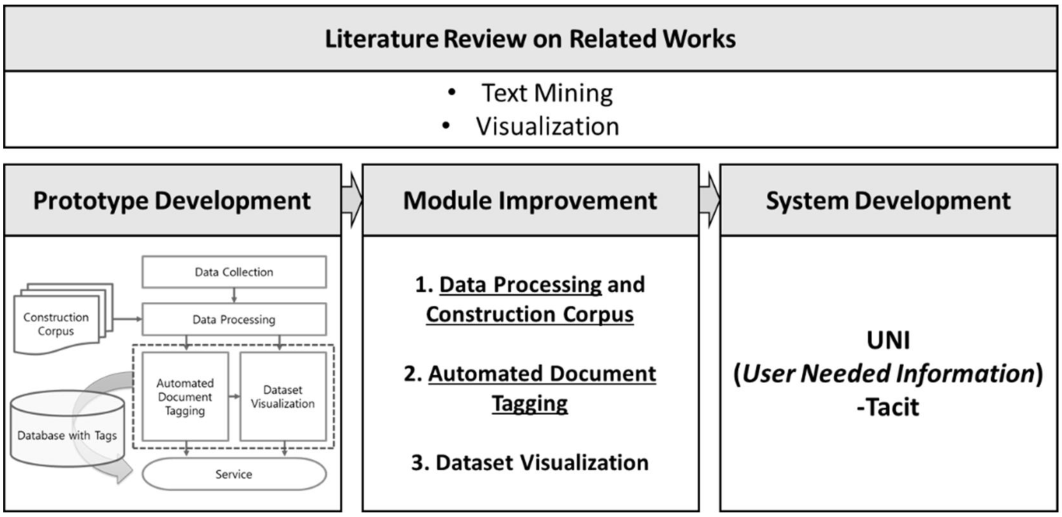

Figure 2: Research framework

In the rest of the paper, UNI-Tacit system framework and user interface are briefly described. Then, the methods of key processes to discover knowledge mechanically are described. The key processes consist of data pre-processing and collocation analysis. The application and discussion of the proposed processes are presented, and the paper concludes with a summary of the research, contributions, and future works.

2. UNI-Tacit System Overview

UNI-Tacit is designed to utilize piled up construction text data effectively and efficiently. With UNI-Tacit, users can view extracted keywords of documents based on automatically processed data and capture essential information easily and quickly through keywords via the visualization function.

2.1 System Framework

UNI-Tacit is constituted by modules, represented by each box (Figure 3). Modules in dashed rectangles are automatic processes (automated document tagging and dataset visualization) and other modules (data collection, data processing, and service) surrounded by a solid line are semi-automatic processes, which include a few manual steps.

The proposed system in this research, mainly focuses on data processing for extracting appropriate keywords from each text data automatically and on dataset visualization for conveying its essential information quickly and efficiently. The construction corpus is used as a data processing module, which reflects the text-related characteristics of the construction industry.

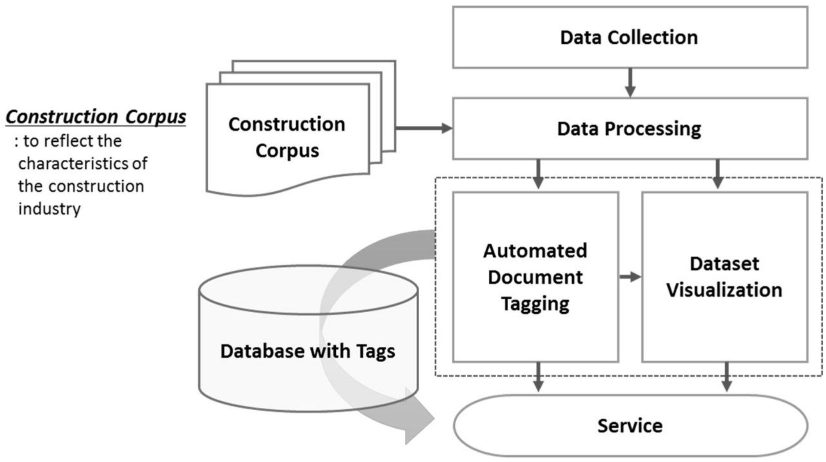

Figure 3: UNI-Tacit system framework

2.2 User Interface

Figure 4 demonstrates the implementation of UNI-Tacit prototype user interface, which employed an opened construction-related online data. The main concept of the user interface is interaction, thus when a user clicks on a tag, the system provides the dataset of documents, including the selected tag, as keywords. To be specific, a global map comes first into view because all countries are tagged, and if a user clicks on a country, a wordcloud is created with the list of the dataset based on its (including the chosen country as a tag) keywords (Figure 4(a), 4(b)). The user can also click on a term he/she is interested in, in the wordcloud and find practical information about that term (Figure 4(b), 4(c)) and the clicking will result in a new wordcloud and a list of dataset for the newly clicked tag.

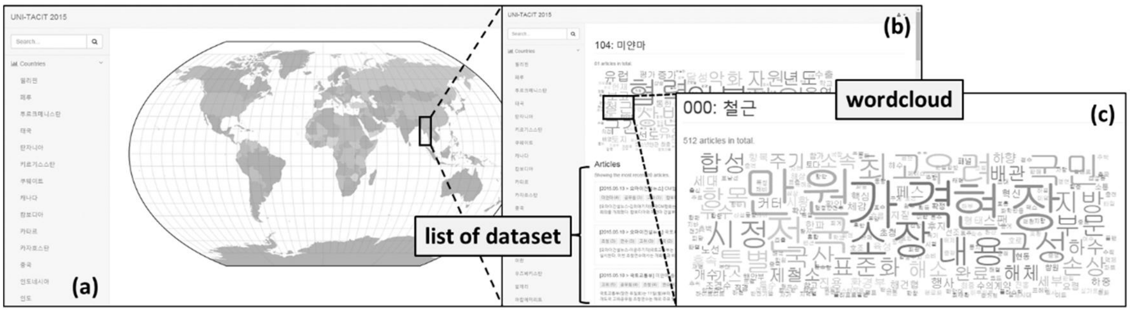

Figure 4: UNI-Tacit user interface

3. Automated Knowledge Discovery

The UNI-Tacit prototype discovered knowledge automatically based on data pre-processing and collocation analysis, which are essential processes to keyword extraction and visualization. The core objective of these processes is to enhance the extraction of exact keywords. To tackle this issue, data pre-processing and collocation analysis methods are proposed.

3.1 Data Pre-processing

Data pre-processing is a necessary step to vectorize text data. Data processing is a semi-automatic process, which includes both automatic and manual steps. Automated steps consist of POS tagging, term frequency calculating, and filtering, and manual steps include dictionary selection, optimum morpheme selection, and filter selection.

In the case of Korean data, the POS tagging process is usually combined with morphological analysis, which identifies the structure of morphemes and other linguistic units in a phrase. Thus, POS tagging is the same as the process of marking-up morphemes in a sentence based on their definitions and context (Park, 2015). Term frequency is calculated based on the POS tagged data, and filtering includes removing unsuitable terms as keywords.

3.2 Collocation Analysis

Collocation is an expression which consists of more than two words that correspond to a customary or habitual manner (Manning and Schutze, 1999). It is common to say ‘strong coffee’, not ‘powerful coffee’. In the same way, one ‘rides a bicycle’, but does not ‘drive a bicycle’. These are collocations in natural language. In this manner, collocations (e.g. strong tea) are more compositional than free constructed phrases (e.g. good boy), but less compositional than idioms (e.g. kick the bucket).

Collocations differ from industry to industry. For instance, tool box meeting(TBM) is a collocation in the construction industry, while it is not a collocation in other industries. To be specific, the phrase *tool box meeting,* in general fields, will be split into *tool, box* and *meeting,* and interpreted just as a tool, a box and a meeting. On the other hand, in the construction industry, *tool box meeting* implies several specific meanings, such as assigning the task of the day, conveying the instructions and contact information to the workers at the beginning of the day. Moreover, there are some collocations which are homonyms, meaning that a phrase can be a critical keyword in the construction industry, but not in other fields, and vice versa.

Thus, collocation analysis and determining an appropriate collocation method, enables the system developer to automatically find some conventional construction phrases out of documents, and to reflect peculiar text-specific characteristics of the construction industry. Collocation discovery also aids data processing by replacing words with the wrong tag, with collocations that are correctly composed phrases, in terms of the construction industry.

Three methods for collocation discovery from construction text data, were analyzed in this study. The hypothesis testing included the t test and Pearson's chi-square test, and mutual information methods, which were selected from among many after carrying out a literature review. Each method was evaluated quantitatively and qualitatively, and the most appropriate method was chosen.

The hypothesis testing detected collocations by assessing whether terms occur together by chance or not. Term occurrences were considered to be independent from each other, which meant that $P(w^1 w^2) = P(w^1)P(w^2)$, and the hypothesis was then tested. Thus, the formulated null hypothesis H_0 implied that there was no relation between the two terms (Manning and Schutze, 1999). The t value for the t test was calculated through the following equation:

$$t = \frac{\bar{x} - \mu}{\sqrt{\left(\frac{s^2}{N}\right)}}. \quad (1)$$

The chi square value for the Pearson's chi square test was calculated by the equation below:

$$\aleph^2 = \sum_{(I,j)} \frac{\left(O_{ij} - E_{ij}\right)^2}{E_{ij}}. \quad (2)$$

These values were used to compute the probability p in relation to a significance level (e.g. 0.05, 0.01, etc.).

The mutual information method also assumed that terms were independent from each other, but it was a measure which was theoretically motivated by information. The pointwise mutual information measured the amount of information (reduction of uncertainty) gained by the occurrence of each term (Manning and Schutze, 1999) through the subsequent equation:

$$I(x', y') = \log_2\left(\frac{P(x'y')}{P(x')P(y')}\right). \quad (3)$$

Both quantitative and qualitative evaluations are required for the appropriate collocation discovery method in the construction industry. Thus, the Jaccard index evaluated the methods quantitatively, as it is commonly used to assess the performance of keywords extraction by the ensuing equation:

$$J(A,B) = \frac{|A \cap B|}{|A \cup B|}. \quad (4)$$

The construction experts' consultations on discovered collocations were taken as qualitative evaluation.

4. Application and Discussion

To demonstrate the performance of the proposed UNI-Tacit prototype system, the system was applied onto a dataset: an opened construction-related online data. In this section, we present the results of the application, followed by a discussion of the results. The application was conducted on a Macbook Pro with Intel Core i7 CPU and 16GB memory on Python programming language.

4.1 Data Overview

The targeted dataset of the proposed system prototype comprised construction-related documents scattered on the Internet. Specifically, construction-related news, editorials, interviews, reports, and official documents on the Internet were deemed to be appropriate for the dataset because these data types are prolific, frequently generated and accumulated in a variety of themes and, above all, treated as being useless at present.

Six construction-oriented websites were selected as the target web pages, which deal mostly with the mentioned data types. Cdaily, Cnews, Fnnews, and Ohmycon sites cover mainly data derived from news, editorials, and interviews. KISCON deals mostly with editorials, reports, and official documents. MOLIT generates primarily official documents and related news. Detailed information on each data sources is ensued in Table 1.

Table 1: Data overview

Korean	***English***	***Number of data***	***Website address***
건설일보	*Cdaily*	*474*	*https://www.kiscon.net/kcn/list.asp*
일간건설	*Cnews*	*4,242*	*https://www.kiscon.net/kcn/list.asp*
파이낸셜	*Fnnews*	*1,561*	*https://www.kiscon.net/kcn/list.asp*
KISCON	*KISCON*	*3,804*	*https://www.kiscon.net/cks/share_bbs/list.asp*
국토교통부	*MOLIT*	*1,492*	*http://www.molit.go.kr/USR/NEWS/m_71/lst.jsp*
	Total	***25,143***	

The dates of the collected data range from the website's inception date to 21/05/2015. The total number of data files for the pilot study was 25,143, which is approximately 279MB as a memory unit.

4.2 Results and Discussion

Raw data firstly went through the data pre-processing step. In this phase, unstructured crawled data was transformed into a structured form. The Twitter dictionary was selected for POS tagging on the dictionary selection step, because the Twitter dictionary requires a relatively short processing time and displays good POS tagging performance on online data. Only Nouns tagged as words frequency, were calculated, since other morphemes are too obscure to represent documents. Lastly, too frequent and too infrequent terms were removed in the stop words removal step, because those terms just lead to the curse of dimensionality with little merit. The terms were sorted by frequency, and the top 30 frequent terms and terms which occurred only once, were deleted. The average number of words per document was 479.97 and the number of unique nouns, excluding stop words, was 21,668.

The selected methods for collocation discovery (the t test, Pearson's chi-square test, and mutual information) were applied to the POS tagged data because collocations are meaningful only when they are discovered as consecutive words. A sentence such as "A dog bites a piece of cookie.", after going through the entire data pre-processing step, would only keep the information of "dog: 1, piece: 1, cookie: 1", which is useless for finding out collocations.

In this study, the focus was on which collocation discovery method was appropriate for the construction industry, therefore collocations were analyzed, regardless of each term's tag. Also, the bigrams (two consecutive words) which occurred more than 30 times, were taken into consideration, because computing all bigrams would just consume time, without any particular discoveries. The number of bigrams with more than 30 times frequency was 49,194.

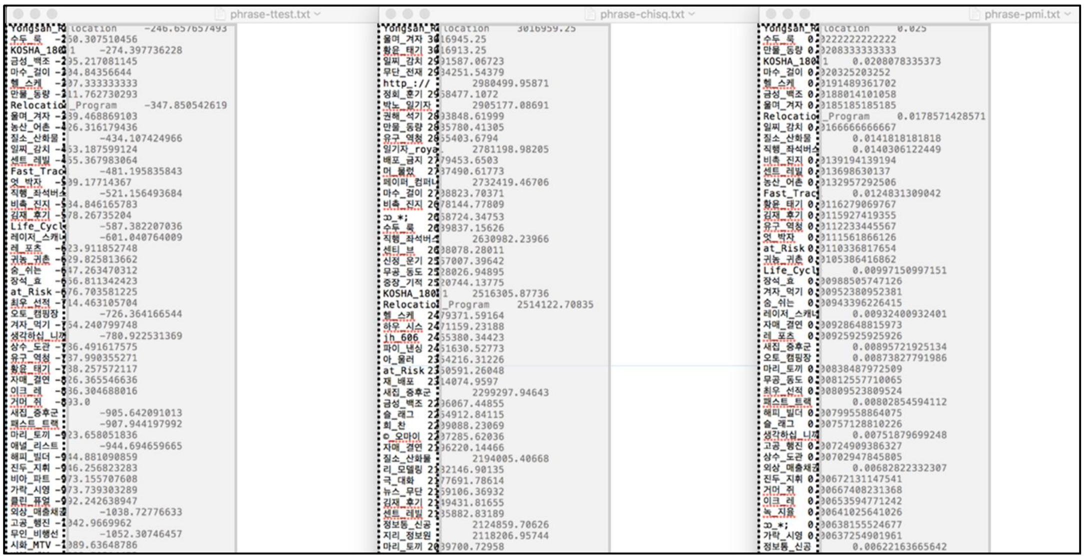

Figure 5: Collocations and calculation results (t test, chi-square test, mutual information)

Figure 5 shows the examples of discovered collocations (in dashed rectangles) and calculated values (in grey rectangles) for each method presented on the list of highest-to-lowest values. The differences between each method can be spotted. Thus, the Jaccard index, which focuses on how many common items two groups have, in their union, evaluated which one would be optimal to the construction industry. The higher the Jaccard index is, the bigger the intersection portion is. Thus, from the qualitative standpoint, the mutual information method showed the best performance, in terms of detecting the most collocations among each method's results for all cases of top 1,000, top 5,000 and top 10,000 collocations.

Table 2: Jaccard index

Jaccard Index	***J(t, chi-square)***	***J(chi-square, mi)***	***J(mi, t)***
Top 1,000	*0.410*	*0.493*	*0.826*
Top 5,000	*0.494*	*0.606*	*0.819*
Top 10,000	*0.559*	*0.670*	*0.840*

The construction experts' consultation guaranteed the usefulness and practicality of collocations. Specifically, there have been considerable errors on the POS tagging process as construction documents do not only include many Sino-Korean words but also follow different word spacing rules respectively. Discovered collocations were of high assistance in the solving of this drawback. An example of this is *레_포츠 (le+ports à leports)* and *최우_선적 (Choi-woo+shipment à the first priority),* which are composed together. There are also collocations, which reflect the characteristics of the construction industry, such as noun phrases, including *Fast Track* and *Life Cycle,* which should be composed together to understand its exact meaning.

The service page of UNI-Tacit prototype system is presented below, in Figure 6. The final output is displayed on the service page, having gone through all modules (data processing, automated document tagging, dataset visualization) in the UNI-Tacit prototype system. When the user clicks on a tag, the keywords of the tag's dataset are drawn in the form of wordcloud, and the dataset list is ensued, below the wordcloud. The extracted keywords are also provided with the document subject and a 100-character preview.

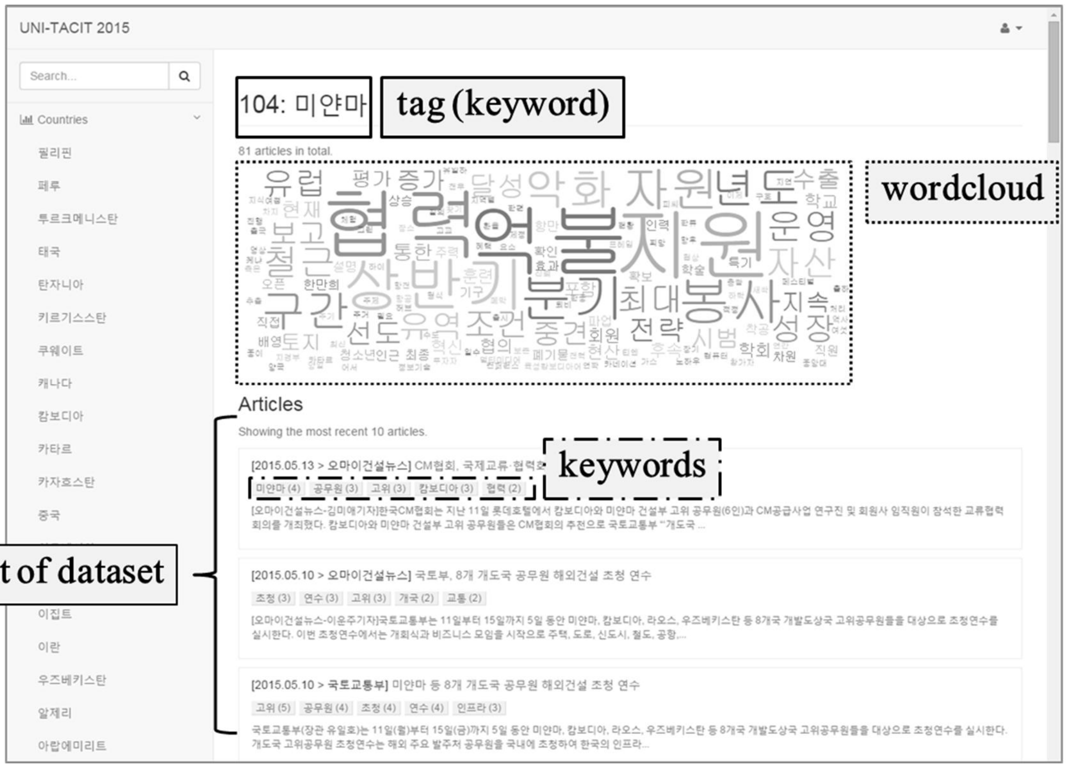

Figure 6: The service page of UNI-Tacit prototype system

5. Conclusion

The UNI-Tacit prototype system extracted correct keywords for a document by data pre-processing and collocation analysis and finally discovered knowledge by document tagging with keywords and dataset visualization based on keywords. Specifically, collocations reflecting the characteristics of the construction industry were discovered and also, the most appropriate method for finding collocations, was determined. Discovered collocations aid text mining in the construction industry overcome technical difficulties, mainly caused by the construction industry's distinct features. From the UNI-Tacit system's point of view, the proposed method of data pre-processing and collocation analysis showed promise, regarding text mining techniques applicable to the construction industry.

In the future, the developed UNI-Tacit prototype system in this study can be improved by developing methods to discover knowledge automatically. Collocation analysis considering trigrams (composed of three consecutive words) would help find more useful collocations. The term-document matrix generated in this study is a base for topic mining, which would lead to better keyword extraction. The dataset visualization improvement is also an attractive subject of research in the construction industry to convey information more effectively and efficiently. The application of the proposed system to English databases is expected to show more novel and promising results, as there are well-developed English text data pre-processing libraries and even more construction related-data in English.

Acknowledgements

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Virtual Reality Headsets for Immersive 3D Environment: Investigating Applications in Construction Jobsite Organization

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Abstract

Virtual Reality (VR), sometimes referred to as immersive environment, is a computer-generated 3D environment that can simulate the real world environment. A user wearing VR headsets can feel the same experience, as he/she would have in the real world. The aim of this pilot study is to investigate the feasibility of 3D VR Headsets in jobsite planning and management, from educational as well as industry implementation perspectives. The specific objectives consist of: (1) to study the current industry workflows for site logistics, layout and planning; (2) to investigate the feasibility of VR Headsets for jobsite planning simulations; and (3) finding ways on how to enhance the effectiveness of jobsite planning process through the use of VR Headsets. A jobsite model during the structural phase of the buildings construction was created using Unity 3D(R) software. Oculus Rift VR headset was chosen for its support and integration with the Unity 3D(R) software. Using the model, three scenarios demonstrating applications of 3D VR Headsets for jobsite management were created. Mixed methods research techniques including a focus group and a questionnaire survey both adopted for feedback and data collection. Presented in this paper are the main findings of this pilot study, which helped us to explore an emerging technology that could be a game changer in the design and construction industry. The results of this research aided in our determination of the best value and applications of VR headsets for jobsite planning and management within design and construction disciplines. We found that VR headsets are indeed very beneficial - allowing the users to immerse into a near-actual environment. The users were able to interact, identify, and gain an in-depth experience pertaining to jobsite management. The application of textures, materials and site development were found to create a life-like feeling. Each participant became physically involved in his/her exploration, exhibiting natural movements outside of the VR environment. This paper also presents some limitations of VR headsets and provides recommendations for future research.

Keywords: Virtual reality headsets, construction, jobsite planning, jobsite management, immersive 3D environment

1. Introduction and Background

1.1 Virtual Reality and Jobsite Organization

Although the term Virtual Reality (VR) has gained popularity recently, its roots can be traced back to the mid-nineteenth century (Wikipedia, 2015). As time evolves, this technology is becoming better, cheaper, and more accessible (Froehlich and Azhar, 2016). The definition of virtual reality is quite straightforward. 'Virtual' means 'near', so the term 'Virtual Reality (VR)' basically implies 'near-reality'. VR refers to "a computer-simulated reality computer technology that replicates an environment, real or imagined, and simulates a user's physical presence that environment in a way that allows the user to interact with it. Virtual realities artificially create sensory experience, which can include sight, touch, hearing, and smell.(Wikipedia, 2015). The term VR was introduced in the 1860s, when the concept of 360-degree art through panoramic murals began to appear. After spanning a period of more than a hundred years for the framework to form, VR came into the public's attention, and the first VR headset was created in 1990s. During the past 10 years, VR has seen a tremendous growth in popularity. Nowadays, it is more often used to describe a wide variety of applications associated with immersive, highly visual, three-dimensional (3D) environments. The 3D environment, which appears to be life-sized from the perspective of the user, can be simulated through computer. It can be interacted with, explored and controlled by a person through a head-mounted display (HMD). HMD is "a pair of goggles or helmet with a screen in front which displays three dimensional images or video". The person who wears a HMD becomes part of this virtual world. With an embedded tracking device, images displayed to the wearer change as he/she moves the head (Wikipedia, 2015).

VR can be extremely useful in the construction industry. Among possible applications, VR technology could significantly aid in jobsite organization, which comprises of a substantial number of tasks spanning from planning to execution stage. Effective jobsite organization is imperative for any construction project as it can provide massive benefits in efficiency that condense the project schedule and productivity that significantly reduces the overall cost of the project (AEC Business, 2015). Yeh (quoted in El-Rayes and Khalafallah, 2005) states that construction jobsite organization during all the construction phases requires the identification of the building footprint, temporary facilities' location including security fences, access roads, parking area and storage areas, stockpiles of excavation, site trailer, fabrication shops, and batch plants. Short and fast transport routes, explicit material flow, efficient use of technology and a safe work environment ensure the success of a construction project (Astour and Franz, 2014). An optimized jobsite organization plan can lead to: (1) optimum usage of available space, (2) less relocation of materials, (3) minimizing travel times of labor, material, and equipment on site, (4) better accessibility to the jobsite, and (5) a safer work environment (Zolfagharian and Irizarry, 2014). As such, effective jobsite organization is significant and critical during all construction phases and should be properly performed and updated as the project goes on.

However, to develop an effective jobsite organization plan, a wide range of factors need to be taken into account. As with the construction of any project, unforeseen complications most likely exist. While preventing all of these issues may not always be possible, having a clear strategy in place to resolve a potential problem can lead to significant cost and time savings. According to Voigtmann and Bargstadt (2008), jobsite logistic processes take up to one third of the total execution time on site, and well-planned and executed construction logistics have the potential to reduce the construction time by 10 percent and the cost by 4 percent in outfitting processes.

Due to the complexity and the number of factors involved, jobsite planners have adopted technologies to improve the efficiency of their tasks. The emerging technology of Virtual Reality provides an effective mean of verifying site operations as well as site logistics. According to Kizil and Joy (2001), people gain 70 percent of information by vision, resulting in systems like HMDs that provide the visual component of immersion to develop virtual environments. The use of high quality three-dimensional graphics, sound and dynamic simulation combine to form a uniquely engaging experience (Kizil and Joy, 2001). By placing users in an immersive environment, it enables the visualization of jobsite arrangements in construction projects at different stages, thus providing the users with a more illustrative site plan and letting them visually see the space utilization. Jobsite organization, including traffic routines for equipment, locations for material stack and manpower availability can also be incorporated into the module to be checked visually as part of the logistics plan (Kymmell, 2008).

1.2 The Virtual Reality Head Gear - Oculus Rift®

This research was conducted using the Oculus Rift Development Kit 2 VR Headset as shown in Figure 1. The Oculus Rift was chosen for its support and integration with Unity 3D® software. The Unity 3D® software was an essential tool for digital model development. Among all of the head mounted VR products which are available in the market, the Oculus Rift, a wearable virtual reality headset which has been labelled as one of the top 10 creations in 2013, has a more tremendous impact on the virtual reality market. It delivers a stereoscopic 3D view with smooth frame rates at high resolutions for immersive virtual reality. A gyroscopic sensor is embedded in the headgear, which can track any tiny rotation the user's head makes so the view can change accordingly, while simultaneously a 3D environment image will be generated on the connected computer (Desai *et al.*, 2014). For now, Oculus Rift has not yet been launched in the construction industry as a commercial product. However, it has the potential to revolutionize the industry in several aspects. With time, the VR headsets will evolve, with applications becoming more apparent and widespread.

Figure 1: Oculus Rift Development Kit 2 (Desai et al., 2014)

2. Research Objectives and Key Questions

To test the feasibility of 3D VR headsets in construction education and practice, this pilot study focused on the area of jobsite organization. The following were objectives of this: (1) to study current industry workflows for site logistics, layout and planning; (2) to investigate the feasibility of VR Headsets for jobsite planning simulations; and (3) finding ways on how to enhance the effectiveness of jobsite management through the use of VR Headsets.

Key questions we seek to answer included the following: (1) Can VR Headsets offer any advantages in jobsite organization as compared to traditional methods?; (2) Should VR Headsets be used alone or in conjunction with the traditional methods?; (3) Are VR Headsets economically viable for commercial usage?; (4) What are the potential benefits and drawbacks of VR Headsets for jobsite organization?; and (5) Are there any potential barriers to widespread adoption within the construction industry?

3. Methodology

The study was conducted utilizing mixed methods research using both qualitative and quantitative research instruments. The study was divided into three phases as shown in Figure 2.

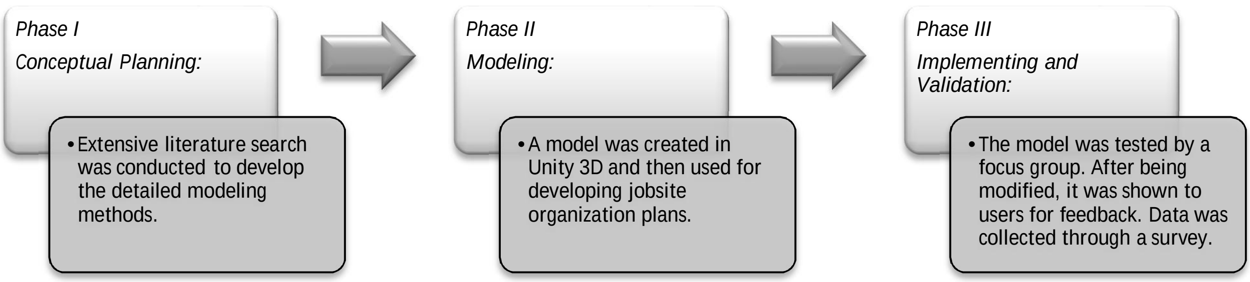

Figure 2: The Research Process

The following sections explain each phase of the research.

3.1 Phase I: Conceptual Planning

The purpose of the conceptual planning phase was to explore existing uses of VR Headsets in construction industry and to develop a detailed plan for creating the jobsite organization models. During an extensive literature review, the following referenced areas of application in construction were identified: (1) Site layout and planning; (2) Rehearsing erection sequences; (3) Progress and monitoring of construction processes; (4) Evaluation of construction scenarios; (5) Inspection and maintenance; and (6) Healthy and safety training. Next step was to review all available hardware (i.e. VR headsets). A number of VR headsets were identified and reviewed such as Oculus Rift DK2, Sony Project Morpheus, Samsung Gear VR, Google Cardboard VR, and LG G3. Among all of the head mounted VR products which are available in the market, Oculus Rift® is found as the best choice. The reason of this has been mentioned in section 1.2. More details of this analysis can be found in Froehlich and Azhar (2016).

3.2 Phase II: Modelling

A model simulating a jobsite was created in this phase. The following software were selected: (1) Autodesk Revit® for creating the 3-story structure, (2) SketchUp® for editing and exporting all the material stack, equipment, characters and related families needed onsite, (3) Unity 3D® for rendering the model, (4) MonoDevelop® for creating the script; and (5) Camtasia Recorder® and Camtasia Studio® for producing the end product videos. Oculus Rift® headset was used to view the model in Unity 3D®. The terrain texture mapping was first created in Unity 3D® software. Unity® is a cross-platform game engine developed by Unity Technologies and is used to develop video games for PC, consoles, mobile devices and websites. A 3-story steel framing structure was created in Autodesk Revit® and then imported into Unity 3D®. All the material, equipment and characters were imported from the SketchUp® warehouse to make the simulated jobsite looks real. Figure 3 shows a screenshot of the model.

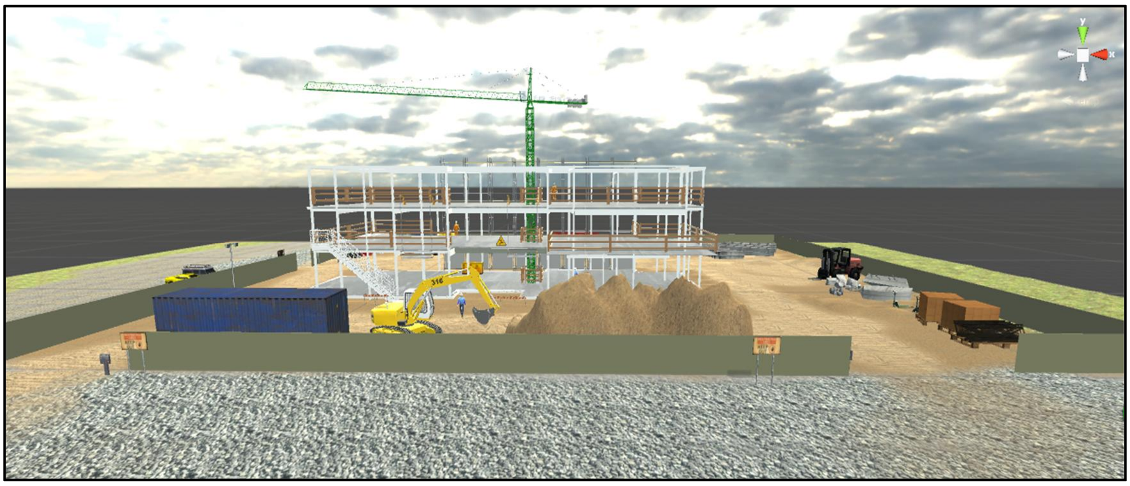

Figure 3: The Jobsite Organization Test Model

After rendering the above model, three scenarios were created, stressing how variation in jobsite organization plans can affect the effectiveness of site utilization. Scenario 1 and 2 were created based on the specific location of this project. Differences of site orientation, site access, crane placement, equipment path, material storage and waste access between these two scenarios. Scenario 3 was created as a vacant jobsite and its purpose was to allow users to create an ideal jobsite. All the material and equipment were placed off-site. By dragging and placing the material and equipment onsite, the end users were able to create their own jobsite layout. The following deliverables were produced: (1) 2D site plan captured from Unity 3D®; (2) 3D site plan (i.e. the 3D rendered model); and (3) 3D site plan with immersive environment using Oculus Rift; and (4) Narrated videos for presentation purposes.

3.3 Phase III: Implementing and Validation

For model testing and relevant data collection the following steps were performed: (1) Opinions were collected from a focus group consisting of eight BIM professionals; (2) After considering the opinions recorded in step 1, modifications were made to the model. Fourteen construction students were then invited to test the model. They were shown how Oculus Rift works in the above-mentioned scenarios. Afterwards, a questionnaire was used to gather their opinions as how they think of trying on Oculus Rift compare to the traditional methods; (3) Responses were analysed using descriptive statistics. Based upon these responses the advantages and disadvantages of Oculus Rift and its use in the construction industry were identified.

4. Model Development, Implementation, and Validation

4.1 Model Development and Implementation

A two-dimensional (2D) site plan is an effective method for implementing a jobsite organizational plan. Providing a simple and concise overview of the jobsite easily communicated to construction personnel. Due to the complexity of the construction projects, the way we organize jobsites is always challenging. Rationalization of the jobsite organization method is essential in catering all the different needs of the personnel as the construction goes on. The M. Miller Gorrie Center, a 3-story steel-framed, brick-clad building, during the structural phase of construction was chose to simulate jobsite organization. Figure 4a and 4b captured from the Unity 3D® model and marked with different colours are the 2D site plans for scenario 1 and 2.

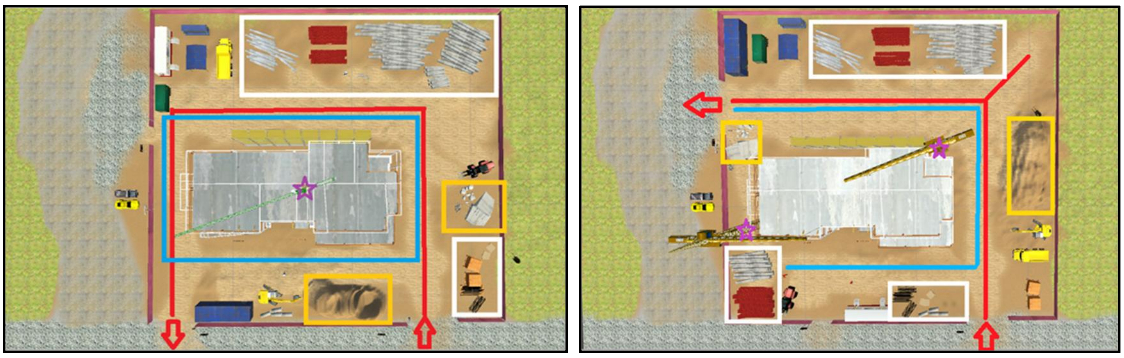

Figure 4: 2D Site Plans (a) for Scenario 1(Left) and (b) Scenario 2 (Right)

Differences can be seen from the following aspects: (1) Site access is marked in red colour. Placement of an entrance and an exit for vehicles in scenario 1 and scenario 2 are next to the jobsite trailer; (2) Crane placement is shown as purple stars. The type of crane, size of the load, crane efficiency, constraints and the associated costs were considered but not shown. In scenario 1 one tower crane was used, while in scenario 2 two tower cranes were employed; (3) Material storage is marked in white colour. Material was staged onsite at each phase of construction. In scenario 1 it was staged on the backside, while in scenario 2 it was staged separately but within the accessible range of the crane and located on the main delivery route; (4) Trash and waste access are marked in orange colour. In scenarios’ 1 and 2, trash and waste stacks were located along the main equipment path; (5) Equipment path is marked in blue colour. Trucks are used and shown on site plans for material delivery and waste removal.

Compared to the 2D site plan, a 3D site plan is a more powerful visual tool providing the viewer a life-like experience**.** It can show a detailed rendering of every component present at the site, including the equipment, materials as well as the site topography. Compared to the 2D plan, the 3D one illustrates how a jobsite may look like in reality, which makes it easier to understand. In addition, a 3D plan could let one see the volume and amount of spaces on site thereby making jobsite layout easier. Figures 5 and 6 depict the 3D site plans for scenario 1 and 2.

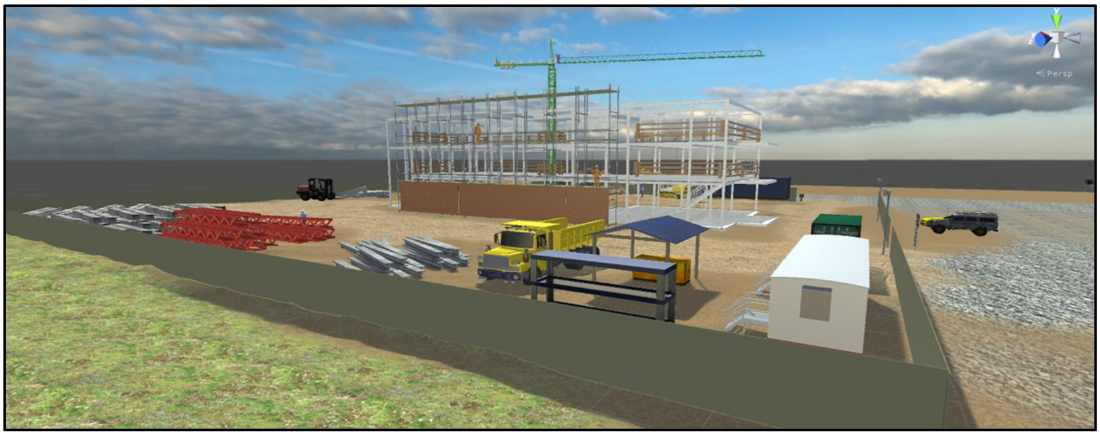

Figure 5: 3D Site for Scenario 1

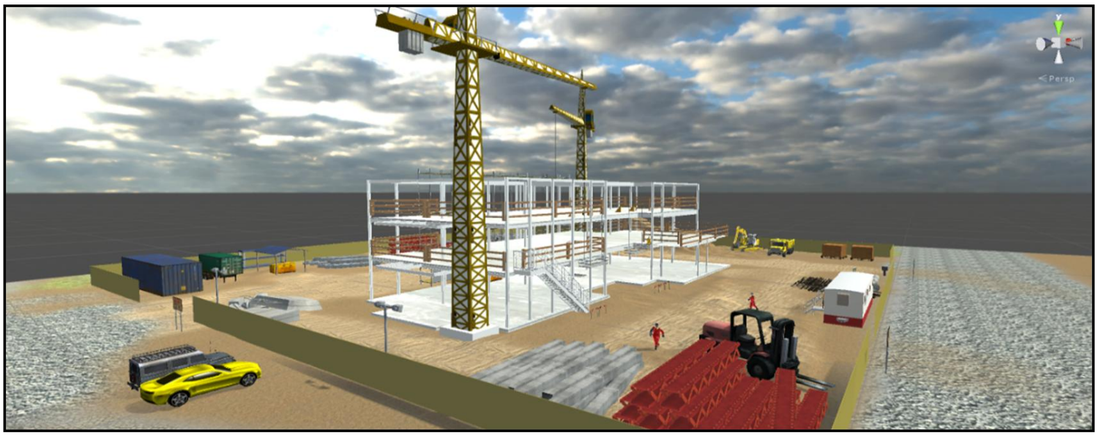

Figure 6: 3D Site for Scenario 2

For both scenarios, immersive environments of the 3D site plans were also developed providing a full VR experience to the users. Utilizing the Oculus Rift®, a 360-degree virtual view could be experienced by the user, sparking his/her early engagement in jobsite organization. Figure 7 shows a user's view through Oculus Rift® headset. The whole walk-through process via Oculus Rift® was recorded and shown to focus group participants for discussion.

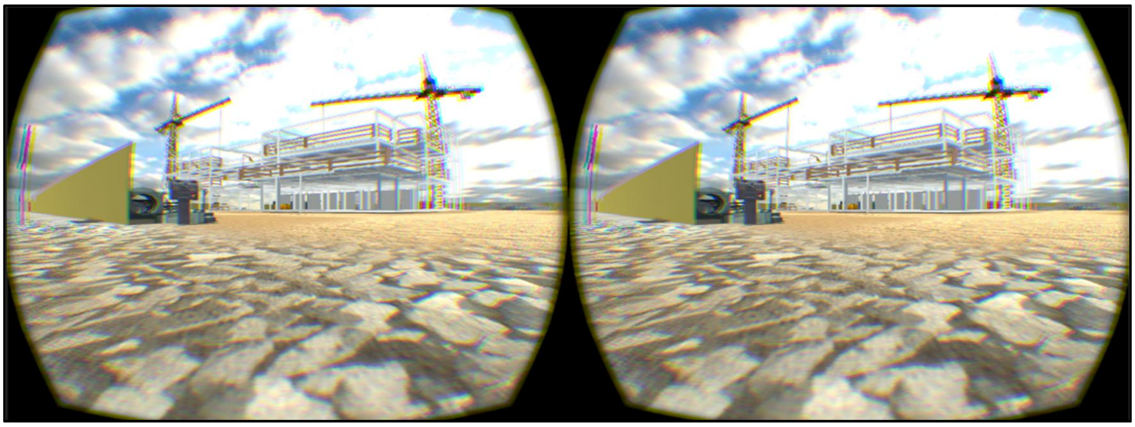

Figure 7: Users View through Oculus Rift® Headset (for Scenario 2)

Scenario 3 was developed assuming a vacant jobsite. All the material and equipment were placed off-site. The embedded script allowed users to interact with the 3D environment by dragging and placing materials and equipment on the site, thus creating their own ideal jobsite layout. Figure 8 shows the equipment and material available to the users in front of the jobsite.

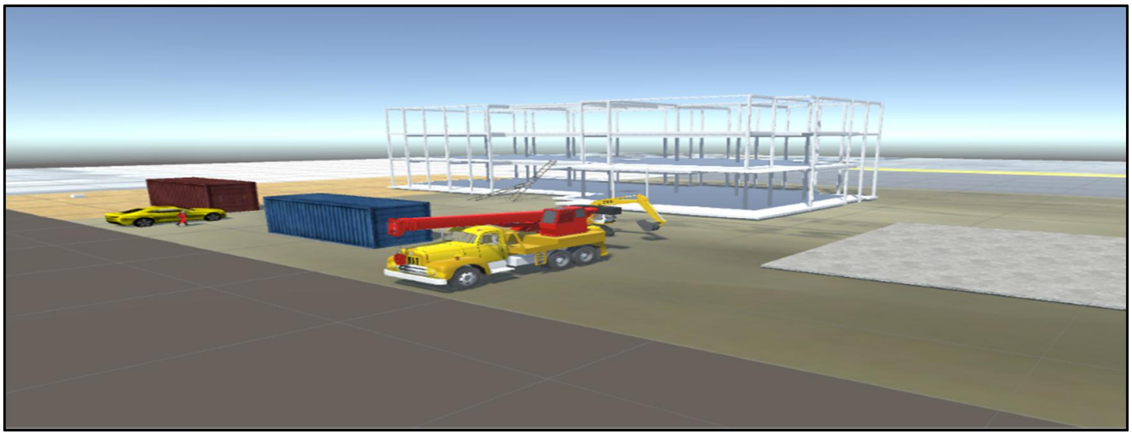

Figure 8: 3D View of Scenario 3

4.2 Validation: Analysis of Responses of the Focus Group

A focus group of eight BIM professionals was formed. The three scenarios and accompanying narrated videos were shown to them and their opinions were recorded. The participants were first shown the 2D site plan, then the traditional 3D site plans, and finally the 3D site plans in immersive environment. They were asked to identify strengths and weaknesses in all the models. They were also asked to identify any advantages of utilizing the Oculus Rift®. Participants considered 'Jobsite Virtual Tour' as best candidate for VR applications. Some specific comments were as follow: (1) "Very promising way to assess potential danger without being put in the actual situation." (2) "It reminds me of a game. It's very interactive and effective. I think it's an interactive idea for safety training and the immersive environment is definitely useful." (3) "It shows actual situation, real life experience rather than Revit model".

The following comments were collected for the application of VR in jobsite management: (1) “Crane placement has a great deal to gain from a VR interface. This would allow workers to see where a jobsite is in relation to the crane. The improved awareness would be beneficial for jobsite safety and planning.”; (2) “Was a good tool for identification and orientation of the jobsite, which provided a better understanding of what to expect on the site.”; (3) “Slower assessment but you get a real life hands on idea of the site layout.”; and (4) “Very beneficial when determining jobsite area and organization as well as safety.”

At the end of the focus group session, the participants were asked ‘Is your company currently using or plan to use the Oculus Rift®?’ Among the eight BIM professionals, five said ‘No’, two of them were ‘in testing and researching stage’, and one company currently utilizing it. One BIM professional revealed potential barriers for the headgear to be accepted by the construction industry: “It’s hard for the construction industry to accept technology that is unproven or still doesn’t work well. It will be a very long time before VR is accepted.” In addition, cost, inability to adapt to the quick changes and motion sickness were some other concerns expressed by the focus group members.

4.3 Validation: Analysis of Responses of the Questionnaire Survey

Fourteen graduate students with some construction experience were invited to participate in the testing process. Each participant was given 30 minutes to test all models (i.e. the 2D site plan, the 3D site plans and 3D walk-through model using Oculus Rift®) and then asked to complete a short questionnaire. Key words identified from the focus group discussion were used for opinions’ measurements in the questionnaire.

In question 1, respondents were asked to rate the effectiveness level of each of the three site plans on a 1 to 5 scale. Table 1 shows the results.

Table 1: Effectiveness of the 3 Site Plans

Measure	*Mean*	*Median*	*Mode*	*S.D.*
2D site plan	*1.23*	*1*	*1*	*0.58*
3D site plans	*1.62*	*2*	*2*	*0.62*
3D site plan with immersive environment	*1.85*	*2*	*2*	*0.36*

2: Highly effective; 1: Moderately effective; 0: No differences; -1: Moderately ineffective; -2: Highly ineffective

The 3D site plan with an immersive environment had the highest mean value with the lowest Standard Deviation (SD). The mean value of 1.85 indicates a moderately to highly effectiveness in jobsite organization. The traditional 3D site plans have the second highest mean value, but a SD of 0.62 indicates some mixed responses. By looking at the median scores, it is apparent that a considerable amount of respondents think that a traditional 3D site plan is as effective as the one with immersive environment. One respondent indicated that both the 3D plan and the 3D plan with immersive environment result in a ‘slower observation process than a 2D drawing’. Some respondents indicated that the amount of effort needed in developing 3D site plans outweighs their benefits over the 2D plans.

Next respondents were asked to indicate the level of possible advantages that Oculus Rift® offers in jobsite organization. Results are shown in Table 2 and Figure 9.

Table 2: Level of Possible Advantages that Oculus Rift® offers in Jobsite Organization

Measure	*Cumulative Mean*	*S.D.*
Site orientation	*1.62*	*0.62*
Site access	*1.23*	*0.89*
Crane placement	*1.08*	*1.00*
Equipment location/path	*1.46*	*0.84*
Material storage	*1.46*	*0.84*

Degree of certainty: 2: Definitely; 1: Probably; 0: Neutral; -1: Probably not; -2: Definitely not

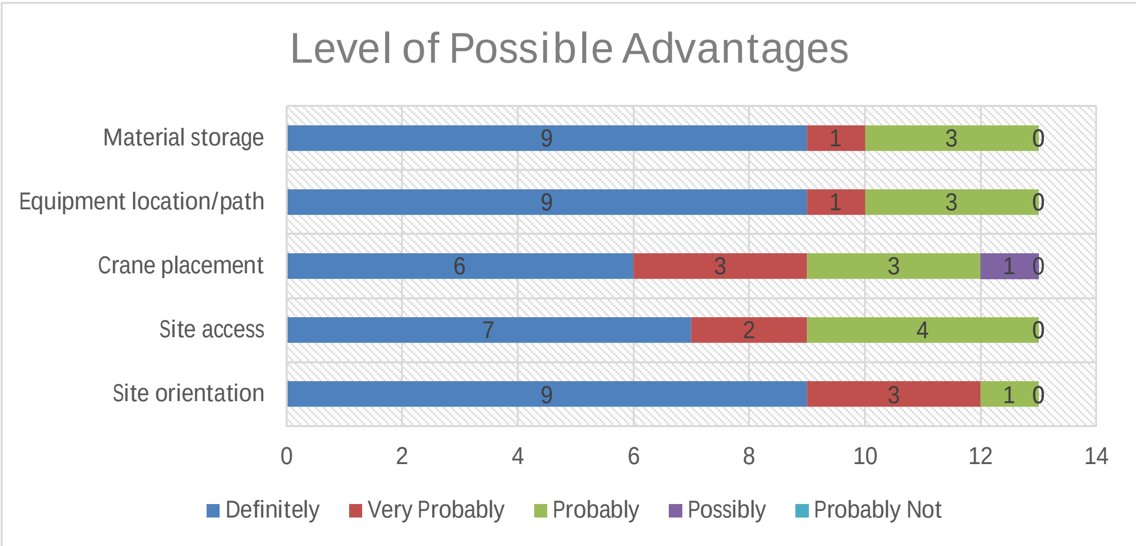

Figure 9: Distribution of the Responses

Of the five measurements indicated that Oculus Rift® offers ‘Definitely Probable’ to ‘Very Probable’ offer advantages in jobsite organization. Following are some specific comments from the survey respondents:

- ‘Crane placement has a great deal to gain from a VR interface. This would allow workers to see where a jobsite is in relation to the crane. The improved awareness would be beneficial for jobsite safety and planning.’
- ‘Was a good tool for identification and orientation of the jobsite, which provided a better understanding of what to expect on the site.’
- ‘Slower assessment but you get a real life hands on idea of the site layout.’
- ‘Very beneficial when determining jobsite organization.’

The following are some of the respondents’ overall impressions either toward the VR headsets or the 3D immersive models:

- 'Proven VR system. Certainly some possible applications but cost/benefit may not be sufficient to justify purchase of the system for some companies.'
- 'Very good organizational tool to use. However, I felt sort of lightheaded afterwards.'
- 'Very neat concept that can certainly benefit the industry.'
- 'It's a neat, interesting software but I mainly see it used for visual presentations of spaces compared to organizations of spaces.'
- The immersive is beneficial. However only if the frame rate and motion can be calibrated.
- 'Wearing it for an extended period of time gave me motion sick.'

Some users complained about motion sickness, which could be directly related to the amount of time spent in the VR environment. Participants stated, "using the Xbox game controller instead of the built-in head tracking eased the blurring associated with the movement". Collective feedback from participants indicated there is a strong interest in learning more about VR headsets in the construction industry. The participants interacting with the built scenarios and being able to identify key aspects as well as conflicts confirms VR as a viable option for jobsite management. Many participants wanted to explore beyond the built scenarios such as visiting the surrounding site and testing various site logistics options to obtain the best combinations (e.g. best location for tower crane placement).

5. Concluding Remarks and Recommendations

This pilot study aimed to test the feasibility of 3D VR headset applications in construction practice and education with focus on jobsite management. The results showed positive responses from both industry professionals and students. VR headsets and their applications in the construction industry have endless potential. Overall, we found that VR headsets are indeed very beneficial - allowing the users to immerse into a near-actual environment. The users were able to interact, identify, and gain an in-depth experience pertaining to jobsite management. The application of textures, materials and site development were found to create a life-like feeling. Each participant became physically involved in his/her exploration, exhibiting natural movements outside of the VR environment. This observation confirms the immersive viability of the VR environment, creating a lifelike reality. The workflow outlined in this paper allows for gaming like scenarios to be developed. There are many other options for creating a VRE, depending on the amount of control and detail. Some simple click and go options are, *insiteVR*, *irisVR*, and *Revizto*. The respondents made some recommendations during the data collection stage. One was the use of mobile controller. As the respondent sometimes needed to turn around in the model and it was inconvenient to use the keyboard to navigate, a mobile controller would allow for easier movement in the environment, i.e. Xbox controller. Another one was to provide more background information and instructions. The VR headset cuts off the user from the outside world. The end users focused more on what they can see instead of what they can hear. Adequate interpretation on what they will experience in the VR environment and what you expect them to see will enhance a better understanding among the end users. From this research, we have also uncovered a number of limitations concerning the effective use of the VR Headset such as: (1) Single user limitation. While conducting focus group, other people have no visibility of what the tester could see in the virtual world. To enhance communication and interactivity, a projector connected to that computer could be used to show the inherent movement of the user to other participants; and (2) Improvement in model quality. Some further improvements to the 3D immersive model could be made. Specifically reducing the size of the model to eliminate the lag while moving in the model and using more real information to rationalize the model.

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Improved Construction Safety: An Analysis of Real-Time Physiological Data through Innovative 'Smart' Safety Vests

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Abstract

The development of systems to monitor the physiological parameters of construction workers to generate early warnings has the potential to improve health and safety significantly in the globally dangerous construction industry. The aims of the recently-formed CIB task group on wearable sensor technology evidence the need for research and innovation in wearable technologies in construction, which lags in technology adoption compared to other industries.

An innovative approach using wearable technology and e-textiles to monitor the physiological parameters of construction workers in real time is proposed to improve health and safety. The technological feasibility of the proposed system was validated using a system implementation.

This paper reports the fully functioning system and its components. The proposed systematic mechanism to validate the usability of the system on a real construction site is also discussed. It reports the planned process to test the smart vest system on a construction site and to capture real-time physiological parameters.

An anticipated outcome of the research project is a significant contribution to the use of wearable sensor technology in the inherently dangerous construction industry to achieve improved safety performance.

Keywords: Construction safety, smart technologies, smart vest, wearable, real-time data

1. Introduction

1.1 Construction industry's poor safety record

Globally, the construction industry is one of the poorest performing industries in terms of its safety record. In the USA, out of 4,251 worker fatalities in private industry in calendar year 2014, 874 or 20.5% were in construction: that is, one in five worker deaths in 2014 were in construction (OSHA, 2015). In the UK the construction industry is the second-worst industry in terms of worker fatalities (HSE, 2015).

In Australia in 2014, the mining sector, the fourth worst performing industry, recorded 13 fatalities, whereas the construction industry, the third worst performing industry recorded 29 fatalities. Due to industry's poor safety record, the Australian Work Health and Safety Strategy 2012-2022 identified the construction industry as a priority industry for work health and safety improvement (Safe Work Australia 2012).

1.2 Health risks due to heat-related illness

Workers exposed to extreme temperature conditions are at risk of heat-related illness (also termed heat stress). Heat-related illness covers a spectrum of disorders (Lugo-Amador et al, 2004) such as heat stroke, heat exhaustion and heat rash. Heat stroke occurs when the core body temperature rises above 40.5°C. It can cause liver, kidney, heart and muscle damage. Often, the nervous system is affected, resulting in delirium, coma, and seizures. Permanent disability, even death, can result. It is evident that workers are unable to recognise early warning symptoms of heat-related illness. Construction fatalities from heat stroke have been reported globally.

Accident statistics report fatalities and serious injuries due to exposure to extreme temperatures. For example, in 2006, 3,100 U.S. workers had a heat-related illness that caused them to miss work (Office of Compliance, 2009). According to recent statistics from Occupational Safety and Health Administration (OSHA), construction worker fatalities were reported in occupation categories such as concreters, carpenters and construction labourers. In Australia, worker fatalities, lost time injuries and serious compensation claims were recorded due to heat stress (Government of Western Australia Department of Commerce, 2014), including in the construction industry (Mining Australia, 2013). From 2001 to 2010, relatively high incidence rates (6.8%) and compensation claims (4.6%) were reported in the construction industry in South Australia (Xiang et al., 2015). This study investigated the association between ambient temperature and occupational heat illnesses, and estimated that claims are associated with the 35.5°C threshold, above which claims increase.

Indoor and outdoor environmental factors or job-specific factors can expose construction workers to health risks due to heat stress. Outdoor environmental factors include high/extreme temperatures and/or humidity, radiant heat from direct sunlight, and areas with limited air movement (no wind or ventilation). Indoors, hot air conditions can be caused by nearby radiant heat sources such as boilers, steam pipes, ovens and heated tanks. Job-specific factors such as physical exertion and the use of bulky or non-breathable protective clothing and equipment can also contribute to the problem (US Department of Labour, 2015). Workers in operations involving high air temperatures, radiant heat sources (such as arc welding), heat-treatment operations, plating, and those working in confined spaces are also vulnerable to risks.

2. Background and Related Work

Regulatory bodies such as SafeWork in Australia, Occupational Safety and Health Administration (OSHA) in the USA and the Health and Safety Executive (HSE) in the UK are increasingly recognising heat stress hazards.

For example, in the USA, OSHA has introduced a practical guide to workers and employers in the form of a tool called the heat index. The heat index indicates the risk level associated with a range of temperatures and suggests protective measures against each risk level. In the UK, the HSE recommends carrying out a heat stress risk assessment in the workplace and a heat stress check list is provided to control the risks.

Researchers predict productivity decreases in other regions of 11–27% by 2080 in hot regions such as Asia and the Caribbean (Kjellstrom et al., 2009), and globally up to 20% in hot months by 2050 (Dunne et al., 2013).

In Australia, heat stress has been recognised as an occupational risk by many state level regulatory bodies. WorkSafe Victoria (2012) and SafeWork South Australia (2012) have developed practical guidance notes that advise how to prevent heat illness from working outdoors in hot weather or where heat is generated as part of work. WorkCover Queensland (2015) outlines a preventive strategy for heat-related health problems at work. However, a recent study in Hong Kong on the institutional analysis of construction accident causality based on the investigation of heat illness cases on construction sites recommends revisiting the guidelines, in recognition of the existence of the system and the institutional environment associated with it (Rowlinson, et al. 2015).

A recent Australian study reports that heat stress in the workplace is not only an occupational health hazard but also significantly reduces labour productivity, based on the self-reported estimates of work absenteeism and reductions in work performance caused by heat during 2013-2014 (Zander et al., 2015). These researchers reported an annual cost of US$655 per person across a representative sample of 1,726 employed Australians. This represents an annual economic burden of around US$6.2 billion for the Australian workforce. This amounts to 0.33 to 0.47% of Australia’s GDP. Similarly, a study done in Australia which included the construction industry on heat-related occupational illness reports that excessive heat exposure presents a significant challenge for the industry or activity (Singh et al., 2015). This study also reports that heat exposure during Australian summers commonly results in adverse health effects and productivity losses.

Edirisinghe and Blismas (2015) propose a technological solution to the problem based on the innovative approach of using wearable technology and e-textile to monitor the physiological parameters of construction workers in real time and to generate early warnings of hazardous conditions for improved health and safety. The technological feasibility of the proposed system has been validated through a prototype system (Edirisinghe and Blismas, 2015). This paper reports the further development of the system and the plan for usability validation of the technology in the construction industry.

2.1 Wearable technologies

Next-generation wearable technologies and e-textiles to monitor physiological conditions have been successfully used in industry sectors such as therapy and rehabilitation (Dunne, 2010), health and fitness (Coyle et al., 2009; Senol et al., 2011) and healthcare & tele-medicine (Lee and Chung, 2009; Pandian et al., 2008). For example, Lee and Chung (2009) developed a wireless sensor network-based wearable smart shirt for health and activity monitoring. In this smart shirt, ECG and acceleration data are transmitted via Zigbee. Another example is the wearable physiological remote monitoring system developed by Pandian et al. (2008). It is a washable shirt, which uses an array of sensors connected to a central processing unit with firmware for continuously monitoring physiological signals. The sensors measure electrocardiogram (ECG), photoplethysmogram (PPG), body temperature, blood pressure, galvanic skin response (GSR) and heart rate.

However, little research has been done on safety, particularly in the construction industry, where technology adoption is slow compared to other industries (Hosseini et al. 2012), with the exception of work on nano-material-based anti-heat stress uniforms (Chan et al., 2012; PolyU, 2014). However, this uniform is not capable of monitoring the parameters and providing real-time feedback/warnings.

The International Council for Building (CIB) formed a task group on wearable sensor technology (TG 92) to encourage research and innovation in wearable technologies in construction in 2015. The smart safety vest system (Edirisinghe and Blismas, 2015), while addressing a significant health problem in the industry, also strategically aligns with the research and innovation requirements in the building and construction industry.

3. Smart Safety Vest

The smart vest measures the body temperature and heart rate of construction workers using the LilyPad Arduino embedded platform, which is a micro-controller board designed for wearables and e-textiles. The data is transmitted to a mobile phone in real time. The system has an alerting mechanism to alert about unacceptable variations of measured parameters. For example, warnings for extreme temperature ranges are generated by flashing LED lights in the vest or by playing audio/video on the smart phone/device. Given the increasing popularity of smart phones, visualisation and alert generation is facilitated through a smart phone. In situations where the national and/or organisational policy does not encourage a smart phone on site (for example, anecdotal evidence suggests that in the UK construction industry the use of mobile phones on site is discouraged) the same functionality will be provided at the central computer.

Figure 1 illustrates the smart safety vest system. The system is composed of three components: smart safety vest, mobile app and smart safety glasses. The functionality of each of the components is described below.

Figure 1: Smart Safety Vest System

- Smart safety vest
  The vest has temperature and pulse sensors sewn into the vest. These sensors monitor the body temperature and heart rate of the wearer. The vest has flashing LEDs to facilitate the alert mechanism.

- Mobile app
  The sensor data is sent to the mobile app via Bluetooth connectivity. The mobile app visualises the data graphically. The mobile app has two functional components to visualise the temperature data and the heart rate data separately. As described above, the mobile app facilitates the alert by generating audio/visual warnings.

- Smart safety glasses

  Smart safety glass is included in the system to demonstrate the feasibility of projecting the sensor in smart glasses. This is particularly useful if the workers are not allowed a mobile phone on-site for them to self-assess their own health conditions.

Figure 2 illustrates the graphical use interface of the mobile app which visualises the temperature data. The current temperature values and the variation of temperature values over the period are displayed.

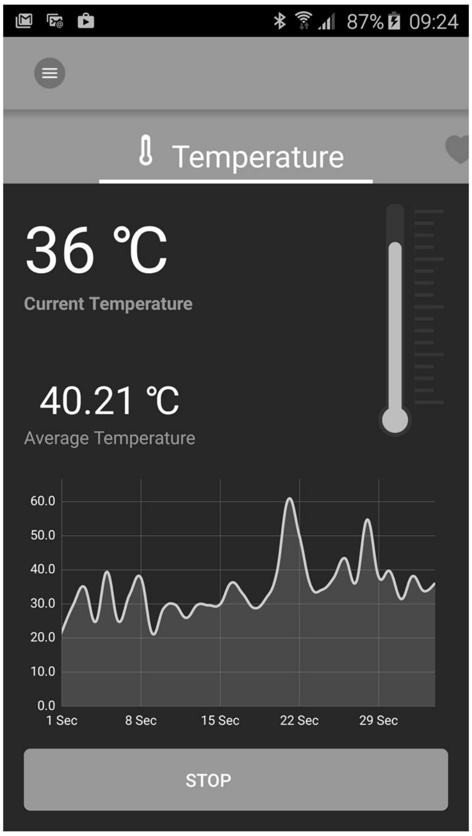

Figure 2: Data visualisation on the mobile app

4. Technology Usability and Extendibility

4.1 Technology Usability Validation

As the technological feasibility of the system has been validated, the next step is to validate the usability of the technology in industry. With recent funding support from an industry award, the system will be tested in the construction industry. Calibrating the sensors to various climates, seasons, and organisational and work procedures will be done during site testing. Workers from a range of work groups at multiple sites including concreters, brick-layers, plasters and carpenters will trial wearing the smart vest during normal duties. The workers will be provided with the mobile app subject to organisational policy. Management personnel will be given access to a central computer to monitor the worker data.

The technology evaluation together with the users' perceptions of using the technology will be evaluated after the trial period. The smart vest usability for the workers will be tested using the widely used system usability scale (SUS) developed by Brooke (1996) and validated by Bangor et al. (2008 & 2009). The widely-used SUS is an inexpensive, yet effective, tool for assessing the usability of a system. The effectiveness, efficiency and user satisfaction of the smart vest system will be evaluated using SUS by surveying the workers at the end of the trial period. Management feedback will also be sought at the end of the trial period to evaluate the usability of the system for organizational needs.

Management feedback will also be sought at the end of the trial period to evaluate the usability of the technology for organizational needs. In-depth interviews will be conducted to understand management perceptions of using the technology. Interviews will be designed based on the Technology Acceptance Model (TAM) by Davis (1989). TAM is widely accepted, used and tested in research to help understand management behaviours in technology acceptance. The interviews will cover the participants' perceptions of using the technology in terms of benefits/advantages, ease of use, trialability, result demonstrability, compatibility of the technology, motivators for using the system (change of image and relative advantage due to technology use), challenges experienced, and willingness to use the technology in future.

4.2 Extendibility

The smart safety vest system has potential for extension into two areas in future. Figure 3 illustrates the future smart safety vest system.

Firstly, the sensors are extendable beyond the temperature and pulse sensors. Depending on the physiological parameters to be monitored, the vest can be extended. For example, muscle sensors can be included to monitor ergonomic hazards. Motion sensors can be included as proximity detectors of exposure to hazardous environments/equipment. ECGs or other biomedical sensors/pads can be included to monitor other health conditions.

Secondly, the alerting mechanism can be linked with healthcare support systems such as emergency services. The alerting mechanism can also be included in a web application for remote telemedicine support systems. These are essential and integral parts of future mHealth applications.

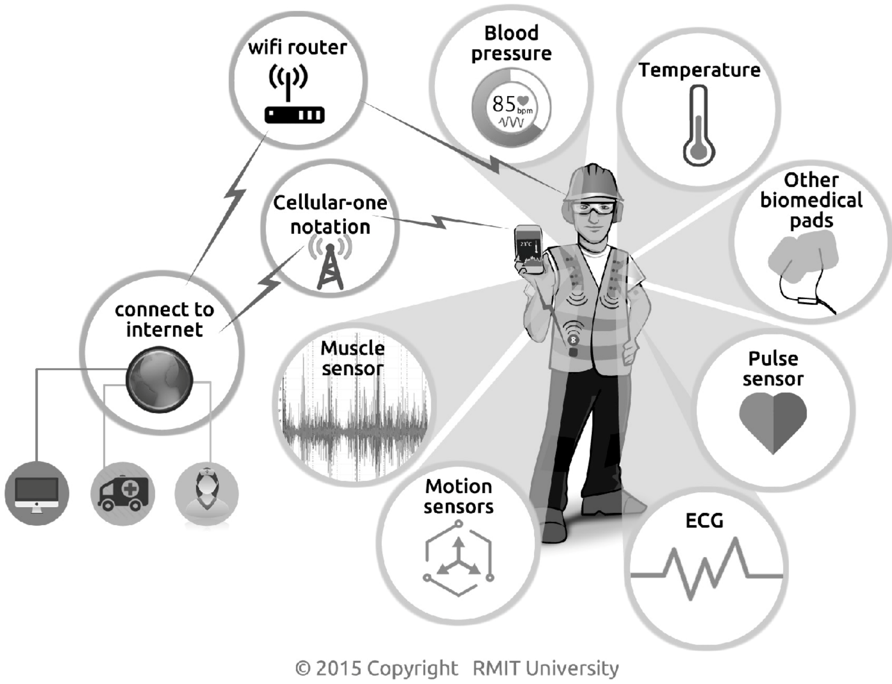

Figure 3: Extendibility of the system

5. Conclusions

This paper presents the innovative smart vest system developed to improve safety related to heat stress conditions in the construction industry. The safety vest system captures real-time physiological conditions of the workers and communicates the data with a mobile app and/or a central computer for management personnel to review. The data in these systems will be visualised in graphical format and early warnings will be generated if abnormalities occur. The plan to validate the technology's usability in industry was discussed.

The feasibility for the workers to use the mobile phones on site can be influenced by the organisational and/or national regulations and policies. For example, anecdotal evidence suggests that the use of mobile phones on construction sites is becoming restricted in the UK. In future the system will provide a central application for the site management to visualise the risk profiles of workers to overcome this limitation. The future work also includes extending the system to other physiological parameters and to link with remote heath care systems.

It is expected that the proposed technology addresses a significant problem in the industry and contributes to the zero harm vision in the industry. At the same time, the smart vest system contributes strategically and in a timely fashion to the research needs of the building and construction industry and is expected to enable step change in industry practice in technology adoption.

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"Next Step": A New Systematic Approach to Plan and Execute AEC Projects

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Abstract

Planning and control of project execution is the core of project management. One key success factor is an adequate implementation strategy. The Architecture, Engineering and Construction industry (AEC) is portrayed as an industry with serious challenges ahead. Among observed problems that often happen in AEC project are the decisions, which are made in wrong time or at the wrong level of organization, as well as solutions executed in the project without being aligned with corporate strategies. This conceptual paper presents a new systematic approach introduced in Norway to fight the many difficult challenges in the AEC industry. The systematic approach is called "Next Step" and is a framework inspired by the RIBA plan of Work. The new framework presented in this paper identifies the key steps and tasks in a project lifecycle from the definition to the termination of the building. The framework focuses on project execution as well on the critical decisions on a corporate level, involvement of the proper stakeholder perspective, and a sustainable development of the AEC industry. The main purpose is to help the actors of the AEC industry. The intention is not to define a constraining recipe, but to give the industry a common language and collective reference for AEC projects. The framework also highlights important issues in the front end of projects concerning strategic alignment and project planning. This paper also reports on the adaptability of the new framework with different procurement forms. The new framework suggests examining the different phases in this systematic approach through different perspectives: by introducing the perspective of the owner, user, supplier and public, the project is driven to achieve strategic goals and leads to a more efficient process and sustainable outcome.

Keywords: Project execution framework, perspectives, stage gates, project delivery methods, contracts

1. Introduction

Planning and control of project execution is the core of project management. One key success factor is an adequate implementation strategy. This is specifically true in the architecture, engineering and construction (AEC) industry. Implementation strategies refer to the systematic approach to planning and execution of a specific project within a corporation. Reasons for wanting systematic approaches are obviously the constant need for continuous improvement and learning from past experiences. These are difficult challenges, and given the wide array of different contexts (national-, financial-, industry etc.) and individual strategies of corporations (business models, markets, growth etc.) and technical solutions (elements, products, materials etc.) it is no surprise the approaches vary a lot. Focusing the AEC industry, the specific challenges are often identified as being increasingly fragmented and complex on one side (Pennanen et al., 2010) and reluctant to change and innovate on the other (Dale, 2007). These characteristics combined portray an industry with serious challenges ahead.

To summarize some observed problems that frequently occur in construction projects: strategic decision-making often rely on documents (Business Case, Project Plans etc.) that are incomplete, inconsistent and in some cases simply wrong by purpose or incident (Flyvbjerg et al., 2002). Decisions are not made in time, sometimes made on the wrong level of the organization (Berg, 1999) or by the wrong individuals. This may be indication of unclear roles in connection to the decision-making process, or ineffective organizations. It may also indicate errors and flaws in decision making on individual or group level as pointed out by many authors (e.g. (Kahneman, 2011; Lovallo & Kahneman, 2003; Raiffa et al., 2006). Another recurring problem is solutions planned and executed in projects, without being aligned with corporate strategies. Projects are often viewed as pure execution without responsibility for delivering the right product, the right result for users and owners. This is evident in the traditional definition of a project as a unique task (PMBOK, 2004). It is also well known that construction projects are tormented with errors and mistakes in planning, design and execution, costing unnecessary money and reputation (Love et al., 2003).

In sum all these challenges form a problem-complex that is too much to handle for each individual project owner, project sponsor or project manager. Allowing completely individual implementation strategies to be developed for each single project will not only be costly in terms of making the same development many times, but will also miss out the opportunity to improve and learn. This conceptual paper presents a new systematic approach introduced in Norway to fight the many difficult challenges identified above. The framework is presented in chapter 3. The main issues in this paper are addressed through three axes, each represented in a research question:

- How can the framework help to achieve the right result for owners and users?
- How can the framework help to secure that the right perspectives are considered?
- How can the framework deal with different procurement forms?

2. Theoretical Framework

2.1 Success and stakeholders

In project management literature there are many definitions of success, yet Oxford dictionary of English simply states, “Success is the accomplishment of an aim or purpose” and failure as “lack of success”. Samset (2010) states “Projects are initiated to solve problems or satisfy needs”. Thus, we can assume that a project success is actually connected to its ability to solve those problems or needs.

The identification of problems and needs and the process of solving them is an important step to be able to define the project, and to define the aim or purposes in order to achieve success. Samset (2010) also argues to look at AEC projects in a larger context than only to solve the immediate problem. He claims that monitoring of a project should be both on tactical and strategic level. The tactical level deal with what most regards as the important success indicators in a project; cost, time and quality. Tactical success in projects is associated with the term “project management success” (Cooke-Davies, 2002). The strategic level looks at indicators as effect, relevance and sustainability. Strategic success is associated with “project success” (Cooke-Davies, 2002).

The AEC industry is a fragmented industry and relies on many different stakeholders to complete a project (Kerosuo, 2015). Each stakeholder have a different perception of the aim and the success of the project and these stakeholders will most certainly try to optimize their own operation (Aapaoja et al., 2012). This leads to sub-optimization of projects (Zidane et al., 2015). The right stakeholder involvement is important to create value in projects. By displaying key stakeholders and together aligning their aims, can help to conquer some of the differences (Yang et al., 2009). Keeping the most important stakeholders in mind, it is important to look at the three major groups of stakeholders and their views. Samset (2010) refers to this as perspectives and list them as the owner perspective, the user perspective and the executing perspective.

The owner is the initiating and financing party, the one who normally has a long-term interest in the investment that the project represents. The user is the party who is going to utilize the result of the project for operating their business. The executing party (-parties) is the architects, engineers and contractors who are executing the project on behalf of the owner – the project organization. The owner typically has, or at least should have, interest in the strategically performance of the project, while the executing parties typically limit their interest to the tactical performance (Slevin & Pinto, 1987). Bertelsen and Emmitt (2005) identify the owner, user and society as important groups that a “client” should represent: “These three groups of interest each value different things at different times in the life of the building.” Identifying the perspectives early might help to change and understand the focus of the stakeholders.

2.2 Project delivery methods

Project Delivery Method (PDM) - a system for organizing and financing design, construction, operations and maintenance activities that facilitates the delivery of a goods or service (Miller et al., 2000). Choosing different PDM will affect the project cost, schedule, success and influence the efficiency of running the project. This makes it a challenging issue for stakeholders and decision makers (Al Khalil, 2002; Chan et al., 2001; Kumaraswamy & Dissanayaka, 2001). The suitability of the selected PDM can improve the project performance to a great extent (Al Khalil, 2002; Han□Kuk et al., 2008; Kumaraswamy & Dissanayaka, 2001; Oyetunji & Anderson, 2006; Udechukwu et al., 2008).

There are large numbers of different PDMs available in AEC industry to overcome the shortcomings of traditional procurement (Alhazmi & McCaffer, 2000). Numerous authors have categorized the range of procurements forms in the literature. However, in this paper we try a new classification of procurement forms, to make it more practical for alignment with the framework. This classification is inspired by a very recent PMI book (Walker & Lloyd-Walker, 2015).The procurement forms could be fitted in three groups:

Segregated procurement forms: A key feature of procurement forms in this group is a trend to separate design and construction/delivery. Segregated forms include well-known traditional approaches. The dominant segregated form of procurement, which is operating in most countries, is Design Bid Build (DBB). In DBB the owner will receive the bid and award construction contract based on the finished designer's construction document. In this procurement approach, it is assumed that the project design is complete enough to enable a bidding process to establish the cheapest and/or the quickest tender cost. It also assumes that the price of design variations encountered throughout the delivery process will not be excessive (Masterman, 1992; T. Rizk & Fouad, 2007; Sanvido & Konchar, 1998).

The advantage of segregated forms, which is the key cause to select this procurement form in many organizations, theoretically lies with market contestability for the lowest cost (bid) in combination with shortest time. Other example of forms in this group is Cost reimbursement (Cost-Plus).

Integrated procurement forms: Integrated procurement forms are to some extent either physically or contractually integrated design and delivery process. A key character of this collection of procurement forms is that there is a planning and control logic driving the project and a confidence that integration is mainly accomplished through planning and control systems. Some of the procurement forms in this group are: Design and Construct (D&C), Management contracting (MC/CM), Joint venture consortia, and BOOT family procurement approaches (PFI, PPP). The most recognized procurement form in this cluster is Design and Construct (D&C) where one entity is contractually responsible to produce design and perform the construction service, typically called design-builder. It integrates the design and delivery functions either through an integrated firm mechanism, which has an in-house design team, as well as a delivery team or by the delivery organization outsourcing the design to another team that becomes its design services provider (Molenaar & Songer, 1998; Molenaar et al., 1999; T. F. Rizk, Nancy, 2007).

In all integrated procurement forms the main focus is on integrating design and delivery processes by emphasizing on planning and control, however, this does not eradicate the importance of collaboration aspect and the people management but it indicates the weight on systems integration through planning and control.

Collective procurement forms: In this cluster the focus is on integrating the project design and delivery teams rather than the process by highlighting collaboration and coordination. Some might claim that this group of procurement forms could be the most mature forms for best outcome and value for money. Collaborative procurement forms like *Partnering, Integrated Project Delivery (IPD), Delivery Consortia/Partner (DC/P), Competitive Dialogue (CD)* and *Alliancing* are fitted in this collection. However, the authors believe that some of the forms in this cluster (partnering, competitive dialog, etc.) are naturally represented as a cultural state or formal/informal contract arrangements rather than procurement choice. They have characteristics, features, and cultural elements that can be applied to other forms.

Collective procurement forms provide a framework for establishing mutual objectives among all parties involved. This normally also lead to developing an agreed dispute resolution system. Collective forms need strong team building skills among participant. Compared to other traditional forms it also needs a different paradigm from highly commercial winner-gets-all and adversarial relation between parties involved. In collective forms, the project owner does not only engage/collaborate with the designers but also collaborate from the very initiate stage of the project with contractors and possibly with significant subcontractors. Collective forms mainly characterized by covering collaboration, transparency, innovation and accountability.

2.3 Phases and decision gates

The governing of projects is a major challenge for project management. With the increased focus on governance over the last decade, phases and decision gates became more in focus and hence have received increasing attention (O.J. Klakegg et al., 2009; Müller, 2009). A fundamental logic in this perspective is that for each step of the development, one should stop and check the status before moving on, that is; one should proceed only if everything is in order. This approach is maybe best summarized in the concept of gateways: a formal control of documents and assumptions before making a decision to accept a project, or to close one phase and enter into the next. The source of this thinking seems to stem back to the term “stage gate” introduced by Cooper (1993). We choose to use the term “decision gate” as a reminder that in a governance perspective, we hold the decision to be the main issue connected with these gates.

The gateway is a key element in an adequate implementation strategy: Seen from an owner’s perspective a decision point (a point for looking forward), whereas seen from the constructor´s perspective it may be a milestone (a point for celebration, following accumulated results), as pointed out by Lereim (2009). The purpose of a decision gate, as seen from a project owner’s perspective, is to make sure the formal decision-making is successful in supporting the success of the organization, business-corporation or public entity. Broadly speaking, this depends on making the right decisions. The logical way of making sure the right decisions may be achieved is to choose the right people to make the decisions, and make sure they have the best possible basis for making the decisions.

Having the best possible basis for making key decisions is a question of extracting the right information. The right information is a question of what is available (known at the time of decision) balanced against the cost of obtaining more/better information and the risk associated with making the decision on less than perfect basis. Decision gates are often characterized by having defined procedures for assessments/control and decision making, defined roles and responsibilities, criteria for acceptance, and a gatekeeper (owner of the gateway process) who decides whether the project is allowed to enter the gateway or not.

The cost of attaining perfect information means it is rational to divide the development in steps and not produce more than needed at each step. Making sure the relevant information is available at the right time and in adequate detail is paramount. Consequently, phases and decision gates are key elements of an information flow framework. Examples from phases given below are meant to illustrate some selected decisive moments in this development:

The first phase is the initial process where the problem or need is acknowledged. This could be due to an owner having a site he wants to realize, or a company looking for other facilities to do their business. This indicates a reason to invest and is often referred to as the business case. Acknowledging that a reason to invest exists is a decisive moment because it drives the decision-making and planning process forward and raises expectations among users.

The next logic step is to view the feasibility of the business case; can it be developed, what are the best alternative concepts, what should the project include. This should now end up in a brief, specifying the contents of a project. Particularly the brief is viewed as a crucial document to achieve a successful project (El. Reifi et al., 2013). The brief is the foundation for a good design and production process. Approving the brief is another decisive moment because this is the point in time where you decide what the users are going to get in the end.

Another key milestone is the handover from the contractors to the owner. This decisive moment represents responsibility shifting from executing party to owner. At this point it is crucial to compare the actual delivery against what was decided in the final brief. For some projects this is when the owners and users for the first time are able to consider to what degree the project fits his or her needs. Traditionally this was where the focus of the project organization ended, but today there is strong focus in the use of the project, looking at how the users of the project succeed in their business and in the management of the facility.

Having a long-term perspective that includes sustainability of the investment is today required, even expected for all parties, despite traditional short-sighted execution perspective. Sustainability has to be considered in in terms of the investment's economical-, social- and environmental consequences. Only when the truth is known about the investment's long-term consequences can its true value be assessed. This makes the decision to terminate, decommission or sell the facility into another decisive moment. This is where the initial intention meets the hard reality of the end and the circle is completed.

3. Result

In January 2015 Bygg21 and The Norwegian Property Federation took an initiative to make a common phase model for the Norwegian AEC industry. The project was undertaken by a research group from the Norwegian University of Technology and Science (Ole Jonny Klakegg et al., 2015). Figure 1 presents an outline of the resulting framework, which was released in December 2015 (www.bygg21.no).

Step	1 Strategic definition	2 Brief development	3 Concept development	4 Detailed designing	5 Production	6 Handover	7 In use	8 Termination
Core process	Owner perspective							
	User perspective							
	Supplier perspective							
	Public perspective							
Management process	Planning							
	Procurement							
	Communication							
	Sustainability - economics							
	Sustainability - environment							
	Sustainability - scocial							

Figure 1: Outline of the framework called "Neste Steg" (Next Step)

The framework “Next Step” is generic and based on a similar set-up as the RIBA Plan of Work (RIBA, 2013). The AEC industry can use the framework with any form of contracts and is open for future development of new PDMs as well. The main purpose is to help the actors of the AEC industry with defining key tasks that need to be fulfilled in the different stages of a project, and to help coordinate their involvement. The intention with this framework is not to define a recipe that needs to be followed to the letter, but to give the industry a common language and collective reference to execute projects.

The different steps of the project are indicated on the top of Figure 1. Each step has a clear purpose and together they all the different phases of a project. In this framework there are 8 steps, including the last important step of termination. Termination can refer to the termination of ownership; i.e. the owner sells the property or the demolishment of the building in order to utilize the site in a different way. The logic of the steps is based on a systems thinking approach with input, process, and output logic, creating decisions gates after each step. The output can be input to the next step or leading to a termination of the project. The process is the actual tasks that need to be completed in order advance the project (Ole Jonny Klakegg et al., 2010).

Inspired by Eikeland (2001) the framework divides the processes into two major categories: Core processes and Management processes. Core processes are main tasks and supporting tasks that develop the professional contents of the project. Management processes are planning, coordination and control tasks that need to be performed professionally to make the core processes work well.

In the core processes, the activities are separated into four different perspectives, allowing the stakeholders to easier identify their major activities and tasks and understand the purpose of the tasks at hand. The fundamental perspectives are described by Samset (2010), consisting of owner- user- and executing perspectives. In addition, the new framework includes a public perspective to put focus on how projects need to work actively with their context. The core processes are described with recommended activities that needs to be addressed, in what perspective they need to be performed, and summarizes necessary start-up conditions (input) and deliveries (output) from each step. The idea is that all parties in the project need to know that these are the main activities and issues to be addressed. The framework does not prescribe who should address each task – it is up to the project management to organize the project. The framework prescribes what perspective, or mindset, each task should be performed in.

The management processes includes several categories of tasks that are of the utmost importance for the project process. Planning, procurement and communication are three vital examples. These processes run continuously over time across all steps, but also include separate tasks for each step. Another category of management processes deals with the sustainability of the projects. To secure a wide perspective all three dimensions of the triple bottom line is explicitly addressed. To secure a long time perspective the 8th step focus termination of the project result (the infrastructure, building etc.). There shall be no excuse for not making sustainability considerations in construction projects.

The planning tasks are linked to making plans for the execution of the tasks, adding details to the plan through each step. Examples of important planning tasks include planning the handover strategies from the contractor to the owner and for the user. The procurement tasks will vary along the steps and have to be adjusted to the execution strategies of the project. A typical question is at what step you procure consultants and contractors: This can vary from step three to step five depending on how early involvement is optimal for the development of the project. Some execution strategies require involvement of all parties on an early stage; other strategies develop a detailed design before procuring the construction companies and suppliers. The framework holds that it is important not only to plan but also to control that the plans are followed. The framework is a powerful tool for project management.

Communication in a project is important and challenging; given that the construction industry tends to be fragmented with many different parties specialized in different areas. The framework explicitly addresses the digitalization of the project process, especially the use of integrated communication tools, such as building information models (BIM) as a communication platform. Developing digital project execution strategies early in the project is important to make sure the parties are all “on the same page”.

Sustainability is necessary for future projects – both in execution and with regards to the result. The AEC industry will not be allowed to continue using energy and producing waste like they used to. The framework differentiates the sustainability in three dimensions: economic, environmental and social. The economic sustainability includes securing the right choices in investment and for the full lifecycle cost of the project result. The environmental sustainability is regarding the use of materials, emission, heating, cooling etc. – both the climate effect and the energy use. The social sustainability is how the project affects the life of the team members, users of the result and people around the project, including ethical dimensions and fairness in distribution of effects.

4. Discussion

Planning and control of project activities is still a challenge in the AEC-industry. As seen in the introduction, this is a serious threat to tactical or project management success (doing it right). However, as argued in the introduction, there is a bigger issue – the strategic or project success (doing the right thing). More systematic planning and execution in every step of the development, from problem to solution to effect to termination, can improve both. Doing this one by one (each company by themselves) will necessarily create non-conformance and miscommunication. It will also require a lot of unnecessary effort in repeatedly inventing the wheel. It will waste time and resources and at the same time create limited results.

Trying to change this situation require major steps. Designing a new framework like described above is only a first step. Whether it is good or bad, suggesting it as a general standard will inevitably spark resistance in a traditional industry. To have effect many actors will have to adapt their systems and management practice to the new framework.

First of all, the time is right. There is a growing attention to the importance of good governance in solving major challenges in the industry, companies and projects. All leading actors in the industry accept sustainability as the standard – at least on paper and in speeches. There is a highly developed understanding that projects are about value creation and that everything that represents wasting time and money or “gold plating” is improper. This is helped by the current slow-down in the economy due to reduced activity in the oil and gas sector. Finally there is a wide range of different new standards being developed for PDMs and information exchange that paves the way for integrated delivery strategies. These strategies obviously need some sort of common framework.

The new framework itself is made as flexible and future oriented as possible. The generic framework is valid for different projects delivery methods (PDM) including future innovations. The framework is scalable in the sense that roles and activities can be adapted to small and big, simple and complex projects. Finally the framework is not a strait jacket that requires everyone to become the same or use the same words. On the contrary, it is designed acknowledging the need for companies to be able to develop their profile and competitive edge. The framework is supposed to be a common reference and “language” that all parties refer to in order to clarify concepts and better coordination. In order to achieve this, the framework should highlight the most important issues in each step, and help to create a platform for timing the right decisions and securing relevant basis for these decisions.

The framework is constructed from well-known principles and international best practice. It has a solid basis. For most actors the changes needed to implement it will be small to moderate. A comparison between the project-models of major companies in the industry reveals that most of the major decision making points are identified in most models(Ole Jonny Klakegg et al., 2015). The level of detail in models varies and the choice of words and graphic presentation is different, but the fundamental structures are remarkably compatible.

Leading organizations in the Norwegian AEC-industry are behind the new framework, including major public clients. The response from the industry has been positive. Other major actors are ready to start using it, and this is the main force that will be able to influence the industry. By January 2016 it is already clear that three different committees in Standards Norway are using Next step as a part of their working basis in developing new standards for the AEC industry. When major clients require it used as a reference, and major executing parties also say they will comply, this has the potential to grow into a strong wave with the force to change a conservative industry. In the long run, the observed improvements will be the best selling points for the model. This of course still remains to be seen.

5. Conclusions

This paper presents a new Norwegian framework for the AEC industry. The framework is not a detailed recipe for project execution, but tries to define the key tasks and steps in a project from the definition to the termination of a building. To sum up we conclude the proposed research questions:

How can the framework help to achieve the right result for owners and users? By defining the decisive moments and the necessary steps on the way from problem to solution until the investment is terminated. By forcing the parties to consider the long-term issues, and assess holistically the relevance and sustainability of alternative concepts, the right choice comes forward and becomes the natural decision.

How can the framework help to secure that the right perspectives are considered? A key feature of this framework is the focus on the key stakeholders and their perspectives. To help the owner make good business decisions, the actors need to think like an owner when they perform their tasks in planning and execution. To create the right solution for the users, the actors need to think like a user and consider how the project can best support the user’s business and facility management. To perform an efficient execution process the actors need to think about project delivery models early and make conscious choices about constructability. To secure that society’s perspective is considered, the model puts emphasis on requirements, approvals and other aspects of context that the project has to work with.

How can the framework deal with different procurement forms? One challenge in delivering a project is at what stage you procure consultants and contractors. The framework helps to deal with this challenge by explicitly state on what stages different procurement strategies has to be considered to be valid alternatives. Collective and integrated procurement forms needs to be considered early – from step three to five – depending on how early involvement of parties is optimal for the development of the project. Segregated procurement forms could be fitted in step five. A typical problem today is that some strategies are constantly considered too late in the process and thus remain unexploited. Other actors choose strategy from tradition and lack of awareness more than a conscious choice. If they are confronted with the new framework there will be no room for such neglect anymore.

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Towards Quantification of the Economic Efficiency Advantage of Alliancing in Complex Infrastructure Projects

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Abstract

Project Alliance is a construction project delivery system where the owner and service providers form a joint organisation as well as share project risks. Challenging projects are expected to benefit from alliancing although existing proof is somewhat ambiguous. Thus, the study aimed to improve the understanding of whether project alliancing can be used to implement a challenging construction project economically compared to traditional delivery systems such as Design-Bid-Build, Design-Build and Construction Management at Fee.

The subjects of study were ideas born in the development phase of an actual alliance project and their refinement into innovations that bring cost savings and added value as data on related savings and other impacts were available. The comparison of the alliance contract and traditional delivery systems was based on expert assessments. Experts assessed first and foremost the capacity of traditional delivery systems to promote the creation, demonstration and introduction of new ideas, and the beneficial effects they can have at best. That allowed comparing the relative performance of different delivery systems.

The alliance model seems to have several features that stimulate birth of ideas and innovations, such as multidisciplinary expertise, contract and risk sharing procedures that motivate innovation, as well as a fairly long development phase that allows developing innovations and putting them into practice. On the other hand, traditional delivery systems feature many identifiable factors that cause fewer ideas to be born, demonstrated and introduced than the alliance model. Moreover, introduction may be delayed due to factors like contract negotiations which often reduce the benefits derived from innovations in the case of traditional systems. Alternative delivery systems are not expected to result in similar cost savings as alliancing, but in a price level clearly above that attainable by alliancing without any actual value creation benefit.

Keywords: Alliancing, project delivery systems, comparison, economic efficiency, transport infrastructure

1. Introduction

Demanding road and rail projects, their conditions and input data are fraught with great uncertainty. The numerous designers and implementers, many interest groups and linkages to existing infrastructure increase the complexity of the projects. Traditional project delivery methods based on a certain distribution of responsibilities have been found to be poorly suited for projects of this type. The uncertainty is reflected in large risk contingencies while the primary interest of the parties is to safeguard their own interests.

In Project Alliance (alliance contracting) designers, contractors and the project owner form a joint project organisation and work in open collaboration. All benefit from the success of the project entity and there is neither need nor opportunity for company-specific sub-optimisation. Moreover, alliance contracting makes good use of the early cooperation of the actors. Thereby it is believed to enable better innovative development and more effective project implementation than traditional delivery methods. Yet, systematic comparison data are scarce.

The aim of this study was to increase understanding of the ability to implement construction projects at a lower cost than normally through alliancing. Its economic efficiency is compared to results achievable by alternative delivery methods. The work concretises in the development possibilities of a project solution, and other possible factors causing differences in relative economic efficiency are not analysed meaning that e.g. possible differences in transaction costs and pricing are excluded. The study was also limited to the alliance's development phase, i.e. the planning period between the selection of the alliance consortium and agreement on the project's commercial terms when conditions for launching construction exist.

2. Compared delivery methods

The most common delivery methods used to implement infrastructure projects in Finland, limited to the investment phase, are Design-Bid-Build, Design-Build, and Construction Management at Fee. Thus, they are also the logical benchmarks of comparison for the economic efficiency of Project Alliance. The project is generally organised as follows when using them:

- *Design-Build* (DB), where a contractor under contract to the owner is responsible for the project's design and construction as an entity.
- *Design-Bid-Build* (DBB), where the owner assumes responsibility for design and the project is constructed on the basis of a separate contract.
- *Construction Management* (CM), where a separate organisation manages the overall project and implementation is realised through numerous partial contracts.

In alliancing, the traditional roles are abandoned on the contract level, and in its purest form all the key parties – owner(s), designer(s) and contractor(s) – form an alliance through which they assume joint responsibility for the project's design and implementation. The alliance organisation comprises people from all partner organisations, including the owner's. Decisions on project implementation are made jointly and unanimously by the parties. Alliance partners also share the risk of project implementation. Thus, the reward of service providers is based on the success of overall project implementation, not on their performance of their individual tasks (Lahdenperä, 2009, DTF, 2006, DIT, 2011).

In alliancing, the key actors are brought together and the alliance is typically formed at an early phase with respect to design. Service providers are often selected as a consortium with an emphasis on competence. Then, actual collaboration begins with a development phase during which the project solution is developed and the project's target cost is set and other central goals are concretised. The implementation phase starts only after agreement is reached between the parties on the above. The case study project also followed the presented procedures (Alliance Executive Team, 2014) although the alliance contract can be applied in many different ways.

3. Present knowledge

The alliance contract has been the subject of active research since the first projects that used it (e.g. Ross, 2003; Walker & Hampson, 2003; Hauck et al., 2004). These and many later project-specific case studies (e.g. Jefferies et al., 2014; Walker & Jacobsson, 2014; Morwood et al., 2008) focus on principles of operation while also trying to assess the results achievable by alliancing. Belief in the excellence of the model is strong in general. However, also as concerns assessment of performance, the study is mainly qualitative with the exception of occasional cost savings estimates. Walker et al. (2015) and Sweeney (2009) are among the rare studies based on a broad stock of projects and exact data. The results speak for the excellence of alliancing as earlier studies. DTF (2009) also examines project outcome data but mars the otherwise positive picture by questioning alliancing based on non-price selection. The significance of project-specific challenges and conditions, however, remains unclear (cf. Rooney, 2009).

Despite their merits, quantitative studies (Sweeney, 2009; DTF, 2009; Walker et al., 2015) are also deficient due to the lack of an unambiguous benchmark. For instance, actual cost is compared to the previously agreed contract price, the target cost or the owner's budget estimate since genuine comparison of projects in a world of individual projects is nearly impossible. This raises many questions because the contract price level is determined differently in different delivery methods, and the owner's budget is a highly unreliable and most often too optimistic standard of comparison (e.g. Flyvbjerg et al., 2002; Cantarelli et al., 2012; Andersen et al., 2016). Thus, it is clear that assessment of alliancing requires further study, especially in terms of quantification of the economic efficiency of alliancing in relation to other delivery methods.

4. Study method

Comparison of the economic efficiency of different delivery methods is not very simple. Statistical comparison of large amounts of data produces exact results, but in the case of individual projects it is problematic since different projects use different delivery methods, and all influencing factors cannot be taken into consideration explicitly. On the other hand, that would not even have been possible in Finland in the case of alliancing since there is only little experience of its use. Therefore, it is best to use the case study method with alliancing whereby in-depth focus on the performance of the model and the ensuing understanding achieved facilitate implementation of the comparison (cf. Yin, 2014; Eisenhardt, 1989).

As to alternative delivery methods, the study uses expert opinions which allows closing the gap between evaluation of the different operational preconditions and impacts of alliancing and other delivery methods. The case study generates data on the new procedure – alliancing – and it is the task of experts to use that data to evaluate the capacity of so-called traditional delivery methods to meet the challenge of alliancing. There is a lot of experience from so-called alternative delivery methods. Consequently, if the experts first familiarise themselves with the results of the case study on alliancing, their evaluations become more reliable.

The starting point of the case study were the innovations of an alliance project, of which the five most significant were selected for examination. First the birth mechanisms of innovations were investigated including influencing factors and boundary conditions. These were then presented to infrastructure experts participating in a focus group workshop: the 17 persons represented owners (7), designers (4), contractors (4) and construction management consultants (2). Then the experts of the workshop divided into five groups. An attempt was made to include members of all actor types in each group. Each group also included a case study project participant to specify knowledge about innovations and their backgrounds.

Each team concentrated on assessing one of the five major innovations. Guided by a list of questions, they were to consider the possibility of the innovation becoming reality if one of the alternative delivery methods had been used to implement the project. Each team also reported the results of its work to the entire group of participants and time was reserved for discussion afterwards. The reporting at this phase formed the framework for the qualitative analysis of the study (Ch. 6.1). After discussion, workshop participants were asked to complete a personal questionnaire, the results of which were used as input data for the quantitative part of the study (Ch. 6.2). The focus group was used to get expert views as well as to give the participants an opportunity to exchange information and views with each other before presenting their evaluations in order to ensure transfer of sufficient background information and comprehensive understanding as a basis of assessments concerning a complex issue (cf. Morgan, 1996; Cyr, 2015). Personal questionnaires were, again, used to avoid the dynamics of randomness related to team work and the related possible bias in results. They also enable more detailed analysis.

In the questionnaire respondents were asked to estimate the *probability* of a certain innovation of the case study project being adopted by alternative delivery methods and what the *benefit/cost saving* compared to alliancing would have been if adopted. The response alternatives (see Fig. 1 below) cover all possible paths forward meaning that the sum of their probabilities would always be 100 per cent by delivery method. The savings in euros achieved by alliancing were made known at the workshop in relation to all innovations dealt with, but in the questionnaire it was 100 per cent for the sake of simplicity. The net gain to the owner was the primary target of estimation when all possible other additional costs or, for instance, the share of the implementer are considered besides savings. In order that the formulation of the question would not lead people to regard the gain from alliancing as the absolute maximum, it was stressed to respondents that the gain could well exceed 100 per cent. Responses to all questions were otherwise complete except that four respondents did not evaluate the expected innovation benefit of Construction Management at Fee. The procedures are explained as to calculation of comparative prices in the results section (Ch.6.2). They are based on the results of the questionnaire as well as the costs of the case project (Ch. 5).

5. The case project

The case project of the study was the Tampere Road Tunnel to be implemented by an alliance. As the project proceeds, Highway 12 (which presently runs along the shore of Lake Näsijärvi above ground) will be put in a tunnel in the centre of Tampere [Alliance Executive Team, 2013]. The tunnel section is 2.3 km long. Moreover, the road and street arrangements, the relocation of utilities/services networks, and the interchanges at both ends of the tunnel are part of the project. Both directions of travel have their separate tunnels with three lanes including a safety lane. Several passageways with fire and smoke compartmentation will be built between the tunnels, and traffic control and guidance systems will play a significant role in the project. All in all, we are speaking of a demanding project fraught with much uncertainty.

Alliance procurement started in December 2011, and the parties signed the development agreement in July 2012. Development-phase planning led to the alliance implementation contract which was signed in October 2013. The road section is expected to be ready for use in late spring 2017 and the finishing work will end about a year later. This is the third alliance project launched in Finland (cf. Amaral Fernandes et al., 2014); the owner had experience from one rail project launched a year earlier (Lielahti–Kokemäki allianssihanke, 2015).

A total of 76 recorded development ideas were born during the alliance's development phase (Alliance Executive Team, 2013), about half of which (39) were accepted for use while a quarter (20) were relegated for assessment at the alliance project implementation phase. The cost-benefit impacts of 28 adopted ideas were reported in the project's first value-for-money report (Alliance Executive Team, 2014) while the other innovations were implemented mainly due to their positive value effects. The total saving was reported to be about M€17.0. The share of the five most significant innovations was M€9.2, and the combined benefit of the achieved shorter schedule M€2.5. According to the owners, the building plans including the innovations are in all respects such that the quality level of the road plan will be met: quality or life-cycle requirements have not been sacrificed to achieve savings.

The target cost based on the alliance implementation agreement is M€180.3 (at May 2013 cost level) which puts the logical estimate of the so-called baseline price at M€197.3 (i.e. 180.3 + 17.0). On the other hand, the road-plan phase cost estimate (ELY, 2011; March 2011 price level), corrected to the index value of the target cost (OSF, 2013), is M€203.6 when the cost items (ab. M€4) missing from the (original) estimate but included in the project are considered.

6. The results

6.1 Factors affecting economic efficiency

With regard to alliancing, experts emphasised its great ability to generate innovations which was the key to high economic efficiency. The joint interest of alliance members is to implement the project in an overall efficient fashion which eliminates obstacles to the expression of ideas as the participants have no need to sub-optimise their performance. Should the implementation of an idea require re-design, the designer is compensated for it. Since the owner is also part of the alliance, alteration of earlier designs is easier when it is also in the interest of the owner. Confrontation does not occur and distrust and risk avoidance do not guide decision making.

Ideas are born mainly during development-phase planning when conservative application of competition regulations no longer prevents new alternatives from emerging. Multidisciplinary expertise becomes integrated in planning and creates good conditions for development. Since ample time can be reserved for the development-phase, ideation, development of ideas, dealing with permits and re-design are possible. All in all, the assessments of the performance of alliancing correspond to those of a parallel survey related to the project, but implemented from a different perspective and using different experts (Lahdenperä, 2015).

Project development is more difficult when using the alternative delivery methods instead of alliancing. In delivery methods based on apportioned responsibility and risks, the actors lack the motive and overall competence required to improve economic efficiency. Even the business logic does not support the presentation of ideas. The distribution of the risks, responsibilities and benefits related to new solutions is unclear without negotiations. Thus, even good ideas are not always brought forward since it does not benefit the inventor of the idea – even the opposite may happen. If a suggestion for improvement is made, however, the other parties may try to prevent its introduction. The parties optimise first and foremost their own share and the best of the project is not the driver of development.

The possibilities and problems of different delivery methods are naturally slightly different. As it is not possible here to delve into these details, reported in Koski and Lahdenperä (2015), a joint summary is presented only. Accordingly, obstacles to birth and presenting of ideas in traditional delivery methods, in accordance with the sequential phases used in the survey (i.e. A–C in Figs. 1–3), are the following:

A. Before contractor selection during design

- The designer does not present an improvement idea as it may involve extra work or re-design. The party fears that the owner considers the idea part of the already purchased expert service package. Thus, the idea should be made part of the design solution without extra compensation which is not reasonable from the designer's viewpoint. Alternatively, the presented idea does not move forward should the owner have to commission re-design by separate parallel orders. Another obstacle can be if the designer has to obtain permits related to the idea.

- Design commissions are generally lump-sum and put out to competitive tender. Therefore, there is no time for ideation and alternatives are rarely analysed. The main aim of design is to produce the necessary design documents. Constructability and cost awareness is also poor, and lack of overall competence minimises improvement ideas especially in DBB where design and construction are differentiated. To be sure, in DB the competence of designers and contractors is utilised synergistically already at the tender phase, but the preconditions for promoting ideas remain inadequate especially due to the challenges posed by public procurement.

B. At competition phase of contractor selection

- Requests for proposal plans can be too detailed and the owner may limit the contractors' alternative proposals. The primary reason is that degrees of freedom and alternatives leave too much room for interpretation which may lead to Market Court appeals and subsequent project delays and extra costs in case of public procurements. Should the owner nevertheless accept an idea suggested by tenderers, the needed requirement changes or even the idea itself, should be made known to all to ensure fair competition. That would eliminate the competitive advantage offered by the idea and only make competition more complicated which prevents effectively the publication of improvement ideas.
- Often the owner also has quite limited resources for processing proposed changes. There is no time to determine the compliance of alternatives with requirements and regulations. That is necessary especially since there can be fear that the presenter of an idea tries to reap all the benefits from it, and the idea does not necessarily benefit the owner, or may even be harmful. The attitude is the result of the experiences from confrontation and sub-optimisation in traditional projects. A short competition phase is also a hindrance since new solutions require redesign or decisions by authorities and affect the tasks of other parties which can be critical especially when using parallel agreements.

C. After contractor selection during implementation

- A proposal for improvement made during the construction phase requires agreeing separately about who pays for design, who assumes responsibility for the design solution's functionality, and how the benefits are shared since lump-sum contracts do not deal with these issues. On the other hand, the negotiations are expected to be so cumbersome and long that people do not wish to go to that trouble, especially if the preconditions for profitable introduction of the ideas have already weakened crucially at the implementation phase. The project has advanced so far that there is no time to introduce the idea, or it will no longer bring sufficient benefits.

- The activity takes place in a climate of general lack of confidence. The parties to the project suspect that anyone who presents any idea only seeks to benefit from it himself, and therefore do not support or approve its introduction. An individual party can also prevent the introduction of an idea in the parallel agreement model if only seeking its own advantage. Agreeing about changes is impossible in the shared responsibilities model. The parties want to save their labour and avoid takings risks by sticking to previously used solutions and operational models and existing building and implementation plans.

6.2 Comparison of economic efficiency

The respondents to an expert survey estimated first the probabilities of the occurrence of the ideas behind the alliance's innovations in alternate delivery methods (Fig. 1). The responses indicated that the failure of innovations to materialise is most probable in DBB (alternatives D–E), but there is not much difference between DB and CM-at-Fee. Often the idea would have been assessed (D) by the actors also in the case of the alternative delivery methods, but it would not have put into practice. Yet, it is clearly more probable that the idea would not even have been presented to other project partners (E) as was stressed especially by contractors.

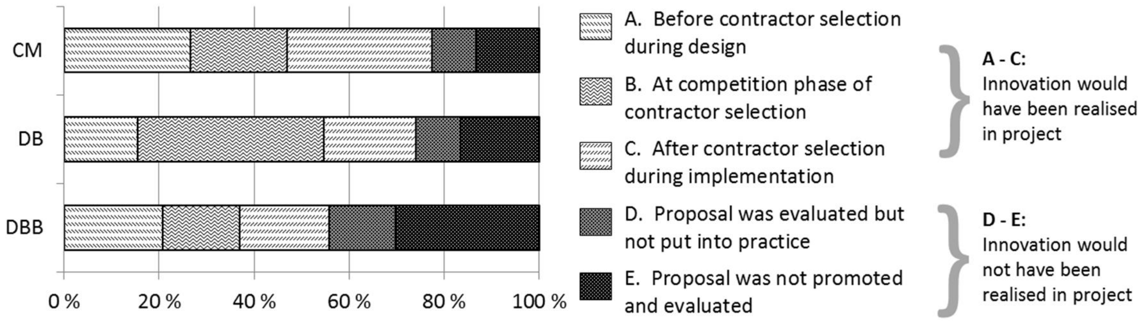

Figure 1: Estimated probabilities of occurrence alternatives (average values).

Yet, the introduction of the idea is not the only crucial factor since its net benefit may differ between delivery methods. Figure 2 shows the probabilities of the described phases combined with estimated net benefits (response averages). Accordingly, the strength of DB is the competitive tendering phase (B) where high probability of occurrence and owner benefit are combined. There DB beats clearly the other methods, but in design prior to competition (A), it fares worse than the alternatives because it involves mainly definition of requirements. After selection of contractor(s) (C), innovation expectancy is generally lower than at earlier phases. This is shown best by Figure 3 where the impact of the estimated probability and net benefit are combined (by multiplication), and the estimated savings potential is described as accumulating in phases. At the same time, the final situation of Figure 3 (C) shows the relative total development potential of different delivery methods. According to the results, DB would be the best alternative for an alliance although CM-at-Fee is nearly as good. Yet, it is estimated that these methods only provide about half of the development benefits of an alliance while DBB's share was only a good third.

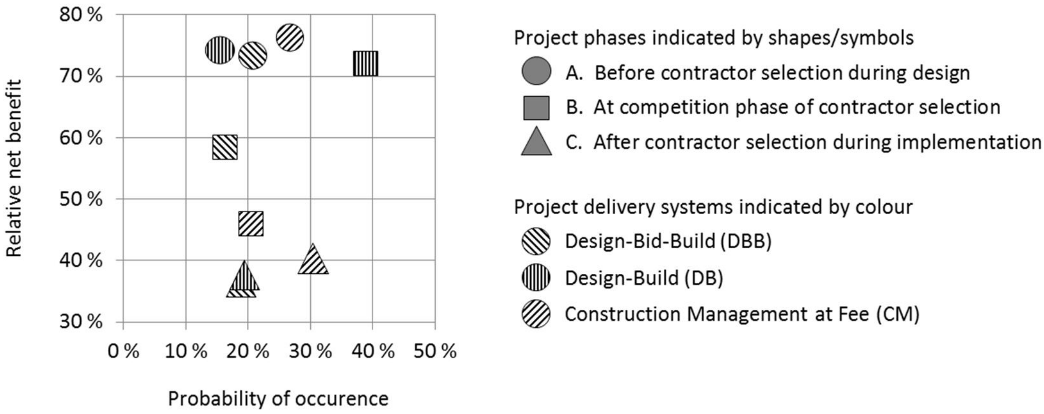

Figure 2: Probability and relative net benefit of occurrence alternatives.

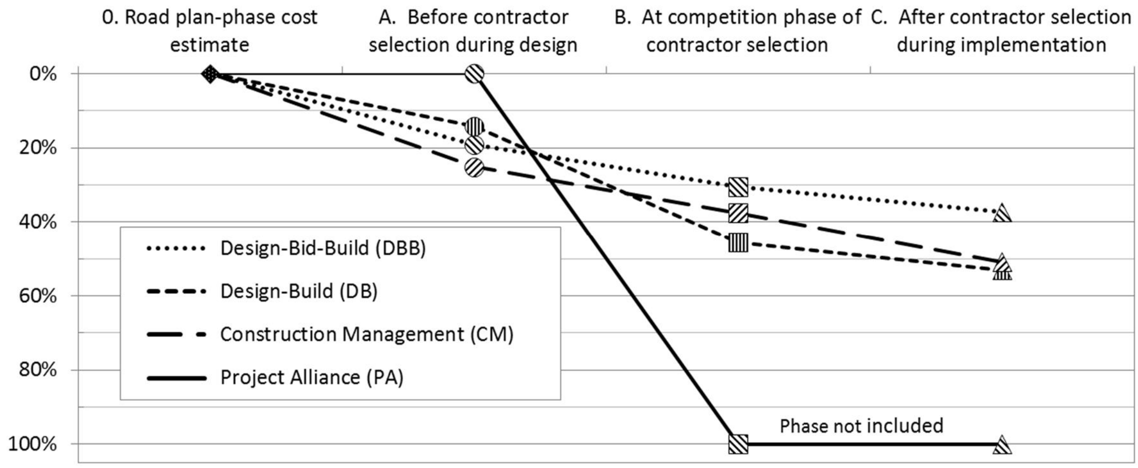

Figure 3: Estimated relative reduction of cost level by phases.

Figure 4, again, presents the comparison costs of delivery methods when this relative total development potential is applied to the cost data of the case study (see Chs. 3 and 5). Calculations were made for the part of owners and other respondents separately although Figure 3 shows their joint estimates only. The comparison cost of a delivery method is the so-called baseline price minus related cost improvement. Two alternative baseline prices are used in calculations. In *Calculation I* (solid colouring) the baseline price is the target cost of the alliance implementation agreement plus the cost savings from innovations (taking into account the 100% saving gives the alliance a comparison price in line with its actual target cost, i.e. 180.3 + 17.0 – 100% * 17.0, etc.). The development potentials of other delivery methods are smaller and the comparison costs correspondingly higher. In *Calculation II* (non-solid colouring) the baseline price is the cost level of the owner's estimate composed before the launching of the project, but index-adjusted for the time the target cost was set (including missing items; 100% development potential equals the difference between the owner's cost estimate and agreed target cost, i.e. 203.6 – 180.3). Baseline cost II is higher than cost I which means that the comparison costs of alternative delivery methods are also higher, respectively.

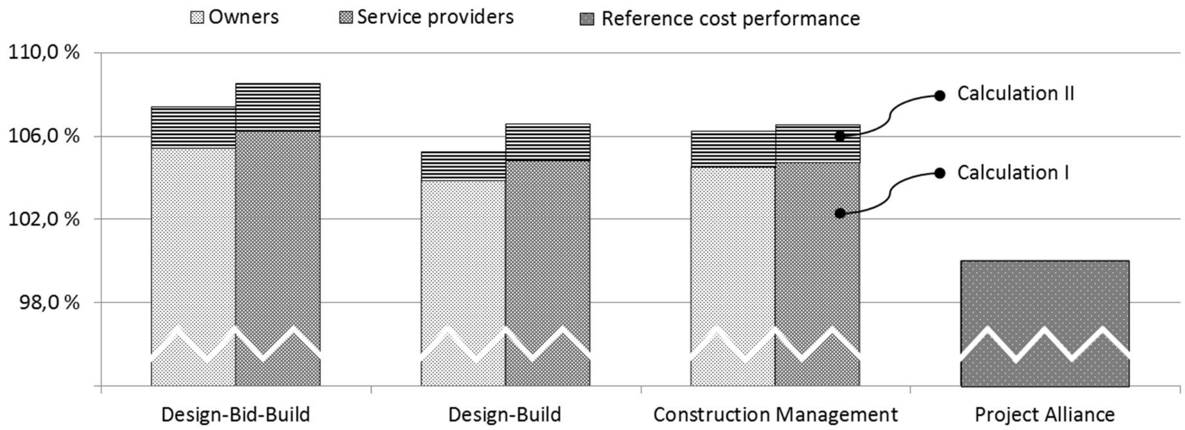

Figure 4: Relative comparison prices of different delivery methods.

Owners assessed the development potential in alternative delivery methods slightly better than other respondents. Yet, the views were quite similar since the differences in overall costs between owners and other respondents were at the most one percentage unit while the difference is mostly smaller than the difference between delivery methods. The difference with the alliance is in any case fully clear in every respect. Thus, it can be said that the use of alternative delivery methods is not expected to provide cost efficiency corresponding to that of an alliance contract, but that they would lead to a price level typically 4–6 per cent higher than that achievable by alliancing (I). An alternative survey (II) indicated even bigger differences (5–8%).

7. Discussion

The study aimed to increase understanding of the value creation capacity of project alliance compared to so-called traditional delivery methods. As to the alliance, the study was, however, limited to development phase innovations while the implementation phase was left out of the comparison. Alliancing can, yet, be assumed to be at least as capable of effective implementation as the other methods. Functioning cooperation boosts effectiveness, and the alliance already had a stock of development ideas to be evaluated only at the development phase while the owner also had the possibility of benefiting from implementation phase improvements due to the target cost procedure. On account of the incompleteness of the case study project, the implementation phase of the alliance was, however, not examined in the study.

As a result of the multidimensional nature of value creation, the cost side received emphasis in this study aiming at quantitative assessment. Yet, the owner did consider that value creation was not sacrificed to reduce costs. Instead, part of the innovations were introduced precisely because they generated added value. Thus, all improvements were not aimed at cutting costs. Inclusion of many qualitative key result areas as payment bases should also enhance value creation. Traditional delivery methods have not incorporated corresponding systems. Moreover, the fast implementation of an alliance project can have positive societal impacts that were not dealt with in the comparison. Thus, alliancing would appear to be even more advantageous than indicated by the calculations.

Although the result suggests that alliancing is superior, its generalisability can be questioned. After all, we are only dealing with a single project. Moreover, the development was also strongly driven by the uncertainty of project implementation as a low target cost was an apparent precondition for a favourable political decision to implement the project since the entire project was questioned anew on the political level while the development phase was underway (cf. Vainio, 2015). On the other hand, the uncertainty has also reduced potential subcontractors' willingness to submit serious tenders which has weakened the ability of the alliance to improve economic efficiency. Assessment of the influence of these factors is naturally impossible.

Determination of the innovation potential and cost savings of alternative delivery methods was based on expert opinions. They were experienced infrastructure construction professionals who were familiarised with the case study project and the innovations to be evaluated in advance. Part of the experts knew the project very well beforehand. The reliability of the responses is also increased by the fact that the experts did not assess alliancing, but specifically its alternative delivery methods, of which they had years of practical experience. Their views on the functioning of alliancing were also quite similar, and no special bias was identified in the responses. On the part of the alliance, again, the data are based on actual performance.

A key point is also that the study not only sought out differences between the economic efficiency of delivery methods, but also focused strongly on determining what is required to come up with and implement improvement ideas. As a result, several factors were found in the processes of traditional delivery methods that hindered introduction of proposed improvements. The emphasis on these hindrances is also fully in line with the estimates of economic efficiency which supports the perceived correctness of the quantitative overall assessment. Moreover, the overall view seems to be in line with literature (cf. Ch. 3) while also providing wider understanding.

8. Conclusions

The study assessed the economic efficiency of different delivery methods – Project Alliance, Design-Bid-Build, Design-Build and Construction Management at Fee – in transport infrastructure construction. The result was that an alliance creates the preconditions for achieving the highest economic efficiency particularly in demanding projects. The indicative comparison suggested at least 5 per cent higher costs for alternative delivery methods than alliancing without any added value. It is obvious, of course, that the relative performance of alternative delivery methods improves in the case of simpler projects, and that mere formal use of alliance contracting does not always guarantee a good result either. Yet, alliancing creates excellent conditions for benefiting from the integration of different competencies. Development in traditional delivery methods, on the other hand, is hindered by inadequate incentives, stringent boundary conditions for designs, tight schedules, rigid attitudes and many challenges related to the functioning of competition.

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The Development of UK PFI from an Organisational Economics Perspective

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Abstract

The increased use of integrated forms of procurement, specifically PFI, for provision of new UK public service assets is a defining feature of tax funded fixed capital investment since 1992. The value for money proposition of PFI relies on the notion that through integrating construction and operations via a single contract, whole life cost efficiency gains are made possible, indeed incentivised. Discussion focuses on improvements in our understanding of PFI, whole life cost and value for money issues over recent years, through reference to key literature including academic papers, empirical analyses, audit reports and industry publications. A range of organisational economic concepts is applied in reflection of recent policy developments, with an underlying theme of potential for *investment in operations*. Review of the healthcare sector's outsourcing practises, as well as the scope and scale of PFI healthcare investment in recent years allows for in depth discussion on issues of asset ownership and control, as fundamental concepts in procurement theory. To conclude, findings of recent studies are considered in light of reforms to the standard PFI model, including the insistence that future PF2 contracts should exclude soft FM services from their scope, as well as increase equity investment in the SPV. The need for greater transparency on the cost and performance of public service assets is posited to support better comparison of the efficacy of alternative procurements methods.

Keywords: PPP, public investment, value for money, whole-life costing, healthcare

1. Introduction – a brief PFI history

1992 saw a fundamental change in UK public procurement. This change would spread to become a feature of many developed nations publicly funded long-term investment. This change concerns the approval to use private financial capital in the delivery of public service assets (Norman Lamont, 1992). When in 1997, New Labour came to power, despite what might have been expected (though their abandonment of Clause 4 may have indicated their accommodation of the private finance initiative (PFI) in principle), they greatly expanded the policies' use with the vast bulk of all projects today reaching financial close under their reigns (2002-2008). In the year New Labour came to power, the first of the Bates Reviews of PFI reported advising government should establish an internal unit to co-ordinate its use (Bates, 1997). This led to the creation of the Treasury Taskforce within HM Treasury. The second Bates review (Bates, 1999) encouraged a more outward facing centralised unit (a proxy regulator) that could engage with the private sector more effectively. The incorporation of Partnerships UK (P UK) aimed to fulfil this ambition. This unit was also intended to better support local public clients of the growing number of PFI projects in the pipeline.

PFI was radically different forms of procurement than most public sector estate management functions had ever been required to use. One complexity of early PFI was a lack of standardized contracts. Local clients and private sector bidders duplicated much of the work to establish similar output based service contracts, these being a defining feature of PFI. This problem led to P UK's development of the Standardisation of Procurement Contracts (SOPC), with the fourth and final iteration in 2007. P UK also published guidance notes and provided assistance to local, decentralised procurement teams. One emerging issue was the lack of public procurement skill in terms of negotiating with an often more informed private sector team (Armstrong, 2005).

P UK facilitated government direct investment in PFI projects via equity stakes. Typically, this included a *pinpoint* equity stake of 1% (one tenth of issued equity given typical gearing at 90%). Shareholdings in special purpose vehicles (SPVs) often took the form of mezzanine type shareholder loans, a hybrid between debt and equity. Public sector investment was intended as a means of monitoring these projects allowing access to useful information as shareholders. New Labour's commitment to private involvement in public services was in no doubt and the establishment of large programmes of capital investment ensued post 2000. Building Schools for the Future (BSF) was the most significant. A part PFI, part conventional procurement programme set to renew all secondary comprehensive schools in England (budgeted at $45bn).

In the aftermath of the GFC, the incoming coalition government stopped the pipeline of PFI projects in 2010 to conduct a review of the policy, as well as scrapping BSF. P UK was brought back into HM Treasury, transferred under the remit of the lager-scoped unit of Infrastructure UK (I UK), itself only recently merging with the Major Projects Authority to form the Infrastructure and Projects Authority going into 2016. The 2010 review finally led to the announcement of PF2 in late 2012 as an adapted form of PFI. Given on-going fiscal austerities, government also took the decision to sell off many of the equity stakes in operational projects. August 2011 saw the sale of BSF Investments to the equity fund International Public Partnerships Ltd. Ironically there is a return by government to consider investing directly into PF2 projects. PF2's application looks likely to pick up to re-establish the longer-term use of private capital in the procurement of public service assets.

PFI is presently being used to deliver over 720 contracts. These have already delivered projects with combined capital values around £54bn (un-indexed, HM T, 2013). The weighted average contract length by capital value is 27.8 years. The longer-term liabilities on the public purse in PV terms for this portfolio of projects is approximately £177bn (discounted at 2.5% RPIX). The following paper attempts to consider the impact of the above developments in the PFI policy from an organisational economics point of view (Coase, 1937). Considerations of the implications for risk transfer, financial and value for money aspects are critiqued.

2. Value for money and whole life cost

One underlying principle of PFI is its incentivisation of investment in operations (Hart and Moore, 1990). The SPV is the legal entity contractually liable to deliver PFI serviced assets. The use of a SPV is crucial in providing off-balance treatment and limited recourse to sponsor corporate assets should the contract go badly. The construction and operational costs are at the discretion of a single agent, the SPV. They are thus, in theory, able to internalise the interdependencies between construction and operations via one contract (Hart et al., 1997; Iossa and Martimort, 2008). The incentivisation comes in the form of higher residual profits on the unitary charge payments (UCPs) revenue if they are able to reduce whole life cost (WLC). The UCP is the predetermined price for the contract paid in periodic instalments subject to adequate service provision. A key feature of the UCP in UK PFI is that a *significant* proportion of the payment must be *at risk* subject to provision of predefined serviced assets. This feature is important given that this allowed PFI's classification as *operational leases* (in the early days), rather than *financial leases*, the latter prohibited by public procurement rules (ONS, 2006).

The value for money achieved on the contract in excess of alternative procurement options will depend on the extent to which *investment in operations* is pursued, how well competitive procurement processes did in capturing these returns for clients, as well as the cost of capital used to deliver projects. There will be other project performance and time value of money considerations that will impact on the value for money (VfM) achieved through the project life cycle (Nasir, 2007). These will include the actual level of risk transfer achieved in light of some high profile failed contracts (NAO, 2009a, 2003a, Whitfield, 2012).

In light of incentives for investment in operations, its expected SPVs to pursue design and build solutions that seek to minimise WLC. This is especially the case for soft FM services[1], where the alternative is to pursue profitable contracts that may fail benchmarking and market testing (BM&MT, NAO, 2007a). Any gain in equity returns resulting from inflated operational contract prices from the client will only partly benefit the equity-owning sponsor, being shared with other equity owners in the SPV. An equity owning delivery contractor will wholly appropriate any gains in terms of higher revenues for operational contracts. This creates a moral hazard for the contractor to extract profits from operational contracts, rather than wait for future financial return on equity. The relevance of this point is limited by the extent to which equity-owning sponsors deliver these services. These are often sub-contracted to other providers, bringing with it further complexity in co-ordinating optimal service delivery (Rintala, 2005).

The higher cost of private capital used to deliver PFI projects is a major impediment for the net value of these returns from *investment in operations* (Public Accounts Committee, 2011), which could be achieved in publicly financed projects if adequate incentivisation of their delivery could be instilled (Mumford, 1998; Palmer, 2000). The nominal values of capital expenses over the project's life (put, arguably too simply, as a function of discounted factor price (r) and quantity (C_i)) will be subject to far less discounting, given the bulk are incurred at the front-end during construction. Their present value thus will be markedly greater, compared to future operational expenses (function of discounted factor price (w) and quantity (O_i)). This limits the extent to which present value reductions of WLC can be achieved via investment in operations. That is, the future potential savings from investment in operations translated into present value

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[1] Soft FM services are services, usually labour intensive, which operate within the facility to support front line service delivery e.g. cleaning, catering, laundry, portering, security etc. They typically account for around 25% of the UCP in a full scope hospital PFI contract, but this will vary between projects. Consider one type of project that has proved popular in recent years, that of public street lighting, which will involve little or no soft FM services.

will have been subject to considerable discounting. This issue is compounded by the higher discount rate applied resulting from recourse to private capital. Here, *w* is used to convey the higher proportion of future operational expenses incurred on labour intensive (waged) factors of production in the form of cleaning, catering, security and other operational service staff. These estimated costs are at risk with potential increases in labour cost, the impending introduction of a UK living wage serves as a case in point. Operational costs are commonly indexed against RPIX variable or fixed 2.5% to account for these anticipated cost increases. Considering the long-term nature of these contracts, it is likely they may witness periods of above long-term average inflation cost increases, though not in recent years in the UK following the GFC.

The downward constraint to this minimisation of WLC is the provision required under the contract (P_i)[2], and the ability of capital and operational resources to deliver these (Murray, A. et al., 2013). Another constraint on PFI's ability to achieve returns from investment in operations, at least in a healthcare context, concerns the labour intensity of required services. While there may be instances of innovations in the way operational services are delivered under PFI, the prevalence is for services that closely resemble forms of delivery seen in non-integrated outsourcing contracts. This suggests a lack of major innovations in operational service delivery resulting from investment in operations. A further finding on the novelty of innovations in pursuit of lower WLCs concerns the risk aversion of debt providers to back new, untested, perceivably risky design solutions (Ive, 2004; National Audit Office, 2010; Rintala, 2005).

The constrained optimisation of whole life asset provision (Murray et al, 2013)

Min WLC: $r_i C_i + w_i O_i$

Subject to: $f(C_i, O_i) = P_i$

The ability of the operator to reduce WLC is arguably higher concerning elements of hard FM, given the functional on-going fixed cost of building performance is determined to a much greater extent during construction. This may be, in part, why these services are not subject to such strict tests of continuing competitive provision. Nevertheless, there will be knowledge held by any incumbent soft FM provider about the interaction of the specific asset's characteristics and optimal service delivery and management. An example of this may include the benefits of site planning design in reducing the need for security personnel.

3. Healthcare sector insight

For a sectorial insight into the diverse PFI programme, we focus on contracts procured by the Department for Health (DoH) in England. To place healthcare PFI into context, the analysis below (Fig. 1) presents two concepts plotted over time. These include the capital values of projects agreed at financial close (left hand axis) and the UCPs liable to pay for the contracts (right hand axis). It includes all UK PFI contracts and those pertaining to DoH and local

[2] In reality it may prove more profitable for an SPV to run riskier lower cost asset management regimes, that incur infrequent penalties and do not meet P_i completely (sweating the asset and holding back *some* life cycle funds).

authority Trusts[3]. As is evident, healthcare contracts represent between 20 - 30% of both capital values and of the on-going UCPs. The present view that seemingly all UCPs liable beyond approximately 2041 are liable against healthcare contracts suggest they represent the entirety of longer-term contracts procured most recently.

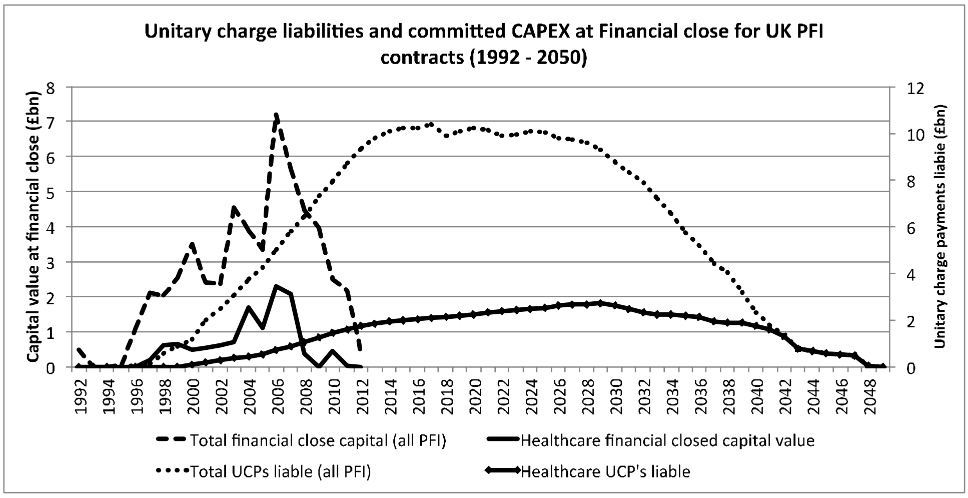

Figure 1. PFI programme and healthcare sector: capital values and unitary charge payments (1992 – 2050, nominal) Source: PFI signed projects list March 2013, HM Treasury

3.1 Contract scope

The scope of operational services in PFI contracts is important in defining the SPV's exposure to potential for investment in operations, as well as the inherent risks attached to levels of service. There is significant variance in the scope of PFI contracts, especially with regard to Soft FM services. A survey of hospital contracts undertaken by the NAO (2010) found that around one third of hospital contracts did not include core Soft FM services such as cleaning and catering. With reduced scope of Soft FM services, the contracts resemble more DBFM (maintenance) rather than DBFO (operation) status. The negative impact on value for money from the higher cost of capital of PFI projects arguably increases here by reducing scope of operations. The higher cost of capital incurred must be at least compensated for by future returns from investments in operations and reduced WC, if VfM is to be more favourable to conventional D&B and separate O contracts. In the DBFM case, the client will fund relatively expensive private finance for a facility in which a separately outsourced operational contractor (for catering say) has not been given the opportunity, or incentive, to *invest in operations*.

3.2 Non-PFI outsourcing

The contract period will of course be important, in part determining the incentive for investment in operations. If the contract is short (say 2 – 5 years) there will be limited scope for the contractor to realise returns from investments in the asset to be operated, hence one of the

[3] A small numbers of additional healthcare projects will have been commissioned by devolved administrations in Wales, Scotland and Northern Ireland. These are not included here due to the devolved and variable coverage of data.

fundamental reasons why PFI contracts are of such considerable length. Considering some specific potential scenarios of asset ownership, the provision of catering serves as a case in which there is variability, in both form of provision and extent of asset ownership. These two aspects will have bearing upon one another in line with transaction cost economics (TCE) theory (Mumford, 1998; Williamson, 1981), in the sense that asset ownership frames the potential risk transfer as asset owners are the bearers of residual risks (beyond those specifiable within the contract). The provision of pre-prepared catering services lends itself to outsourcing as an activity considered less and less as a core (in-house) function of public clients. Insight on the extent of in-house catering within the NHS is covered in data from Patient Environment Action Teams, compiled previously by the then National Patient Safety Agency (disbanded in the 2010 *'bonfire of the QUANGOs'*). Using 2010 data, of the 1232 facilities surveyed approximately 57% of facilities recorded catering as provided in-house (Table 1 below). This vastly underestimates the extent of private catering in the NHS as many of the newest PFI facilities are very large General Acute hospitals with many times more beds than other smaller facilities. Using another dataset from 2008[4], and just looking at NHS hospitals that are completely new as of 1995 (Table 2 below), we see that where as there are over twice as many new non-PFI hospitals, (95 to 37), the combined gross internal floor area of these PFI facilities is over 4 times that of non-PFI conventionally procured facilities.

Table 1. Reported status of catering service provision for English Hospitals, 2010. Source: NPSA PEAT data 2010

	Catering service				
Catering provision	**Cook-Serve**	**Delivered Meals**	**On-Site Central Production**	**(blank)**	**Grand Total**
Contracted[5]	185	225	70		480
In-House	292	213	198	1	704
Mixed	18	22	7		47
(blank)				11	11
Grand Total	**495**	**460**	**275**	**12**	**1242**

Table 2. The type, size and application of PFI for new hospitals from 1995 to 2008. Source: NHS Information Centre, Estates Returns & Information Collection data, 2008

Type of hospital	**PFI**			**Non-PFI**		
	Number	**Size**		**Number**	**Size**	
		Average GIFA (m^2)	**Std. dev**		**Average GIFA (m^2)**	**Std. dev**
Community	7	4,696	2,168	16	3,728	2,008
General acute	8	51,777	39,410	5	6,509	4,481
Long stay	6	8,018	5519	20	3,982	3,919
Multi-service	3	26,081	38,402	4	3,003	269
Short term non-acute	11	6,600	5654	33	3,463	3,632

4 Hospital Estate Facility Statistics (HEFS), as collated via the Estate Return and Information Collection (ERIC) by the NHS Information Centre, Leeds. Available from *hefs.hscic.gov.uk*.

5 Includes PFI facilities where catering is provided within the scope of the contract, besides traditional outsourcing.

Specialist	2	8,733	7,869	17	5,440	7,166
TOTAL	**37**	**17,933**	**27,459**	**95**	**4,112**	**4,323**

Source: (Ive et al., 2010, Table 9)

One can also see from the Table 1 above, there is a higher prevalence of the catering services being provided as *delivered meals* when it is contracted (47%) compared to when it is in-house (30%). This might imply the quality of contracted catering services is inferior, though recent analysis suggests catering is an area where private provision is able to reduce costs considerably, without anticipated lower indicators of service quality (Mohammadi et al., 2013).

3.3 Procurement lead times

One on-going criticism of PFI concerns the long procurement periods witnessed securing preferred bidders, and further towards financial close of the contracts. The typical period between OJEU and financial close, where data is available is between 2.25 and 3.25 years (n=372, Fig. 2, HM Treasury, 2013). This is a considerable period of time incurring comparatively larger transaction costs than other public procurement options. One of the factors here concerns the due diligence processes required by lenders before approving debt finance pre financial close. Another major source of transaction costs come from the prescriptive output specifications of contracts. These costs, at least in the UK, will have benefitted from the introduction and development of SoPC. One constraint on reducing procurement costs for other types of projects, especially Schools and Hospitals, will have been the decentralized nature of these clients, where an NHS Trust will commonly only procure one PFI hospital. This limits the potential for learning and efficiency in future procurements using such new forms of procurement. Considering the period between financial close and commissioning is typically between 1.25 to 2.25 years (50% - 70% of the period from OJEU to FC, and of course including the construction period), it would seem the main impediment to more prompt delivery of these projects is the competitive processes required to secure a preferred bidder. The lack of clients having properly thought through project requirements before commencing procurement is cited as a major cause of delayed procurements (NAO, 2003b).

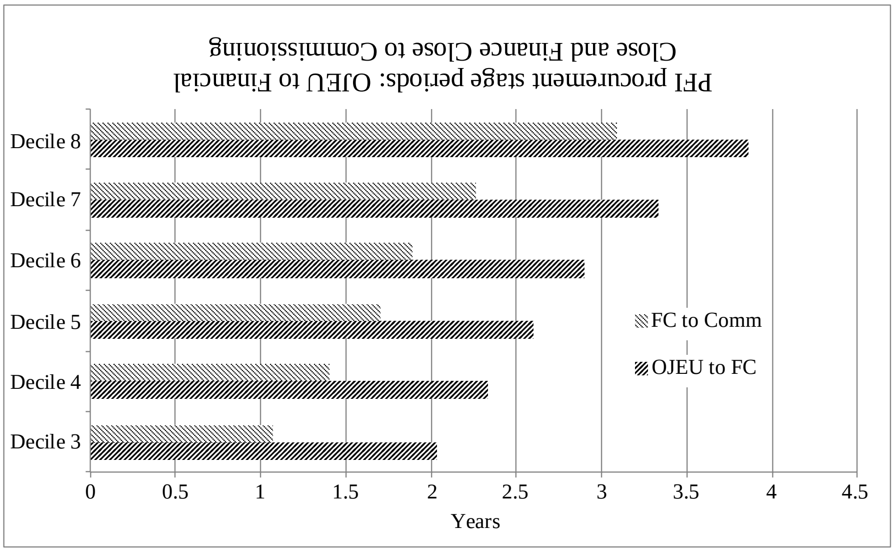

Figure 2. Procurement lead times for PFI projects.
Source: PFI signed projects list March 2013, HM Treasury

3.4 Competition during procurement

Depending on the specific project, typically 7-9 consortiums will respond to the invite to tender, reducing to 3-5 for the actual fully developed bid. Actual competition is limited somewhat given the considerable bid costs involved in PFI (Construction Industry Council, 2000, 1998), leading to the common strategy that any repeat bidder needs to win at least 1 in 4 projects to cover the considerable sunk cost, as a form of transaction cost, of failed bids. Social infrastructure projects (specifically schools and hospitals) have witnessed considerable price creep during preferred bidder stage (Armstrong, 2005). This is not surprising given the prevalence of decentralised public clients, a factor in determining the commercial expertise of clients, and thus their ability to negotiate with consortium bidders (Assenova et al., 2002). Relatively few Local Authorities will have experience with more than one PFI schools project. Contrast this with, for example, the Highways Agency (now Highways England, a more devolved agent of government) who would have been able to build experience and develop expertise in managing the procurement process of a clear project pipeline. That will have contributed to maintaining competitive tension through to financial close.

3.5 Balance sheet treatment

Another source for early scepticism about PFI concerned it's treatment of the facility asset with regard to who is acknowledging the future financial liabilities. Under public procurement rules, liability for the asset should be determined by who owns the *operational risk* for the service, and as such can be considered an *operational lease*, rather than a *financial lease* (ONS, 2006). Pure finance leases are not available as a form of capital investment for UK public clients. The acceptance of PFI in the 1990s relied on the assurance there was significant operational risk transfer to justify operational lease status (HM Treasury, 1997). This operational risk comes in many forms, dependent on the terms of contracts. It was required to be *significant,* represented by a minimum 20% of the UCP that must have some deductible element based on contractual performance. This risk transfer allowed government to classify liabilities on such contracts not as determined financial risks but rather contingent on contractual performance, avoiding the requirement to place significant sums of *committed* liabilities on the government's balance sheet. In more recent years, criticism of this approach has led government to acknowledge the significant liabilities under PFI contracts (House of Commons Treasury Committee, 2011). Now, of the near whole portfolio of projects (n=696, HM Treasury, 2013) 95% are recorded as on *balance sheet* under International Financial reporting Standards (IFRS).

3.6 Life cycle allocations

Lifecycle allocations exist to provide for on-going capital replacement and maintenance. They are built into UCPs the SPV receives for the contract. The relative size of life cycle allocations will be of considerable importance to lower WLC. A more intensively used facility, say a waste to energy disposal plant (in more recent PFIs) undergoing significant wear and tear, might reasonably require a higher proportion of WLC allocated to the life cycle fund. This will ensure the asset is maintained adequately and does not lead to increased risk of unavailability due to asset failure. Specifically when those life cycle expenditures are intended to be incurred will bear on the project's NPV as the anticipated return to the SPV investing in the asset. Further, when in reality those expenditures are incurred will bear on the on-going profitability of the SPV. If the SPV wants to take the risk of not expending life cycle funds, and accept the resulting chance of non-availability if the asset deteriorates and becomes unavailable (incurring financial deductions from the UCP), they may make additional returns. There is increasing pressure for public clients to share in these savings, as many early projects were considered to have over allocated resources to these life cycle funds (HM Treasury, 2012). Analyses comparing the annual comparative total cost of a wide range of FM expenditures seem to suggest there is little difference between PFI and non-PFI renewed schools (Edkins et al., 2011). Further, this study highlighted the vast differences in specifically hard FM expenditures between conventionally procured (and operated) schools and PFI schools. PFI schools were shown to incur typical life cycle expenditure profiles compared with flat line expenditures in non-PFI schools up to 9 years into operation. This raises concerns about the accumulation of backlog maintenance in non-PFI schools, an issue that PFI was designed to resolve.

3.7 Financing PF2

Following the latest review of PFI (2010-2012) and announcement of the PF2 reformed policy, there is now a requirement for larger allocations of shareholder finance within future projects (increased to 15% from 10%). There are many relevant implications of this. One might be to reduce the likelihood that sponsors will *walk-away* from contracts[6] given the higher sums of their own money[7] tied up in the SPV. Another implication is the strengthening of the incentive for investment in operations. Mandating that more SPV capital is equity increases the proportion on which the financial returns from investment in operations can be earned.

An undesirable implication of increasing proportions of equity will be a positive pressure on the weighted average cost of capital, a core concern for PFI projects generally. Theory (Grout, 1997) and practice (NAO, 2012; Vecchi et al., 2013) tells us that as PFI resorts to privately sourced finance (as opposed to the government raising public debt via gilts), it will incur a higher overall WACC. The highly geared nature of PFI Co's helps reduce this differential. The cost of debt and equity do relate to the proportions of each capital source applied, with higher gearing typically increasing the cost of debt as anticipated interest cover ratios tighten[8]. Further, it is reasonable to expect the returns of PFI equities to reduce in time given the established nature of this procurement route, as well as the increasingly active secondary market for PFI

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[6] The incidence of this is quite rare in UK PFI by any reasonable benchmarks. Considered from an option theory perspective, discounting the significant sunk costs incurred by the SPV in building the facility, the present value of expected future losses would assumingly have to be *significant* to absorb the reputational cost of walking away. Additionally, the expected loss would have to counter front loaded procurement costs and potential refinancing gains.

[7] The vast majority of initial sponsor equity stakes in PFI Co's is typically held by the main build and/or operational contractor involved in delivering the project, though there is frequent subcontracting of services.

[8] The extent of this is tempered by the low levels of client and market (demand) risk in availability assessed PFIs.

equities (De Biasio and Murray, 2015). This is an area the government could help assist, promoting transparency in this unlisted market (Whitfield, 2014), if they intend to continue the use of private capital in this way.

Following the GFC, the debt margins on project finance (inc. PFI) increased significantly, if only temporarily. With debt's larger proportion in the SPV's financial capital employed, this will have increased the WACC of SPVs established during those periods' higher debt costs, as well as some of those that had little choice but to refinance in that period. It seems reasonable to assume a minority of PFI Co's operating in 2016 will not have had, or chosen, to go through a refinancing following the GFC, given initial debt tenors are typically around 7 years. Quantitative easing no doubt helped SPVs access cheaper debt finance in the GFC aftermath. There will have been instances of SPVs who had neared construction completion during the GFC that will have required refinancing (e.g. a bridge loan). This will have lead to at least a temporary and significant increase in the SPV's WACC.

For those sponsors that have sold off their equity stakes in recent years, they cease to be incentivised in minimising WLCs in future operations. Their remaining revenue stream from the project will be the payment for any on-going operational services, and not the residual financial returns above on-going cost of service provision. This issue could also cause conflict with the wider SPV shareholder, as the contractor is left chasing higher margins on delivery of operational services, rather than waiting for equity returns via the SPV. This may lead to SPVs seeking to replace incumbent providers, if they believe new providers can provide better value services. Whether they would offer equity to incentivise this new supplier is unlikely given the standard model for commercial service outsourcing. If not, the new supplier would do well to encourage spending of unspent life cycle funds to renew the asset they are responsible for future maintenance and/or operation of. Observing these actualities through PFI Co's life cycles is an imperative to develop evidence based, incentivised forms of private finance procurement.

3.8 Soft FM services in PF2

The decision of the coalition government to remove soft FM services in PF2 is questionable, given the emphasis placed on operational innovations PFI projects are supposed to deliver. This is in spite of evidence to suggest the performance of such services within operational PFI contracts are at least as good, often better, than those seen in conventionally procured facilities (Edkins et al., 2011; NAO, 2010). The reduction in the operational scope of future PF2 projects will mean that the potential returns from *investment in operations* are materially reduced, given the sizable proportion of the UCP payment that go to pay for soft FM services in present contracts (NAO, 2007b, pg 5). This will have a negative effect on the potential for, and pursuit of, whole life cost reducing innovations. Presumably, these services will now be kept in-house or separately outsourced, incurring separate and additional procurement transaction costs.

4. Conclusions

The development of PFI in the UK has been something of a learning curve, especially in aspects of their procurement. The typically much lower period from financial close to commissioning suggests projects are reaching operations promptly, as acknowledged by the NAO in numerous studies (NAO, 2009b, 2003b). Key issues such as balance sheet treatment, as well as fairer distribution of considerable re-financing savings via gain share mechanisms serve as good examples of how this policy has adapted to be more acceptable for continued use.

The considerable proportion, and variety, of PFI projects in the Healthcare sector demonstrates it's ability to deliver medium to large projects, some very complex, that may have not been deliverable under alternative procurement methods without cost overruns and a lack of integration between build and operations. One finding concerns the observation that the entirety of recent longer-term PFI contracts is solely within the healthcare sector (Fig. 1). Given the continued high profile nature of NHS reforms, especially the role of community based primary care, it is hard to conceive private finance will not have a role in many of these future projects.

Equity incentives within SPVs will impact on the pursuit of investment in operations. The requirement for increased equity investment in future PF2 projects should serve to increase these incentives and strengthen to case for using such forms of procurement. Procuring authorities might benefit in future by appreciating this, especially if they intend to consider the pursuit of WLC savings as a viable defence against the higher costs of capital involved.

Further research should focus on developing fair benchmarks of both build and operational cost and performance if government is to support the use of this controversial policy. One area for work concerns the collation and analysis of SPV accounting data that should give insights into the levels of risk transfer against the UCP liable on the government. Greater transparency is needed to compare the efficacy of alternative procurement routes, an area where government as the client could do more, as consistently reiterated by the NAO.

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Model of Public and Private Partnership Project Development: Lithuanian Case

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Abstract

Public-private partnership is one of the recent co-operation models, which has been widely and successfully applied in Western Europe and over the world. PPP programming is boosting in Lithuania recently: 22 new PPP projects are on the way at the different preparation and development stages. There is a need for the system of PPP project prioritization from the public sector perspective. In order to make PPP projects successful, the appropriate evaluation procedures have to be applied and adequate criteria used for the project assessment.

The objective of this research paper is to analyse the model of PPP project development in Lithuania and to suggest the new criteria for the certain stage of the PPP project assessment procedure which would help to justify distribution of limited public sector financial resources for the most sustainable projects within the area of any specific sector. In order to achieve the objective, the legal basis for the implementation of the partnership between the public and private sectors as well as the PPP project development methodology in Lithuania was analysed. The criteria set for PPP projects evaluation was developed by the authors and according to results of the expert evaluation survey their relative weights were established. The new approach was applied in the case study for PPP projects evaluation by using SAW, COPRAS and TOPSIS multi-criteria assessment methods. All three selected methods revealed the same effectiveness priority results of the considered PPP projects.

Keywords: Public and private partnership, project, multi-criteria evaluation

1. Introduction

Lithuania, like many other Eastern European countries is searching for the new ways to improve the existing public infrastructure and services as well as to create the new ones. Public-private partnership is one of the recent co-operation models, which has been widely and successfully applied in Western Europe and over the world to stimulate the economy and attract the investments into the local infrastructure development.

According to the European PPP Expertise centre (EPEC) Review of the European PPP Market in 2014, 82 contracts with the total budget of 18,7 billion EUR were signed in Europe and in Turkey in 2014 (EPEC, 2015). “In countries which are commonly considered to have a mature PPP environment and favourable conditions for project implementation (e.g. United Kingdom, France), investment projects implemented under the PPP model amount to 10%–15% of the annual state investment programme” (Aleška, 2013).

Statistical data provided by Ministry of Finance of the Republic of Lithuania proves that implementation of PPP model and its impact on the economic development of the country has been growing in Lithuania. 34 PPP contracts have been implemented in 2014, of which 32 were concessions contracts, and only 2 Private Finance Initiative (PFI) projects: Vilnius Balsiai school construction project was finished in 2011 and Palanga seaside resort bypass construction in 2015. In total 47 PPP contracts were concluded and 139 million EUR were invested until January 1, 2015. Most of the PPP contracts were implemented in utilisation, recycling and waste management sector (10 cases), in the area of culture, sports, leisure facilities, equipment and other infrastructure (9 agreements) and energy sector, including heat and electricity, petroleum and natural gas (8 contracts). According to PPP accounting data investment reached 15,84 million EUR in 2014, payments for private entities amounted to 10,72 million EUR, and public sector entities received income of 4,34 million EUR.

PPP programming is boosting in Lithuania recently and becomes a part of EU SF programming for 2014-2020, which also promotes the partnerships between the public sector and business. 22 new PPP projects are on the way at the different preparation and development stages. In order to make PPP projects successful, the appropriate evaluation procedures have to be applied and adequate criteria used for the project assessment from the private as well as public partner perspective.

The objective of this research paper is to analyse the model of PPP project development in Lithuania and to suggest the new criteria for the certain stage of the PPP project assessment procedure which would help to justify distribution of limited public sector financial resources for the most sustainable projects within the area of any specific sector.

2. Lithuanian Model of Public and Private Partnership project development

“Public-private partnerships” means the ways of co-operation between a state or municipal authority and a private entity as specified by laws, whereby the state or municipal authority transfers to the private entity the activity assigned to its functions, while the private entity invests into this activity and the assets required for carrying it out and receives a remuneration therefore as specified by the laws. The forms of partnerships between the public and private sectors shall be specified by this Law, the Law of the Republic of Lithuania on Concessions and other laws” (Republic of Lithuania Law on Investments, 1999, as last amended on 16 June 2009).

PPPs in Lithuania are regulated by the Law on Concessions, adapted in 1996 (amended 2011), Law on Investments(1999), Law on Public Procurement (1996), Resolution on Public-Private Partnership of the Government of Lithuania (2009), Law on Management, Usage and Disposal of State and Municipal Property, Civil Code, and other documents. Lithuanian legislation describes available schemes for PPP implementation: contractual and institutional Public-private partnership. The contractual partnership is carried out exclusively on a contractual basis without the establishment of a mixed investment project realization company (concessions, PFI). Institutional partnership is carried out by establishing a special purpose company - mixed capital (public and private) company. PPP projects can be implemented both at the central and municipal level (Manual for the Public–Private Partnership Projects, 2014). Legislation allows private entities to initiate PPP projects.

In 2009 there was a programme introduced by the Government to enhance PPP in priority sectors: transport, education, social housing, public order and safety. In 2009 Lithuanian Government authorized the public institution Central Project Management Agency (CPMA) to provide methodological and advisory assistance to the issues of the development and implementation of public and private partnership projects. PPP Competence Centre was set up by CPMA in 2010. PPP project development and implementation methodology was officially approved on 16 April 2013. According to the survey conducted by the European Bank for Reconstruction and Development Lithuania was ranked very high among other Eastern Europe countries for the comprehensiveness of PPP regulatory framework (1st place), PPP environment in general (2nd place) and for clearly defined institutional framework (3rd place) (The Economist Intelligence Unit, 2013).

The PPP development process of the state level projects in Lithuania, acting institutions and their functions are described in Figure 1. The PPP development process of the local level essentially corresponds to the state level procedures with the exception that PPP Commission is substituted by the Municipal Inspector and the Government – by the Municipal Council.

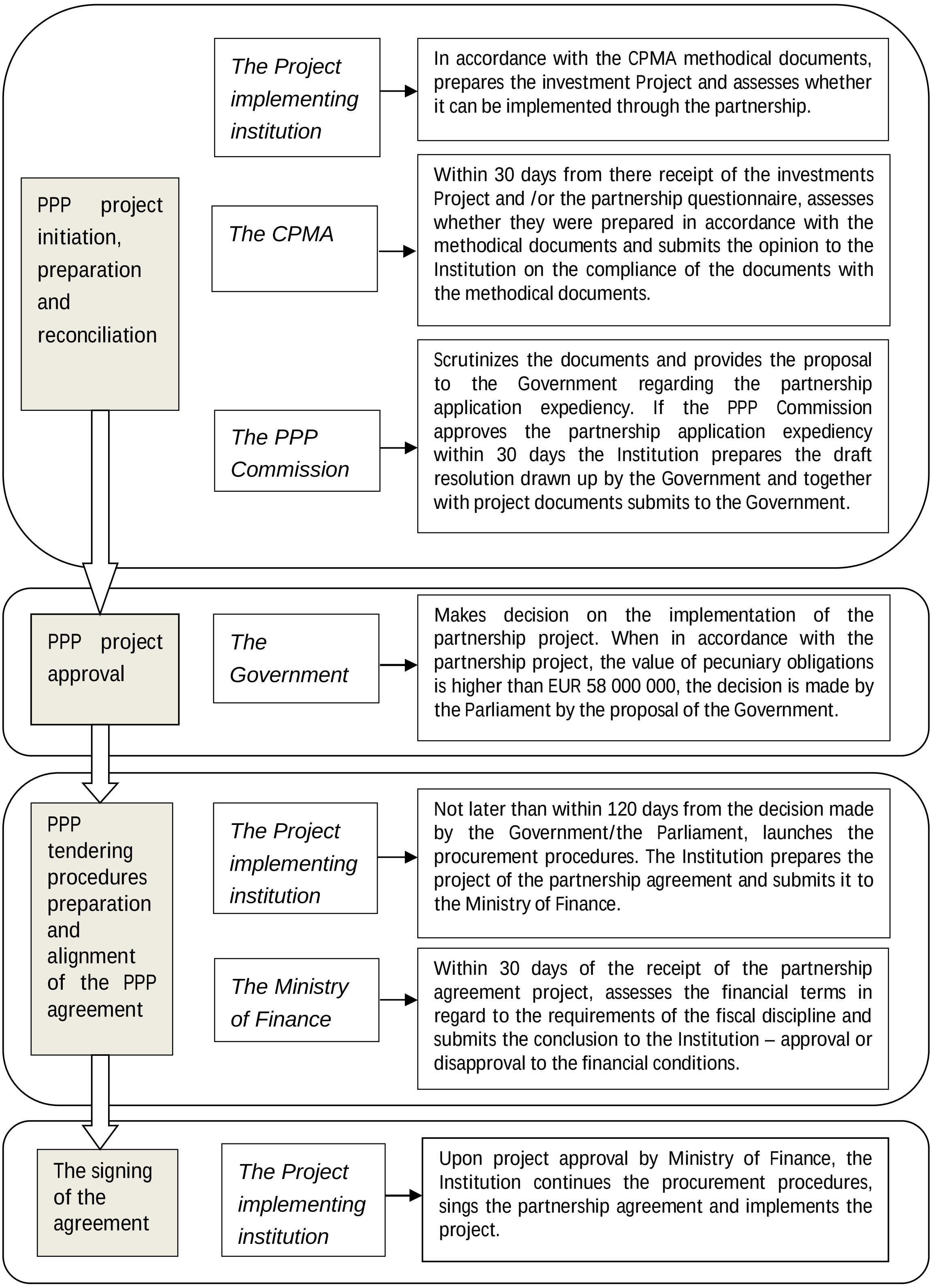

Figure 1: PPP project development model (adopted from PPP Competence Centre. Viešojo ir privataus sektorių partnerystė: Lietuvos patirtis ir ateities perspektyvos [Public and Private Partnership: Lithuanian experience and future perspectives], 2014)

3. Public and Private Partnership Project Evaluation

As a result of recent scientific literature review, the main research areas were identified related to the PPP projects development (Table 1). While the foreign authors investigate financing and management problems, analyse different PPP application areas, share the best practise of the PPP coordinating institutions, European Commission Directorate - General for Regional Policy (2006) and most of the Lithuanian authors emphasize the significance of the criteria used to assess the PPP project effectiveness at the stage of feasibility study: political, administrative and legal environment, communication between the public and private sectors, etc. (Table 2).

Table 1. Research areas of PPP projects

No.	*Research areas*	*Authors*
1	*PPP projects implementation efficiency, financing and management problems*	*Mouraviev, Kakabadse 2014; Turhani 2013; Rufin, Rivera-Santos 2012; Makovsek 2013; Jasiukevičius, Vasiliauskaitė 2012.*
2	*Analysis of diversity and characteristics of PPP application areas*	*Rajan et al. 2014; Carpintero, Petersen 2014; Song et al. 2013; Cruz, Marques 2013; Gordon 2012; Jooste, Scott 2012; Grasman et al. 2014; Iliescu et. al. 2014 Devkar et al. 2013.*
3	*Best practice for PPP projects in the world: the coordinating institutions and their activities*	*Rossi, Civitillo 2014; Hwang et al. 2013; Rebeiz 2012; Chen, Hubbard 2012; Mouraviev, Kakabadse 2014; Silvestre, Feraz Esteves De Araujo 2012.*
4	*Criteria of PPP projects effectiveness*	*Skietrys, Raipa 2009; Vičkačkienė 2010; General Directorate of Regional Policy of European Commission 2003; Šutavičienė 2013; Kavaliauskaitė, Jucevičius 2009.*

Table 2. Criteria of PPP projects effectiveness

Authors	*Criteria of PPP projects effectiveness*
European Commission Directorate - General for Regional Policy (2003)	*Free access to the market and fair competition* *Public interest advocacy and increasing of added value* *The optimal level of grant financing* *Selection of the most effective forms for partnership project*
Skietrys, Raipa (2009)	*Political, legal and administrative environment* *Aspiration of higher quality; Communication*
Kavaliauskaitė, Jucevičius (2009)	*Institutional environment; Staff performance and competence* *Managerial and organizational aspects* *Identification and coordination of different organizational cultures; Knowledge management* *Balanced stakeholder aspirations realization*
Vičkačkienė (2010)	*Long-term investment plans for various sectors* *Legal and administrative system* *Clarity of the competences of the public sector* *Confidence of the private sector*
Šutavičienė (2013)	*Analysis of public needs; Legal environment;* *Clear vision, goals, objectives, main directions* *Dissemination of analytical information*

The existing PPP project evaluation stages and criteria from the perspective of the public sector in Lithuania are presented in the Figure 2. According to the Republic of Lithuania Government Decree No.1480, November 1, 2009 (last amended in 2015) PPP Commission approves/rejects the projects based on the CPMA recommendations and institution's financial capability. However, the National Audit Office Report (2013) states: "the areas to be improved include initiation and development of partnership projects. Prior to the preparation of feasibility studies, none of the analysed projects had been subject to detailed assessment in order to find out whether it is appropriate to carry out these projects in the form of PPP. Also, none of the feasibility studies evaluated the financial capacity of the institutions, although this is a very important criterion". In authors' opinion, public PPP commitments should have the financial limits, and clear and transparent criteria need to be established for project prioritization within the certain area. Thus, the set of the criteria (shaded area of Figure 2) was developed by the authors and is recommended to be used for the PPP project evaluation by PPP Commission from the public sector perspectives:

- **C1 - Impact on the regional labour market.** This criterion refers to the number of new job places created due to the project implementation and the number of unemployed people in the region, measured as a percentage.
- **C2 - Share of the project value per single consumer of project target group**. The ratio is calculated dividing the value of public sector capital investments and operation expenses by the number of targeted users (recipients) for whom the infrastructure and public services/ social economic benefits supposed to be created, calculated in EUR.
- **C3 - Complexity of the public services.** It reflects the responsibilities and risk acceptable by the private sector. Criterion is calculated taking into account different tasks/ services or groups of services to be transferred to the private sector during the project implementation and operation period.
- **C4 - Expansion of the provided services within the region.** It refers to the increased percentage of customers after the PPP project implementation in regard to the total number of people residing within the public institution's service territory.
- **C5 - Size of the target group within the region.** The criterion represents the proportion of the population in the region which receives the benefits of the implemented PPP Project, measured as a percentage.
- **C6 -Project priority in regards to regional strategic development plan**. It defines the priority of the project implementation area within the municipal/state strategic development plan. The criterion is measured on a scale from 1 to 10 points. Scores are calculated by dividing the project area priority number by the total number of priority areas and multiplying it by 10 - the number of max points. The project is of the highest priority when it's score is equal to 1.

The authors define the following advantages of the suggested methodology:

ü accurate and clear criteria are used to prioritize the PPP projects of the same area;

ü less projects are presented for Government, Parliament or the municipal council consideration;

ü the most rational and sustainable PPP projects within the certain field are selected for funding by the end of the financial period.

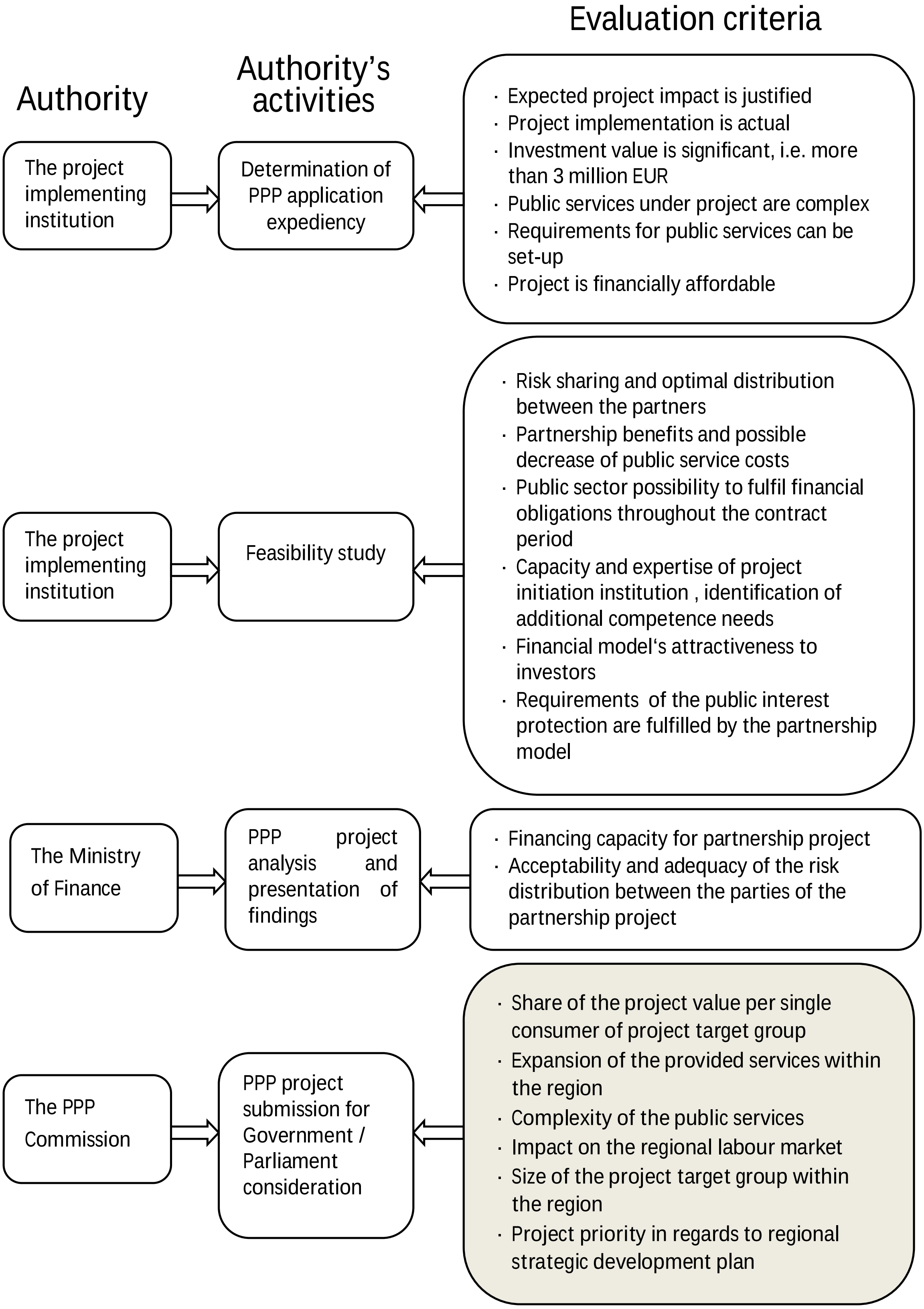

Figure 2: PPP project evaluation criteria

4. Effectiveness of PPP Projects: Case Study

Three Lithuanian public-private partnership projects were selected for analysis and priority identification. Information about all of these projects is presented on the PPP Competence Centre website (www.pppLietuva.lt) as well as the documents of public procurement. New construction or reconstruction of the existing buildings in all of the projects is planned to be carried out as well as building maintenance and operation services provided for the period of 25 years. In fact, two of these projects belong to the public security sector within the central government level, and the third one to the sports and leisure sector within the local (municipal) level. It is conditionally assumed that all projects are classified in the same area and are funded from the same source of the public sector, taking into consideration the limited availability of financial resources. The selected projects are:

A1 - Project of Vilnius County Police Headquarters. Project goal - to create the conditions for the proper performance of the police functions in Vilnius city by building and operating appropriate facilities for Vilnius Regional Chief Police Station Custody and Vilnius City 1st Police station. Project Owner - Police Department under the Ministry of Internal Affairs. Total area 8,155 m^2. Max Project value 57 million EUR. PPP Contract: Design-Build-Finance-Operate (DBFO). Project term - 25 years. Current status- Private partner selection.

A2- Sports palace renovation and wellness complex development project in Naujoji Akmenė city. The aim of the project - to ensure the sports and leisure facilities accessibility and attractiveness for community and tourists of Naujoji Akmenė municipality. Project owner - municipality of Naujoji Akmenė. Total area 3,625 m^2. Max project value 8 million EUR. PPP Contract: Design-Build-Finance-Operate (DBFO). Project term - 25 years. Current status – Preparation for tender.

A3 - Project of abandoned buildings reconstruction into the prison in Pravieniškės 1st prison territory. Project goal - to relocate the existing prison from the current Lukiškės remand prison in the central part of Vilnius to Pravieniškės. Project Owner - Prison Department of Lithuania. Project term - 25 years. Max Project value 30 million EUR. Total area 4,883 m^2. Number of prison places 320. PPP Contract: Design-Build-Finance-Operate (DBFO). Current status - Private partner selection.

The significance of PPP projects evaluation criteria was determined by using pair-wise expert evaluation method. The questionnaire was developed and electronic survey (www.manoapklausa.lt) was filled out by 28 experts who directly participate in public and private partnership projects initiation or development and work for the agency „Invest in Lithuania“, CPMA, Ministries of the Republic of Lithuania and local governments. In regards the results of expert evaluation the priority row of criteria was developed (Table 3).

The case study projects were analysed by applying multi-criteria evaluation methods: Simple Additive Weighting (SAW), Complex Proportional Assessment (COPRAS) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS).

Table 3. The weights of PPP criteria

No.	*Criteria*	*Weights of significance*
C2	*Share of the project value per single consumer of project target group*	*0,23*
C4	*Expansion of the provided services within the region*	*0,19*
C3	*Complexity of the public services*	*0,18*
C1	*Impact on the regional labour market*	*0,15*
C5	*Size of the project target group within the region*	*0,15*
C6	*Project priority in regards to regional strategic development plan*	*0,10*
	Total:	*1,00*

The matrix of initial data for the alternatives *A1*, *A2* and *A3* was created with the criteria values which were calculated by using data from PPP Competence Centre, public procurement documents, Lithuanian Statistical Department, also information received from project initiating institutions (Table 4).

Table 4. Matrix of initial data

	C1	*C2*	*C3*	*C4*	*C5*	*C6*
A1	*0,34*	*799*	*9*	*12*	*22*	*6,67*
A2	*0,26*	*7404*	*13*	*13*	*14*	*6,00*
A3	*3,90*	*324566*	*9*	*105*	*0,0005*	*3,68*
Optimality	*Max*	*Min*	*Max*	*Max*	*Max*	*Min*

By applying multi-criteria evaluation methods of SAW, COPRAS and TOPSIS, Project of Vilnius County Police Headquarters was identified as the most rational and sustainable from the public sector perspective. Sports palace renovation and wellness complex development project in Naujoji Akmenė city was selected as the second one in priority. The Project of abandoned buildings reconstruction into the prison in Pravieniškės 1st prison territory was assigned to the third place (Table 5).

Table 5. The summary results of multi-criteria evaluation

	SAW		*COPRAS*		*TOPSIS*		*Final ranking*
	Priority	*Value*	*Priority*	*Value*	*Priority*	*Value*	*Priority*
A1	*1*	*0,59*	*1*	*0,33*	*1*	*0,49*	*1*
A2	*3*	*0,40*	*2*	*0,32*	*2*	*0,48*	*2*
A3	*2*	*0,56*	*3*	*0,31*	*3*	*0,46*	*3*

5. Conclusions

Legal basis for PPP projects development in Lithuania was significantly improved during the period of 2010-2015. Up to date only two institutional PPP projects have been successfully implemented under the partnership scheme, but the number of new PPP projects is growing and the responsible institutions have to justify the public sector participation in the light of limited state/municipal budget resources. There is a need for the system of PPP project prioritization from the public sector perspective.

Analysis of Lithuanian PPP project development model was carried out and the conclusion was made that PPP model requires improvement, especially at the stage of feasibility study. By evaluating the projects in the early development stage it would be possible to identify the most efficient projects, thereby reducing the number of further activities and saving the costs.

The criteria set for PPP projects evaluation by PPP Commission was developed by the authors and according to the results of expert evaluation survey their relative weights were established. The following priority of criteria based on their importance was identified:

- Share of the project value per single consumer of project target group
- Expansion of the provided services within the region
- Complexity of the public services
- Impact on the regional labour market
- Size of the project target group within the region
- Project priority in regards to regional strategic development plan

Case study of the three selected PPP projects revealed the same priority line of projects' effectiveness by applying SAW, COPRAS and TOPSIS multi-criteria evaluation methods. This demonstrates the validity of the proposed evaluation methodology, thus it is recommended for practical application of PPP project assessment from the perspectives of Lithuanian public sector.

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Risk Identification for PPP Road Projects in Bangladesh

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Abstract

The Bangladeshi government is considering Public Private Partnership (PPP) procurement options in the road sector by encouraging the involvement of local and foreign investors. However, there is ongoing evidence of poor success rating in implementing road projects in Bangladesh. Although the policy makers, public sector clients, private investors and the lenders are aware of the benefits of road projects procurement under PPP arrangement, there is little information on the likely risks and their impacts on PPP road projects. This paper therefore identifies and prioritises the risks associated with PPP road projects in the context of Bangladesh through a questionnaire survey of public clients, contractors and consultants that are involved in road sector projects development. In order to prioritise the 36 previously identified risk factors associated with PPP road projects, a questionnaire survey was conducted among the three groups of respondents: public clients, contractors and consultants. The survey results show that availability of land is the most significant risk factor for PPP road projects in Bangladesh. The other top ranked risk factors are improper planning for PPPs, risk in financing in PPP road projects, delay in land acquisition, corruption in government sector and toll road acceptance by the public majority. It is concluded that these risk factors need to be prioritised and addressed through government initiatives in order to encourage local and foreign investors' participation in the PPP road projects in Bangladesh.

Keywords: Risk management, public private partnership, Bangladesh, road construction, project procurement

1. Introduction

Project implementation through Public Private Partnerships (PPPs) is now an accepted alternative to traditional procurement methods in delivering public service infrastructure facilities. The private partners can be engaged in delivering public services through different models of PPP procurement (Akintoye and Chinyio, 2005). It is widely used because of its special characteristics such as ease of pressure on public fund, proper allocation of project risks and efficiency in project completion with innovative design and construction methods, which encourage the public clients to initiate PPP-based infrastructure projects worldwide (Li and Akintoye, 2003).

Over the past two decades, private sector financing through PPPs has become increasingly popular as a way of procuring and maintaining public sector infrastructures, in the sectors such as transportation (roads, bridges, railways, ports, airports etc.), social infra-structures (schools, hospitals, prisons, social housing etc.), public utilities (water supply, waste disposal and treatment, water treatment etc.), power sector, government offices and accommodations and other special services such as communication networks, defence equipment. However, PPP project implement process comes across a number of risks in different forms such as political, cultural, technological, social, legal, environmental, financial, macroeconomic, project default risks etc. In addition, owing to its complex nature, large volume of capital investment, long- term concession period and involvement of diversified parties, project implementation through PPP models has been adjudged to be full of risks (Li and Zou, 2011). Moreover, in PPP road project, traffic revenue or demand risk, toll pricing and collection risks are other important factors that can create uncertainty in getting back the cost of capital and profit to the private entity by the end users throughout the long range concession period (Singh and Kalidindi, 2006).

Impact of risks in completing a PPP project is usually significant. Failure to manage the risks has direct or indirect impact on goals and objectives of the organisation. Thus, all the parties involved in PPP procurement need to know the nature and complexity of project risks. The public sector clients need to address the project risks for assessing financial and economic viability before embarking on any project (Singh and Kalidindi, 2006), preparing a successful concession agreement and transferring the major risks to the private sectors as they are best able to manage them (Ibrahim et al., 2006).

The Bangladeshi government is embarking on PPP options in the road sector by encouraging the involvement of local and foreign investors. However, there is evidence of poor success rating in implementing road projects in Bangladesh. Project procurement through PPP models in Bangladesh is new and at the embryonic stage; a few PPP projects have been started recently including two PPP projects in the road sector. The client organisations are being encouraged to procure PPP road projects. However, the policy makers, public sector clients, private investors and the lenders do not have enough information about the likely risks and their impacts on road projects procurement under PPP arrangement, Not too many private investors are expressing interests to take part in bidding competition for PPP projects because of risks that could be attributable to the procurement arrangement including lack of confidence on their return on investment. This paper therefore identifies and prioritises the risks associated with PPP road projects in the context of Bangladesh

2. Risks associated with PPP road projects

Several studies (Xu et al., 2010; Chung et al., 2010; Singh and Kalidindi, 2006; Thomas et al., 2003) have identified the significant risks associated with PPP road projects, their impacts and development of risk management tools for different countries.

Wang et al. (2000) identified a list of risks in PPP road projects in the context of China. This comprises political risk factors such as change in law and policy, delay in approval, corruption in government, government's reliability and creditworthiness; and force majeure risks, which are regarded as the most critical risk factors affecting the BOT projects in China.

Thomas et al. (2003) identified the major risks in Indian BOT toll road projects and classify them into four different phases of a project. The first phase is the development phase which comprises of land acquisition/resettlement risk, permission/approval risk and delay in financial closure. This is followed by the construction phase risks comprising technological risk, design risk, project delay and cost overruns risk. The operation phase risks are traffic revenue risk, operation risk, demand risk, debt servicing risk. Lastly, the project life cycle risks comprise legal risk, political risk, partnering risk, regulatory risk, environmental risk and force majeure. In addition, Singh and Kalidindi (2006) emphasised risk in traffic revenue (i.e. demand risk) affecting the commercial success of PPP toll road projects in India.

Wibowo and Kochendorfer (2005) work on PPP toll road project in Indonesia shows that construction cost overruns, delay in land acquisition and total delay in project complementation, pricing of toll rate, estimation of future traffic volume, change in regulation and some macroeconomic factors such as inflation, interest rate are the most significant risks affecting the success of PPP toll road projects in Indonesia.

Ogunlana and Abednego (2009) listed risk factors for PPP road way and conducted a case study research on Cipularang Toll-way Project in Indonesia to identify the major risk factors on the project. The study shows that project financing, lack of government support, delay in decision/approval, problem with land acquisition and change in design affected mostly the success of the project.

Xu et al. (2010) identified 17 major risks associated with PPP road project; these are ranked in accordance with their importance on PPP Highway projects in China through Delphi questionnaire survey technique and identify the most critical risk groups using factor analysis. They concluded that government intervention (political interference on project procurement) and government maturity (corruption and poor decision making and inadequate law and order situation) are the two most critical risk groups affecting the success of PPP Highway projects.

Rajan et al. (2010) conducted a case study on East Coast Road project, a PPP road project in Chennai, India. The most critical risk factors identified on the project are project finance risk, poor decision making by the government, delay in land acquisition, cost overruns, risk associated with traffic revenue and collection of tolls.

In the Australian PPP road project, Chung et al. (2010) identified the most critical risk factors as fluctuating traffic volume, design and construction risk, operation and maintenance risk, risk for change in country's legislation and policy, pricing of toll, debt coverage risk and low level acceptance of toll road by users.

Li and Zou (2011) developed a fuzzy analytical hierarchy process (AHP) to assess the risks in PPP projects. They identified the risks associated with PPP roadway project in China which are verified by the PPP experts and assessed them using fuzzy technique. From this study, planning deficiency, low residual value, lack of enough competition, design risk, delay in approval, change in legislation and traffic volume risk were identified as the most critical risk factors for PPP highway projects in China.

Based on the literature above, Table 1 is produced which shows that fluctuating traffic (or demand risk) is the mostly cited risk factors associated with PPP road projects. The commercial success of PPP road projects depends in some ways on the toll collected from the traffic use of the assets if investors are otherwise not compensated by the public sector clients. Private investors perceive the returns on investment from PPP road projects is risky despite the assumption of any traffic revenue presented in the PPP business case by the client organisations (Singh and Kalidindi, 2006).

Delay in construction is another most cited important factor. Construction time overrun is a general factor for any type of project which could result from insufficient experience of the contractors, use of inappropriate construction methods, inaccurate time and cost estimating, improper project planning and scheduling, incompetent project team, unreliable subcontractor, obsolete technology etc. (Long et al., 2004).

Delay in land acquisition, frequent change in laws/policies and risk in operation and maintenance are the third most cited risk factors. Road project requires acquisition of public land. The acquisition process involves several steps such as estimation of land and other assets, supply of necessary documents; followed by a number of steps to get the final approval, which often consumes significant time and cost for the road projects (Wang et al., 2000). Risks associated with frequent change in law includes changes in government policies, laws and regulations related to public procurement, methods of handling inflation, fixation of currency conversion rate and methods of setting taxation rate by the different organisations of the government: these can hinder the success of a PPP road project (Wang et al., 2000).

Factors such as residual value risk, availability of land risk, unstable law and order situation, risks in evaluation of PPP procurement and delay in annuity payment are the least cited risk factors.

Table 1: Risk associated with PPP road projects (Content analysis)

Risk factors	*Wang et al. (2000)*	*Kalidindi & Thomas (2003)*	*Wibowo & Kochendorfer (2005)*	*Singh & Kalidindi (2006)*	*Ogunlana & Abednego (2009)*	*Chung et al. (2010)*	*Xu et al. (2010)*	*Rajan et al. (2010)*	*Li and Zou (2011)*	*Total number of citations*
Frequent change in policy /laws	*x*	*X*	*x*	*x*	*x*	*x*			*x*	*7*
Government intervention					*x*		*x*			*2*
Corruption in government sector	*x*						*x*			*5*
Delay in approval	*x*			*x*			*x*	*x*	*x*	*5*
Lack of government support		*x*			*x*					*2*
Unstable law and order							*x*			*1*
Lack of competition in bidding						*x*			*x*	*2*
High bidding/tendering cost	*x*								*x*	*2*
Bid evaluation risk (subjective)							*x*			*1*
Risk in contract management	*x*				*x*		*x*	*x*		*4*
Planning/pre-investment risk				*x*					*x*	*2*
Design risk					*x*	*x*		*x*	*x*	*4*
Availability of land				*x*						*1*
Delay in land acquisition	*x*	*x*	*x*	*x*	*x*			*x*	*x*	*7*
Resettlement/relocation risk				*x*						*1*
Cost overruns	*x*	*x*	*x*	*x*			*x*	*x*	*x*	*6*
Delay in construction	*x*	*x*	*x*	*x*	*x*	*x*	*x*		*x*	*8*
Change of project scope				*x*			*x*			*2*
Risk in quality control				*x*	*x*		*x*			*3*
Health and safety risk	*x*								*x*	*2*
Force majeure risk	*x*			*x*	*x*	*x*				*4*
Environmental risk	*x*							*x*	*x*	*3*
Commissioning risks	*x*								*x*	*2*
Operation and maintenance risks	*x*			*x*	*x*	*x*	*x*	*x*	*x*	*7*
Residual value risks									*x*	*1*
Fluctuating traffic /demand risk	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*9*
Competing/alternative routes	*x*				*x*	*x*				*3*
Risk in collection of toll		*x*						*x*	*x*	*3*
Pricing/fixing of toll rates	*x*	*x*	*x*		*x*	*x*		*x*		*6*
Acceptance of toll road		*x*				*x*				*2*
Project financial closure risk		*x*		*x*	*x*		*x*	*x*		*5*
Debt servicing risk		*x*				*x*		*x*		*3*
Delay in annuity payment				*x*						*1*
Fluctuation of exchange rate	*x*				*x*		*x*			*3*
Fluctuation of interest rate	*x*		*x*	*x*	*x*		*x*	*x*	*x*	*7*
Inflation	*x*		*x*		*x*		*x*		*x*	*5*

3. Research Method

The principal objective of the study was identification of significant risks in PPP road projects in the context of Bangladesh. To identify the risk associated with PPP road projects, the available literature on risk associated with PPP road projects have been analysed and the risk factors have been listed in a tabular form through content analysis (after Bryman, 2008). A total of nine research papers on risk in PPP road projects have been reviewed to identify the risks associated with PPP road projects. Based on the nine research papers, 36 risk factors were identified (after Xu et al., 2010) as shown in Table 1.

A questionnaire survey which contains all 36 identified PPP road risk factors have been used to gain a wider spread of opinion on risk factors in the context of Bangladesh PPP road projects based on a 5-point Likert scale (5=Very important; 4= Important; 3=Moderately important; 2=Less important, and 1= Unimportant). The questionnaire was piloted with 5 road procurement experts. Construction professionals both in government and private sectors as well as consulting firms, who have vast experience in procurement of road projects in Bangladesh were targeted.

The respondents are (i) public sector client respondents drawn from Roads and Highways Department (RHD), Local Government Engineering Department (LGED), Bangladesh Bridge Authority (BBA) and City Corporations; (ii) private sector contractors who are road project construction experts from national level construction firms (enlisted by the public procurers) in Bangladesh; and (iii) consultants who are public procurement consultants working in consulting firms, donor aided public procurement project and as freelance consultants.

As there was no systematic database for the road construction professionals in Bangladesh, non-probabilistic quota sampling technique instead of random sampling was used with a view to comparing the perceptions on PPP road risks from the three groups of respondents. A total of 120 respondents (40 from each group) was asked to rate the factors based on their experience in road project procurement. The questionnaires were self-administered in Bangladesh over a period of two months. A total of 82 completely completed questionnaires was returned, representing a response rate is 68.33% (public clients 80%, contractors 75.5% and consultants 52.5%).

These risk factors are presented to Bangladeshi respondents. Mean score (MS) for each risk factor from the 5-point Likert scale was calculated (after Chan and Kumaraswamy, 1996) as follows:

$$\text{MS} = \frac{\sum_1^5 (f.s)}{\text{N}}$$

Where f = frequency of each rating for each risk factor; s = score given to each risk factor by the respondents (ranging from 1 to 5); and N= total number of responses for each risk factor. In addition, the standard deviation of the MS for each factor is provided to show the variability.

4. Results of the Survey

Table 2 shows that 61% of the respondents had over 10 years of experience in road projects construction and procurement; suggesting that the majority of the respondents were operating at senior level of construction professional experience.

Table 2: Experience level of the respondents

Years of experience	*Overall*		*Public Clients*		*Private Contractors*		*Consultants*	
	No.	*(%)*	*No.*	*(%)*	*No.*	*(%)*	*No.*	*(%)*
Less than 5 years	*9*	*11%*	*8*	*25%*	*1*	*3%*	*0*	*0%*
5^+ to 10 years	*23*	*28%*	*12*	*37.5%*	*9*	*31%*	*2*	*10%*
10^+ to 20 years	*38*	*46%*	*8*	*25%*	*13*	*45%*	*17*	*80%*
More than 20 years	*12*	*15%*	*4*	*12.5%*	*6*	*21%*	*2*	*10%*
Total	*82*	*100%*	*32*	*100%*	*29*	*100%*	*21*	*100%*

4.1 Ranking of risks in PPP road projects

The responses of clients, contractors and consultants are ranked based on their mean score (MS) and standard deviation of a list of 36 identified risk factors involved in PPP road projects. Also, an overall ranking of the risk factors is presented by combining the data from all respondents.

Table 3 shows ranking of the risk factors by the three respondent groups and the overall ranking from all the three groups of respondents. The mean scores ranged from 4.43 to 2.13. Availability of land (MS = 4.43), improper planning for PPP project procurement (MS = 4.33), financing in PPP road projects (MS = 4.27), delay in land acquisition (MS = 4.24) corruption in government sector (MS = 4.09), acceptance of toll roads (MS = 4.02) are considered the top most risk factors by the respondents.

The top most significant risk factors for clients are: delay in acquisition of land for the projects (MS = 4.50), initiating PPP projects without proper planning by the client organisations (MS = 4.41), availability of sufficient land for construction of road projects (MS = 4.38), lack of qualified bidders to invest in large scale road projects (MS = 4.13), financing in PPP road projects (MS = 4.06), resettlement and relocation of utilities (MS = 4.03), frequent changes of laws, rules and regulations related to public procurement of Bangladesh (MS = 4.00).

The most significant risk factors by contractors are: availability of land (MS = 4.55), financing in PPP road projects (MS = 4.48), corruption in government sectors (MS = 4.41), improper planning for PPP road projects (MS = 4.34), government intervention in large scale project procurement (MS = 4.28), and delay in land acquisition (MS = 4.14).

The most important risk factors associated with PPP road projects in Bangladesh identified by the consultants group are availability of land for road project (MS = 4.33), financing in PPP road projects (MS = 4.29), improper planning for PPP road projects (MS = 4.19), acceptance of toll road by the users (MS = 4.14), corruption in government sector (MS = 4.05), delay in land acquisition (MS = 4.00), government intervention in project procurement (MS = 3.90), unstable law and order situation (MS = 3.86) and lack of qualified bidders (MS = 3.76).

Table 3: Rankings of risks in PPP road projects in Bangladesh from different perspectives

Risk Factors	*Overall*			*Clients*		*Contractors*		*Consultants*	
	R	*MS*	*SD*	*R*	*MS*	*R*	*MS*	*R*	*MS*
Risk of availability of land	*1*	*4.43*	*0.817*	*3*	*4.38*	*1*	*4.55*	*1*	*4.33*
Improper planning for PPP	*2*	*4.33*	*0.771*	*2*	*4.41*	*4*	*4.34*	*3*	*4.19*
Risk of financing in road PPP projects	*3*	*4.27*	*0.847*	*5*	*4.06*	*2*	*4.48*	*2*	*4.29*
Delay in land acquisition	*4*	*4.24*	*0.639*	*1*	*4.50*	*6*	*4.14*	*6*	*4.00*
Corruption in government	*5*	*4.09*	*0.820*	*11*	*3.81*	*3*	*4.41*	*5*	*4.05*
Risk in acceptance of toll road	*6*	*4.02*	*0.801*	*10*	*3.88*	*7*	*4.10*	*4*	*4.14*
Government intervention	*7*	*3.98*	*0.875*	*13*	*3.75*	*5*	*4.28*	*7*	*3.90*
Lack of qualified bidders	*8*	*3.94*	*0.880*	*4*	*4.13*	*9*	*3.86*	*9*	*3.76*
Unstable law and order	*9*	*3.90*	*0.730*	*9*	*3.97*	*10*	*3.86*	*8*	*3.86*
Delay in getting approval	*10*	*3.80*	*0.761*	*8*	*4.00*	*11*	*3.76*	*11*	*3.57*
Frequent change in laws	*11*	*3.79*	*0.698*	*7*	*4.00*	*12*	*3.72*	*12*	*3.57*
Delay in construction	*12*	*3.59*	*0.816*	*12*	*3.81*	*14*	*3.31*	*10*	*3.62*
Risk in collection of toll	*13*	*3.55*	*0.996*	*18*	*3.25*	*8*	*3.90*	*13*	*3.52*
Risk in resettlement	*14*	*3.52*	*0.959*	*6*	*4.03*	*17*	*3.00*	*14*	*3.48*
Inflation	*15*	*3.29*	*0.839*	*20*	*3.13*	*13*	*3.38*	*15*	*3.43*
Risk in contract management	*16*	*3.29*	*0.853*	*16*	*3.41*	*15*	*3.21*	*17*	*3.24*
Increase in project cost	*17*	*3.28*	*0.879*	*14*	*3.47*	*18*	*3.00*	*16*	*3.38*
Operation & maintenance risks	*18*	*3.06*	*0.791*	*21*	*3.09*	*19*	*2.97*	*20*	*3.14*
High tendering cost	*19*	*3.04*	*0.909*	*31*	*2.81*	*16*	*3.14*	*18*	*3.24*
Fluctuation of interest rate	*20*	*3.00*	*0.770*	*24*	*2.97*	*20*	*2.93*	*19*	*3.14*
Fluctuating exchange rate	*21*	*2.98*	*0.769*	*27*	*2.94*	*22*	*2.93*	*21*	*3.10*
Subjective tender evaluation method of PPP	*22*	*2.94*	*0.998*	*19*	*3.22*	*23*	*2.55*	*23*	*3.05*
Maintaining quality of works	*23*	*2.91*	*0.973*	*15*	*3.44*	*29*	*2.24*	*22*	*3.05*
Unwillingness of the government for PPPs	*24*	*2.88*	*1.011*	*17*	*3.28*	*25*	*2.41*	*24*	*2.90*
Fluctuating traffic volume	*25*	*2.80*	*1.048*	*26*	*2.94*	*21*	*2.93*	*31*	*2.43*
Force majeure risks	*26*	*2.77*	*0.907*	*25*	*2.97*	*24*	*2.48*	*25*	*2.86*
Existing/alternative routes	*27*	*2.67*	*0.969*	*28*	*2.94*	*26*	*2.31*	*26*	*2.76*
Fixing the toll rates	*28*	*2.57*	*1.089*	*22*	*3.09*	*31*	*2.10*	*32*	*2.43*
Variation in scope of works	*29*	*2.55*	*0.918*	*33*	*2.75*	*28*	*2.28*	*28*	*2.62*
Environmental risk	*30*	*2.54*	*0.971*	*30*	*2.84*	*32*	*2.10*	*27*	*2.67*
Delay of annuity payment	*31*	*2.52*	*1.009*	*32*	*2.81*	*27*	*2.31*	*35*	*2.43*
Changes in design of work	*32*	*2.51*	*0.878*	*29*	*2.84*	*30*	*2.17*	*29*	*2.48*
Payment of debt	*33*	*2.51*	*1.009*	*23*	*3.00*	*33*	*2.00*	*30*	*2.48*
Health and safety risk	*34*	*2.34*	*0.864*	*34*	*2.72*	*35*	*1.86*	*33*	*2.43*
Commissioning risk	*35*	*2.23*	*1.010*	*36*	*2.63*	*34*	*1.90*	*36*	*2.10*
Risk in residual value	*36*	*2.13*	*1.167*	*35*	*2.69*	*36*	*1.34*	*34*	*2.38*

*R = Ranking, MS = Mean score, SD = Standard deviation

Spearman correlation analysis results for the 10 most important risk factors to test for any agreement between various groups of respondents is presented in Table 4. This shows that there is general agreement between the consultants and contractors in respect of the ranking of the top ten risk factors, whereas there are significant disagreements between clients and contractors, as well as clients and consultants. This test reinforces the concordance of perception between the two private sector groups (contractors and consultants).

Table 4: Test for agreement on the overall ranking of the 10 most important risk factors as perceived by different group of respondents

Groups of respondents	r_s	*t*	*Reject H_0?*	*p-value*
Clients and Contractors	*-0.297*	*-0.880*	*No*	*Not significant*
Clients and Consultants	*-0.103*	*-0.293*	*No*	*Not significant*
Contractors and Consultants	*0.867*	*4.914*	*Yes*	*Significant, <0.05*

*r_s = Spearman's rank correlation coefficient; t = t-statistics; H_o = null hypothesis; p = probability that rejects the null hypothesis.

5. Discussion of the results

Overall, the survey results show that risk in availability of land for road projects, improper planning for PPP procurement, risk in financing, delay in land acquisition, corruption in government sector and risk in acceptance of toll roads are the top ranked factors in the context of Bangladesh. However, the prioritisation based on the Table 1 (undertaken through content analysis of literature review) is quite different from this survey result. For example, availability of land is mentioned as a significant risk factor in only one of the literature, whereas, it is ranked first in this study. On the other hand, fluctuating traffic revenue is cited in all the research papers; however, this factor is ranked 25th important factor in Bangladesh.

It is noted that the three respondent groups (clients, contractors and consultants) ranked the risk factors associated with PPP road projects according to their objectives and interest in road sector project development. However, the consistently least important risk factors overall and within the groups for PPP road projects in Bangladesh are the risks associated with residual value of the asset, commissioning of the asset, health and safety, payment of debt to the financial institutions and changes in design of works. The top ranked risk factors and how they could impact the success of PPP road projects in Bangladesh are discussed as follows:

Availability of land for PPP road projects: The risk of availability of land for PPP road projects is ranked 1st overall. This is not surprising given that availability of land is a common problem for road project for the countries with high population density like Bangladesh; availability of land is regarded as one of the significant risk factors for PPP road projects in India (Thomas et al., 2003). Bangladesh is an agriculture-based country with high density of population. Road construction projects need considerable land and in Bangladesh it is associated with high market price. In addition, a PPP new road project development might lead to a need to demolish high-rise buildings, markets and other structures which are located adjacent to the existing roads. Thus scarcity of land creates high barrier to the implementation of road projects in Bangladesh. For example, it was speculated that one of the large PPP road projects in Bangladesh, Dhaka Elevated Expressway (with the estimated cost of over US$ 1 billion), would fail at its initial phase because of insufficient and costly land in Dhaka city (GOB, 2011).

Improper planning for PPP procurement: Although 'improper planning for PPP procurement' is identified as one of the least cited factors in the literature reviewed, this factor is ranked 2nd in the context of PPP road projects in Bangladesh. This is a critical risk factors for Bangladesh as development of most road projects in Bangladesh is considered on the basis of political imperatives. The financial and economic needs are often ignored while initiating projects. As a result, many road projects in Bangladesh have been known to experience time and cost overruns and in some cases abandoned due to improper procurement choices and planning.

Financing of PPP road projects: The risk factor ranked 3rd overall is ranked 5th by clients and 2th by both contractors and consultants. This is an important factor to contractors and lenders as it may affect the project revenue and cash flow regime, which has a direct impact on payment for the services provided by the asset and consequently the recovery of capital invested by the lender. Lenders perhaps perceive PPP investment risk as a 'business' risk and are rightly concerned if this is inappropriately passed to the project consortium. Increase in project cost, government intervention, corruption, fluctuating traffic volume, change in laws/policies by the government etc. are some of the factors which could create risk and uncertainty of the investment in PPP road projects for investors.

Delay in land acquisition: Delay in land acquisition is ranked fourth overall. While clients ranked it as first, the contractors and consultants have ranked the factor as sixth. For road projects construction in Bangladesh, the public clients have had acrimonious experiences with land acquisition. Land acquisition requires a number of steps to get the approval needed coupled with associated complexities, which could lead to considerable time and cost overruns. The impact could mean that the contractor is not able to start the physical work on site or the work is delayed during the construction stage until the problem is resolved. There are evidence of poor performance of road project developments in Bangladesh due to land acquisition problems.

Corruption in government sector: Overall, the risk factor is ranked fifth (third by contractors, fifth by consultant and eleventh by clients). Corruption is prevalent in Bangladesh public sector (Zafarullah and Siddiquee (2001). Bangladesh is ranked among the top corrupt countries based on corruption index by Transparency International. As a result, contractors and consultants often give corruption in public sector as a reason for delays in project execution. The corruption activities could be found in every aspect of construction including tendering process, necessary documents approval, interim payment, utility connections etc. A high level of corruption in the public sector of a country could demotivate local and foreign investment in PPP projects.

Acceptance of toll roads by the end users: This risk is ranked sixth by all the respondents. This is not surprising given that the road users in Bangladesh are not used to paying tolls for the use of roads and bridges; road assets are traditionally constructed and maintained by the public sector. There is a risk that the end users may divert to non-tolled routes to avoid paying tolls on PPP roads, which may hinder generation of revenue needed to cover the investment and profit margin of PPP road investors.

6. Conclusion

Given some benefits acclaimed to project procurement through PPP models over the traditional procurement methods, governments in both the developed and developing countries, are encouraging the private investors in the delivery of public facilities and services through PPP procurement. However, PPP procurement involves a complex procurement process, multi-party involvement and high capital investment along with long-term concession period, which sometimes discourage the private contractors to invest in the uncertain business environment. PPP has been used to deliver infrastructure in many countries where there is not enough public sector funding.

Hence, PPP procurement method could become one significant option for the government of Bangladesh to develop its road sector projects. This has the potential to reduce pressure on the government associated with: huge public sector funding, need for foreign loans, timely completion of road projects; attracting local and foreign investors; etc. However, PPP road projects procurement is adjudged to have many risks that must be mitigated or properly allocated to parties involved in the development.

In PPP projects, the private investors normally assume the revenue/demand risk for the use of the asset including the risk in design, finance, construction and maintenance, although sometimes demand risk may be shared by the public sector assuring the guarantee of a minimum level of use. The results of the survey of Bangladesh respondents show other risks that should be considered. These are availability of land and delay in land acquisition, improper planning for PPP procurement by the government, risk in financing in PPP road projects, corruption in public sector, government intervention and risk in acceptance of toll roads. These are the top risk factors that might affect the success of PPP road projects in Bangladesh.

In order to encourage the private sector (financial institutions, private investors, contractors, etc.) involvement in PPP road project, the government of Bangladesh should initiate processes and guidelines to minimising the impact of the above mentioned risk factors. Land for road projects seems to be a major risk factor that should be addressed in terms of on how to make this available or work with the community in order to gain the trust of investors and to achieve successful road projects development through PPP. The policy makers should also engage pressure groups and stakeholders in a constructive dialogue and involvement very early in a PPP road project development on the requirements of PPP road projects and associated tangible and intangible benefits. Creation of a sound business environment through development of policy and legal framework and guidelines for PPP should be considered a priority by the government in order to gain the trust of both the local and foreign investors. In addition, the planning and procurement processes should be given very care consideration coupled with the engagement of the right professionals from both the public and private sectors very early in the process.

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Methodological Proposal for the implementation of fuzzy logic in the allocation and risk quantification for social infrastructure projects under PPP modality in Colombia

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Abstract

In recent years, Colombia has had strong economic growth. The constant need to expand infrastructure have led to the development of road projects in the form of public-private partnerships (PPP). However, draft social infrastructure has been stalled by the lack of legislation to help correct equitable allocation and quantification of risks between the private and the public sectors. Therefore, this paper seeks to make a methodological proposal of an equitable allocation and quantification of risks for the public and private sectors in Colombia for the development of social infrastructure projects under the framework of PPPs. This work is done through the verification of international experiences and previous local studies on the determination of the factors that affect the decision of the existing risk situation, and with this basis, we seek to find the feasibility of establishing a methodology capable of quantifying and allocating risks through a fuzzy logic approach and mathematical models for the modeling and parameterization of the risks associated with the awarding of contracts and delivery of such projects.

Keywords: Public-Private Partnerships, Fuzzy logic, social infrastructure, Economy

1. Introduction

Following the steady economic growth that has taken Colombia over the past two decades, the state has been forced to consolidate government plans based on building national infrastructure to boost a developing economy. Thanks to the consolidation of economic treaties and projects that enable or facilitate the dynamic economic policy, the C.E in the country during the past three years has averaged the third highest in Latin America with an average of 4.9 percent annually. From this, one of the main needs of the country is the construction and maintenance of transport infrastructure; the so called 4^{th} generation (4G) projects have been promoted through joint (public and private) resources in order to expedite construction and to distribute the associated risk. However, with the enhancement of private public associations in the country, given already years ago, different challenges arise even today, after having consolidated a law focused on this issue are pending.

So far, efforts have been focused on PPPs for road infrastructure as Colombian law scheme is specifically suited for road concessions without going into much detail about other schemes. However the demand for other type of services in the country requires this model to also be applied to other projects like social infrastructure development. However, even when the risks and financial income are different, law conditions are equally enforced; therefore, the private investor bears some suspicion when proposing or seeking social infrastructure PPPs. This is evident in projects declared void because no private was presented.

To partially solve to this problem, the authors propose a methodological approach for the correct risk allocation and quantification in social infrastructure projects based on a fuzzy logic approach. This mathematical models allow the modeling and parameterization of the risks associated with the procurement, contracting, and implementation of such projects. This article seeks to stablish the feasibility of the implementation of such a methodology in the Colombian context under the current conditions.

The remain of this article is as follows: First, we contextualize the reader on Social Infrastructure PPPs and their current state of risk quantification and allocation. Then we state a theoretical and conceptual framework on fuzzy logic and risk in PPPs. Later, we develop a methodological approach for the implementation of this concepts in risk allocation and quantification in PPPs and, finally, we state some recommendations about it applicability in the Colombian context.

2. Public-private partnerships in social infrastructure projects.

Social infrastructure projects are developments identified by the government or the private sector in search of promoting development and investment in urban and rural areas nationwide. Projects of this type seek to satisfy basic and complementary needs of a population in terms of the development of basic rights and government plans. Examples of such projects are schools, in search of the right to education; hospitals, searching for the right to health and life; prisons, with a view to safety plans; service networks or road axes, allowing the development of the country.

However many of these projects cannot be realized due to the lack of public resources. On other occasions, the project life cycle requires maintenance and strict control that is out of the functions of a public body. For these cases, a figure, which allows a partnership between the public sector and the private sector, is often encouraged. The private sector contributes a certain amount of resources that allow the state to carry out such projects. The private meanwhile, expects an economic return for the execution of the project and/or its operation and maintenance, where the investment will be paid.

Additionally, these projects carry great uncertainty and risk for both parties. Therefore you should always pre-assess the suitability of each project using this form or simply make a project through public procurement if the private cannot take the risk assigned. Basically the study currently undertaken by public organizations to establish the viability of these projects is based on a quantitative analysis intended to estimate revenues, costs and project risks.

When there is doubt about the most convenient way, financially speaking, a project (CP or PPP) is performed what is known as value for money. This concept defines Grove (Grove, 2012) as:

> "The result of the comparison of the present value of risk-adjusted costs to develop a public project (Project Public Reference) with the present value of risk-adjusted cost of the same project developed under a PPP scheme."

This analysis should ensure that with the proper development of the project, if realized in the form of a PPP, it will be economically sustainable from a level of initial investment, operating cost, and worthiness of assuming the risk associated. For this, the risks should be allocated between the private and the public parties so that each sector assumes those factors that it is able to efficiently manage (Loosemore & McCarthy, 2008). In this sense, there are two kinds of risks: the risk transferred, which assumes the private; and the risk retained, which assumes the public.

In this order of ideas, the cost of risk of the project refers to monetary impact on the initial budget due to the occurrence of the risk. Although current analysis to define this type of project is done in a quantitative way, this method has serious shortcomings because it does not consider elements of decision. For this reason, countries such as Peru, Chile and Mexico, more developed in the implementation of PPPs, have sought to incorporate in their quantitative analysis the relevant dimensions of subjective nature. However, these efforts have been corrected by the inclusion of the probabilities in the analysis.

Some other experiences (citas...) have proposed the implementation of a system based on fuzzy logic to develop the quantitative analysis of income, cost and risk in PPP projects. These authors have identified that this method is preferable because...

Accordingly, the authors propose a fuzzy logic mathematical approach to apply it in the allocation and quantification of infrastructure projects in Colombia for PPP project development. For this, we have identified four steps in the application of quantitative methods of analysis for the implementation of projects financed in Colombia, Chile and Peru: Identification, Assignment, Measurement, and Mitigation. However, the opinions of experts vary depending on particular interests, and thereforeit is difficult to have a unanimous opinion that allows the correct setting of the parameters for these 4 steps. That's why, as part of the validation of information, and in order to find a balanced response should be performed fuzzy analysis of subjective responses for both the public and private sectors.

3. Theoretical and conceptual framework

Classical logic holds that an event may or may not belong to a certain universe as if it contains conditions of ownership within this set. As before, a car can be considered if tin full commercial value is high, if your engine is powerful, if the finishes are unique and if production is restricted. In this sense a Ferrari belongs to high-end set while a Renault does not. Classical logic is clear in the separation by placing barriers between each set of elements.

However, because the division between sets depends on subjective or undefined conditions, this membership is not always so simple. Therefore, it is not clear to say that an event belongs entirely to a set. This concept is more clearly belonged-law one meets most conditions but not all event; in these cases could not make the event one party or another set di, then what happens? Fuzzy logic postulates the determined degree of membership for which an event may partially belong to one or more sets as the case requires. Alfa Romeo trucks, following the example of cars, belong to the set of high-end and mid-range set with a degree of partial belonged; It is not fully acknowledged within a set.

The same happens with millions of things based on linguistics. What is the limit that marks whether something is high, medium or low? How to know if a temperature is cold or hot? How to tell if something is white or black? These are all vague concepts that classical logic fails to establish clearly, just remember that an object can not only be white or black -that known that Eskimos recognized more than 20 shades of white. Fuzzy logic is a more flexible and complete logic in these situations. A level of 100% owned within a set put us in a particular case of fuzzy logic that corresponds to the classical logic.

A basic definition of risk according to the RAE is "Contingency or proximity of damage ". This risk must be understood on two parameters: the threat and vulnerability (Davis, 2007). These are listed in the following equation.

Risk = Hazard x Vulnerability

The threat understood as a magnitude of harm and vulnerability as a possibility of such magnitude occurs. The vulnerability can be expressed by the following relationship:

Vulnerability = exposure x susceptibility / resilience

In mathematical modeling the risk is understood as a stochastic parameter. This leads to the risk is subject to random events. These random events are what are called environment of uncertainty within a mathematical model. These mathematical models with uncertainty are represented by fuzzy variables. For practical purposes, the risk is modeled through these variables.

These fuzzy variables have a "probability space", which is expressed by the degree of membership, or occurrence, within an event. For example, a variable called earthquake that represents the risk of an event of occurrence of an earthquake in the construction of a building project, is composed of a threat and vulnerability. Threat is understood as the involvement of the structure, and a vulnerability that the probability of this natural event will actually occur during project implementation. Therefore, as denoted expression before, if the threat is high but very low probability, the risk is low. Similarly, although the threat is low, if the probability is high, the risk will remain high because the occurrence of the event is high.

There are two types of uncertainty: stochastic and also known as lexical or inaccuracy. The stochastic uncertainty focuses on the occurrence of an event, it is a question with two possible solutions. (Akbiyikli & Eaton, 2004) We base the lexical uncertainty on the vagueness of the events and the way of perception of events. It is related to how to evaluate concepts and draw conclusions. In this case, complex situations are evaluated using abstraction and referring to analogies. An example is, will it or not be white? Or will it cost more than planned?

Assuming that not all events can be simulated within the parameters of the theory of probability, it is difficult to define the perceived events. That is, the theory of probability to define both an A or B event can occur; however it cannot stipulate the behavior of A or B, or rather cannot define what is A, B or AB. An example of this is seen in the following sentence:

> "The projects in the form of public-private partnership, the risk of over-construction costs is taken by the private and vulnerability to the risk of occurrence is high." (J.Cala, 2015)

The probability theory can model whether or not the risk will occur, however cannot be implemented due to the combination of subjective categories in the process. In other words, it cannot be said to be high or low (Figure 1 and Figure 2).

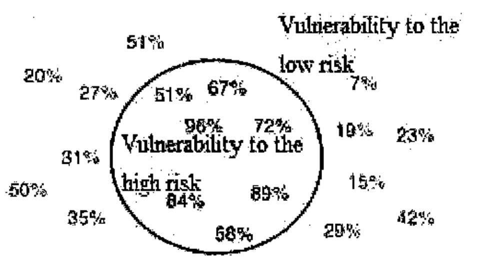

Figure 1. Representation of a set. Classical logic.

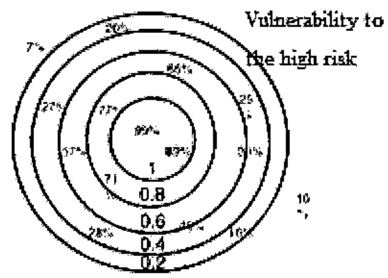

Figure 2. Representation of set b. fuzzy logic.

In the assembly (Figure 1), we have the traditional logic, which is necessary to group the myriad of events in two categories. The events occurring must belong to the set high or not high, that is, in a mathematical reasoning take the values [0, 1].

In Figure 2, a fuzzy set is observed. This type of assembly does not categorize the countless events such as high or higher; but sets limits or levels not clearly defined, the high set membership. That is, to mathematically model a situation an event rather than "0" or "1" can take values between [0,1]. In this vein, the value of the events within the group can be represented by the function uA (x) in which x is the variable represented within a range between 0 and 1. (Ponz Tienda, Pellicer, & Yepes, 2011)

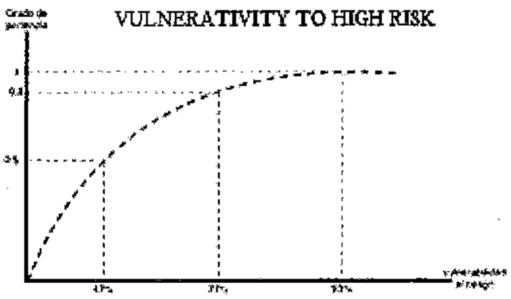

Figure 3. Function belonged Simple variable high risk vulnerability

In the example in Figure 3 it shows that for an event which should be considered if the vulnerability to risk is high, when we have 47% of vulnerability we no longer say it is on the whole not high, but It is set high in a degree of membership of 0.5. That is 0.5 would be correct to say that you have a high vulnerability. As can be seen, the function defines a set belonging Fuzzy. This comes to be understood as an input to the system established with a domain generating a specific grade of membership.

However, the perception of the variable fuzzy logic allows us to combine multiple subject categories. So, for the variable risk vulnerability there will be low, medium, high categories. For each category there will be a membership function. An example of this will be below.

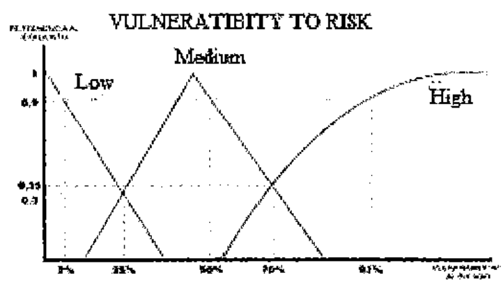

Figure 4. Function Vulnerability categorized variable irrigation.

In Figure 4, the function categorized, in which a specific event may be included within two categories exemplified. Vulnerability of 25% can be understood in two sets with a 0.3 belonged: the low set and the environment. Vulnerability 70% can be understood as high or medium with a membership of 0.35. Because of this we can create new scenarios of reasoning.

This leads us to believe if necessary and / or desirable to categorize the variables so as to obtain a function categorized rather than a simple? What variables can be categorical? How to define these categories? And even more importantly, how to define functions belonged depending on the variable?

On the issue of risk it is very important to understand that both affect a decision. Moreover, in areas where public-private partnerships, apart from having to see who takes the risk and the percentage, the quantification of this and belonged in the allocation. Therefore, each process variable is intended to model under fuzzy logic has to first go through a process of "fuzzification" that will allow us to develop operations and parameters analysis under the same logic. That is, a normal variable you want to reach fuzzy variable characteristics.

3.1 Fuzzy number and fuzzy set

First, a set of elements in which the degree of membership is continuous and abrupt, is called fuzzy set. Similarly, a fuzzy number is set. This, however, must be convex and regular; you must have a continuous function and sectioned membership. Fuzzy numbers are generally triangular, as seen in the example above: A triangular fuzzy set can be the means allocation in the example of vulnerability to risk. His fuzzy number is given by [10/45/80] all in percent.

Other concepts to consider are the core, the lower support and the upper support. For this case, the core corresponds to the value 45% and has a membership of 1, and supports the values 10% and 80% respectively belonging 0. Another common way to find these kinds of numbers is the keystone; these are not already defined by three but by four values. These will define the larger base with a zero belonged and belonged with a smaller base 1.

3.2 Fuzzy Order

The ordering of fuzzy numbers is the greatest difficulty when performing arithmetic operations or generate conclusions. Clearly with the naked eye, two triangular numbers are impossible to compare if they share a range of values. In the following chart, we show an example of a quantitative analysis of risk quantification, we have two triangular fuzzy numbers and we want to know which of these two numbers is greater.

To accomplish this, there is a method of the centers of gravity, which is to determine the centroid of each of the triangles and compare them. This centroid corresponds to the center of mass number, which can be applied to any type of fuzzy number and it is not triangular.

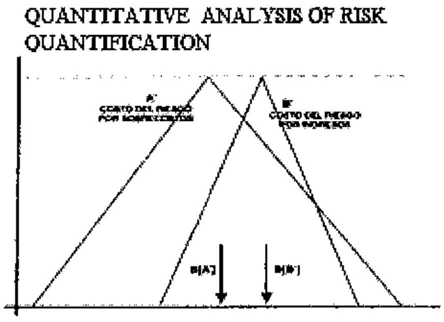

Figure 5. Example diffuse management

Supporting the idea above, normal or sharp numbers are a special case of fuzzy logic, as was mentioned previously. In these numbers the core and the supports coincide.

For the example, although the number A 'has a higher top bracket, the centers of gravity of the triangular numbers do not lead to the conclusion that the cost of risk is greater than the cost income over costs.

3.3 Steps to risk management using the concept of fuzzy variables for the validation of information

Below will be shown as each of the previously mentioned steps for the proper use of risk can be seen from a fuzzy plane.

3.4 Identification: Typology of assessed risks in quantitative analysis.

Within the current methodology of analysis, risks are divided into two groups: on one side are the costs of risk of cost overruns, corresponding to the deviation of the investment costs; and secondly the risk of hospitalization costs corresponding to the deviation in the expected revenue. (Ministry of Economy and Finance of Peru, 2014)

These two kinds of risk are what we call as direct financial cost risk of diversion. This is the first approach to identifying risks public-private partnerships. Generally the costs associated with income risk are taken by the public body; And for purposes of the methodology that should always be made and supported by the public sector. An example of this is the fact that the public sector ensures a minimum rate of vehicles per year traveling on a road made in the form of PPP. Therefore, it is stricter than the rules established by income customers must be made and secured to the private sector from the public.

For the risks of cost overruns must first perform a literature review that includes the study of projects in other countries, which have already been detected, analyzed and categorized into different kinds of risk.

From this shortlist of good risks reported in past studies must make a selection to identify which of all these risks, literature, are more relevant to the national level, for social infrastructure and for future allocation and quantification. In this order of ideas, the dispute moves to identifying the risks of cost overruns, in which engineering risk, bad weather, public policy and others are included.

It is important to emphasize "systematic risk management enables early detection of risks and encourages PPP stakeholders to identify, analyze, quantify and respond to the risks and take measures to introduce risk mitigation policies". (Akbiyikli & Eaton, 2004) An approach to the screening of the risks presented by a project under the PPP mode evidence is presented in Table 2. This identification work is summarized from a literature search to a selection process through a multi-criteria selection or MAUT.

For this selection we should identify the different risk categories that mainly influence the risks associated with operating, legal risks, risks from natural events, risks of social and cultural factors and uncontrollable risks from macroeconomics. All these groups are going to have in all events associated with cost overruns.

To establish the risks to be assessed, quantified and assigned, a project must recognize the principles and factors that influence the equitable allocation of risks APP Projects (Xu, Yeung, Chan Chan, & Wang, 2010). It must be taken into consideration that this identification affect either medium or long-term economic stability of the project, the strength and the tax base and the scope and impact of the project.

Once the pre selection has been made based on "best practices" and review of the literature, a technical level review must be conducted by a panel of experts to verify the validity of these risks on projects associated with the national situation. For which they should introduce a series of questions in order to verify which of the identified groups has greater influence on each project to be assessed. The experts will give a quantitative value from 1 to 5, where 1 corresponds to a group that does not have any influence and 5 to a group that strongly affects the project. Following this evaluate each event affects both identified belonging to the group using the same quantitative criterion.

Once these subjective values have been stablished, because they come from a personal opinion a fuzzy logic validation should be performed. This will lead us to find the value associated with the vulnerability of the project to each event and risk group using the methodology of "defuzzification" of barycenter's. With the previous result we will know what are the real risks to be considered for allocation. This identification process should be a part of a database that both the public sector and the private sector have for any project, whether it is a school, a hospital, a highway, or a government building.

3.5 Assignment: Application of fuzzy logic in the current model

The mapping process should be run from an academic background in order to ensure the validity and transparency of the risk equitably. Therefore the first thing to be done is to find patterns and mapping projects in other countries, such as assuming a theoretical panel of experts. It will assess and identify at least 10 times the allocation of a specific risk for other projects in order to have a representative base dice.

This process should be performed observing projects corresponding to the same type of infrastructure. Once you have this review, the result of this will be taken into account as part of the real expert panel, consisting of engineers, economist, and administrators. This new panel of experts should, in its sole discretion, assign to 1-5 risk to each party; 1 corresponds to a whole risk associated with the public sector, the value 5 corresponds to an assumed entirely by the private risk and a value of 3 corresponds to a risk assumed alike. (Chang, Jimenez, McAleer, & Pérez, 2011)

The validation of these opinions will be performed using fuzzy logic. Using the centroid again reach a value assignment for each of the associated risks. Based on these opinions we will get the fuzzy number vertices. From there all alpha cuts are calculated.

The center of gravity, which in this case corresponds to the value 1.87, is calculated. Corresponding rule 3 to approximately 80% allocation for the public sector and 20% private. Once the academy has reached a value of allocation should be socialized with stakeholders. Each party must be able to assume the risk percentage by value of quantification.

3.6 Measurement: Application of fuzzy logic in the current model.

Once the assignment has been made, you begin to speak of retained risk (public sector) and transferred risk (private sector). At this time, the current methodology introduces the concept of public private CPP or comparator. This is an element of analysis of revenues and costs required by law and regulated by the National Planning Department in 2014.

Measurement, attempts to quantify the impact that affects the cost of the project investment. For this you must keep in mind two scenarios: the first one is where it is assumed that the risk does not occur and where the expected value of the project cost is about zero. In the second scenario, the risk occurs with an estimated probability and the associated loss is a factor (fraction) between zero and one of the investment cost (CI). Therefore, the value associated with the project cost overrun in a given risk, taking into account the two scenarios is equal to the product of the probability factor and together with IQ. (Ministry of Economy and Finance of Peru, 2014)

E (on cost) = β * P * CI (occurrence of risk)

However there will always be controversy about the factor to use for each risk and the likelihood of risk. These values, according to the methodology proposed must be extracted through two processes. The first is the review of projects, previously selected and classified according to their type, which will form a guide of good practices that will be the starting point of our analysis. First you should evaluate projects from different countries to Colombia with great power in the field of infrastructure projects PPP mode. These countries are Chile, Mexico, Peru, United Kingdom, Australia and China, as they have found in this investigation.

Analyzing these projects should find the rate of occurrence of each risk assigned. Likewise you have to keep track of the percentage cost overruns on each CI I entail. Once the data is available, and the sample is representative for the type of project to be analyzed we should perform a statistical analysis to see the spread of the data and to validate them. Once this analysis is obtained and data validity checks, these are modeled on fuzzy numbers, following the model presented in the allocation. Subsequent to this review, you should check for similar projects already undertaken at the national level. If there is need to perform the same analysis with external projects.

Now the second process for risk measurement is performed through a panel of experts. Which must establish a professional approach and an analysis of the project it is the probability of occurrence of risk and budgetary factor involvement. These subjective values of each expert be validated by fuzzy numbers. They also correlate with those found in the literature search. In order to reach a unified consensus value range of each parameter.

Now this expected value should bring this value to perform the proper analysis taking into account the value of money over time. However, this discount rate with which it is done must be projected inflation. This process must also find the factors of each risk analyzed in order to determine patterns of error. These error patterns form the guide of good practices for projects in Colombia.

4 Conclusions

A base for future development of the country lies in the development of its infrastructure. There is currently a strong impetus to the construction of road infrastructure; however it is necessary to encourage private and public initiative towards the implementation of social infrastructure projects. A fundamental part of this is the regulation of identification standards, allocation and measurement of the risks associated with such projects. Colombia currently has no specific and clear rules to regulate the methodology of these three concepts. Therefore an approach to a new equitable and transparent methodology for risk management does believe that Colombia could become one of the most developed region in terms of social infrastructure countries.

Finally, it is up to the academic to be the mediator in all the interests of both parties (public and private). Fuzzy logic, like many academic data validation tools can handle capturing subjective data, which is necessary for these cases. To achieve a correct and complete risk management public-private partnerships would be the main engine of social development in the country for the coming years, as seen from the construction sector.

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Risk Assessment Proposal for Social Infrastructure through Public-Private Partnerships in Colombia

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Abstract

The implementation of Public-Private Partnerships (PPP) has provided an opportunity to cover the need for investment on social and economic infrastructure. The success achieved with the development of PPP projects on countries such as Australia and the United Kingdom, has established a significant start point for countries like Singapore, China and Mexico. International experience and many studies have identified that the viability and success of PPP projects in social infrastructure depend on two main factors: a strong public policy and adequate risk management among participating parties. This research presents a methodological proposal for risk allocation in social infrastructure projects in developing countries, adapted to the especial characteristics of the Colombian context, partially filling the existing gap in scientific literature. This paper is divided in two parts. First, the authors argues the benefits of creating, and establishing a national public policy based on the legal implementation and development of PPP projects in the pursuit of economic, social and environmental prosperity. Finally, this study presents a proposal for the creation of a reliable and practical model to achieve an adequate risk allocation for social infrastructure, based on the selection of 17 critical risks using the multi-criteria decision method and the design of a structured interview for experts in different contexts.

Keywords: Public-private partnerships, social infrastructure, risk management, national strategy

1. Introduction

The scheme of Public Private Partnerships (PPP) has been presented as an opportunity to bridge the gap of infrastructure deficiency without compromising national resources, obtaining more efficient and higher quality projects. Especially, PPP is the provision of a public service by a distribution of responsibilities and risks between a public actor and a private actor. Since its implementation in 1992 in the UK, 193 countries around the world have implemented and accomplished projects under this scheme (Chou & Pramudawardhani, 2015). This worldwide application of PPPs has been used in a variety of projects ranging from energy supply projects (Pongsiri, 2004), to telecommunications and subsidized housing (Efficiency Unit, 2003). However, given its complexity and nature, its implementation has not always been successful.

One of the main causes of failure is the improper risk allocation management. (Efficiency Unit, 2003).

The implementation of PPP schemes in emerging economies has been slow due to diverse political, social and economic factors. In Latin America it has been specially difficult as a result of: (a) political instability in the region, (b) the challenging assimilation process of changes to the traditional status-quo, especially given to the presence of private operators in the provision of public services, and (c) the high risk premiums demanded by private participants in the development of projects due to high initial investments, distant cash flow incomes and the country economic risk (Engel, Fischer, & Galetovic, 2008).

Although there are many studies in risk management for PPP, in the analyzed literature, no studies were found which evaluated the risk allocation for social infrastructure in developing countries. Therefore, to partially fill this gap, the authors propose a risk allocation methodology for social infrastructure projects in developing countries, adapted to the Colombian context.

This exploratory research is divided in two stages. The first one follows a PPP qualitative approach which is based in a comprehensive review of related literature and the identification of the most relevant risks in the PPP projects. Stage two follows a quantitative approach for risk identification thoroughly an analysis of the Colombian context. The risk selection process was conducted through two steps. (1) Pre-selection of most relevant risks in literature choosing those that appeared in 5 or more studies. (2) A final selection was made by the method of Multi-Attribute Utility Theory MAUT. For each risk, 5 criterions were analyzed and objectively quantified when possible and subjectively qualified by experts on a scale of 1-9: (A) Scientific literature relevance. (B) National impact, (C) Applicability to social infrastructure (schools, hospitals, government buildings, plant sewage treatment, etc.), (D) Public-private relationship and allocation, and (E) Value For Money (VFM) impact (Economic viability for the public sector). Finally, a proposal for risk assessment is made to allocate the identified and qualified risks.

To introduce this proposal properly, section 2 deals with the advantages of PPP as a strategy for growth and improved competitiveness and the specific issue of social infrastructure development. Section 3 illustrates the state of the art for risk management in PPP. Section 4 gives an introduction to the Colombian context. Section 5 exposes the proposal of risk allocation and finally conclusions, limitations and future extensions of the research are drawn.

2. Public Private Partnerships

The collaboration between public and private sector has been materialized in the concept of Public-Private Partnerships (PPP) that are related to the contractual cooperation between public authorities and various private agents to achieve objectives for the public goods provision and its corresponding services. According to the World Bank (2012), PPP have four characteristics and relevant principles: a) Projects with a long-term development, b) Private investors participates in the financing of the project, c) The private investors is responsible for the infrastructure maintenance and operation, d) The relationship between the public and private parties must establish an appropriate risks distribution.

There are three advantages in PPP contracts implementation (CAF, et al., 2010): a) Technical innovation due to the competition between proponents and the inclusion of the private agent in the design, construction, financing, maintenance and operation of the project, b) The private sector investment in social infrastructure set free the public budget for other types of investments, c) Improvement in the project quality due to strong monitoring and evaluation from public institutions.

However, the main opponents of the PPP procurement system identifies two disadvantages for its execution (CAF, et al., 2010): a) PPP transaction costs are higher than transaction costs generated by traditional public project, b) The PPP require greater financial cost compared to a public project financing through public project.

National infrastructure, both physical and digital, is an important instrument of social interconnection (CAF, et al., 2010). It has the ability to integrate space, improve accessibility and make certain the equality on populations. A good infrastructure guarantee of international competitiveness, job creation and economic stability. Yescombe (2007) Identified two infrastructure types: a) Economic: Describe all assets or property that aims to provide a function and economic activity. E.g. road, canals, and railroads, b) Social: Infrastructure dedicated to provide a public service with social purposes. This projects are usually smaller in scale and, therefore, tend to be complex, given the close and ongoing involvement with the community (Jefferies & McGeorge, 2009).

There is a confrontation of opinions on the purpose of carrying out projects under the scheme PPP. For example, Leone (1999) establishes that PPP projects are a "words game" created by the leaders to hide the privatization of assets and present an "attractive idea to the voter's minds". On the other hand, McGeorge (2009) establishes that PPPs are a funding mechanism for the public sector where the private sector assumes responsibilities and risks. Although the discussion is also presented in economic infrastructure, the development of PPP projects in social infrastructure increases and amplifies the discussion. This is mainly due to the presence of a private operator in the provision of public services which are directly related to the person, because it makes it particularly difficult to accept by the user and citizen. Jefferies & McGeorge (2009) identify this discussion as one of the primary constraints to the development of PPP projects in social infrastructure as "private-sector bidders are often presented with a situation where the financial rewards are less and the operational demands are more complex than for hard economic PPP projects".

3. Risk management in PPPs

As mentioned by Seldon Global SC (2014) , "the key to understanding the role of risk in a PPP is the link between the way in which the risks are managed and the degree of efficiency achieved in the projects". The development of a public-service project whit private participation requires it to assume certain responsibilities to ensure the quality and continuity of the service. The transfer of risk to the private agent is the most appropriate way that it assumes responsibility for the project development. However, this also means that the private sector have to effectively minimize their risks, get a maximization of economic benefit, considering that the materialization of risks results in high costs and potential economic losses. Accordingly, risk quantification and allocation determined the economic viability of the project and the benefits obtained by the government for developed the project through the PPP scheme. Therefore, as shown, risk management plays a key role in all stages of project development, from planning to operation and maintenance.

Cases such as Indonesia and Thailand, reflect the importance of proper risk management. In those, the increase in economic rates, regulatory changes and land acquisition did not allow the private party development the project properly and the project had high economic costs and created absolute mistrust between participating sectors (Ogunlana, 1997). On the other hand, cases such as Hong Kong and the United Kingdom are a clear example of successful implementation of the PPP scheme, Bing, et al (2005) argued that the high success rate of PPP in the UK was due to effective risk allocation caused by the properly communication between the parties involved on.

Finally, risk management defines competitive advantage of a private proponent within the local market. Basically, experience, innovation for cost reduction and the perception of risk assumed by the private agent are the factors that will define the competition for the development of a proposal for allocation risk in social infrastructure PPPs.

4. Colombian context

Latin America and the Caribbean have shown an increasing economic growth since the beginning of the millennium, demonstrating its solid growing potential. This is often encouraged by the development of infrastructure projects as it provides the means for increasing national competitiveness and directly improves employment rates. The growth rates of these emerging economies reached 10.5% and 9.0% respectively (Inter-American Development Bank, IDB, 2008).

In the Colombian context, the National Competitiveness Report (Private Council on Competitiveness, 2014) shows a current worrying situation in the country weakening from 68th place among 139 countries to 66th place among 144 countries. Despite the successful growth of the Colombian economy in the last decade and the implementation of programs of social and economic development (seventh place in Latin America), Colombia is so far away from the goal set for 2032, in which it was intended to be the third most competitive economy in Latin America. This may be the evidence that the country is in a development stage and that the infrastructure development instruments have not been appropriate to achieve a more competitive economy.

The most concerning issues the country should focus on, obtained from the Private Council on Competitiveness (2014) are: a) Health and elementary education: In this issue Colombia has fallen 26 places since 2010 and is currently ranked 105th worldwide and 14th in the region. As mentioned above, human capital is one of the bottlenecks in productivity in Latin America, especially in Colombia. For example, the coverage of elementary education is a great concern. That is to say, it is not just a quality problem regarding teachers training, it is also educational infrastructure coverage, access to it and therefore, financing of it. The main issue with the health system is it is difficult to access and of low quality. b) Efficiency of the employment market: The country is currently ranked 84th worldwide (15 places down from 2010), this element is directly related to regulatory and legal subjects around minimum wage laws and tax issues. c) Infrastructure: The country is currently ranked 84th in the world in reference to this issue, with more than 30 stalls difference with Uruguay, the country with the third most competitive infrastructure in Latin America. Beyond the lack of road, rail, port and airport infrastructure, Colombia has deficiencies in sectors such as energy supply, where it is identified that the main constraints are the efficiency of the industry and regulation of the sector. Nowadays it is developing the structure of the fourth generation of road concessions, where it is expected to reduce the deficit of road infrastructure. d) Innovation: This pillar has lost 12 positions, reaching 77th place in the world and ninth out of 13 Latin American countries in 2014, this is worrisome because the country has 346 investigators per million of citizens. According to the World Management Survey (World Bank, 2014), the country is the worse qualified in terms of quality management in Latin America, the central problem of this issue is the absence of a medium and long-term public policy. According to the Private Council on Competitiveness, "the country still lacks an effective structure that allows to align the different public and private stakeholders in initiatives that generate productivity and sophistication of national production through the use of local competitive advantages” (Private Council on Competitiveness, 2014).

Devlin and Moguillansky (2009) identified different countries that achieved during 2003 to 2012, closing the income gap compared to richer countries in more than ten points. This was the case of Spain, Finland, Ireland, Korea, Singapore, Australia and New Zealand. Despite their difference, several important similarities for obtaining these national achievements in economic progress were identified. Mainly, the remarkable development of these countries has its basis in the formulation and implementation of a strategy in the medium and long term to promote accelerated production change. That means, establishing lines of action with specific objectives to determine and achieve international integration of the country, reduction of poverty and increased productivity, and therefore increased competitiveness. These strategies can be based on the development of multi-year plans that should have the following priorities: a) Economic stability, b) Robust tax policy, c) Solid investment rates, d) International dynamic, e) Innovation and human development, f) Conservation of national practices.

Hausmann, Rodrik and Velasco (2006) identified that due to market failures, these strategies tend to be selective because governments have limited resources to carry out projects, programs and promote resources for development. Moreover, unlike the nineteenth century where the public sector were the main sponsor of the market, nowadays the private investments dominates the production sector. Therefore, the development of countries requires cooperation between the public sector and the private sector, which allows them to "get the opportunities of social benefits and resolve the primary constraints of new productive activities" (Devlin & Moguillansky, 2009). Through a PPP scheme, the public sectors could get involved in a partnership with private sectors for the development of infrastructure.

5. Proposal for risk assessment for social infrastructure PPPs in Colombia

The proposal for risk assessment is divided into two stages. The first one stage is the risk identification and selection for the assessment process. The second stage is the proposal for risk assessment.

5.1 Risk identification and selection

Multiple previously studies have concentrated its efforts in identifying, measuring and mitigating risks process involved in developing projects through PPP. For example, Bajaj, Oluwoye, & Lenard (1997) focused on analyzing the methodologies used for identifying risks. They found the most commonly method used was the top-down strategy. This analysis makes a hierarchical list based on stages, each stage more detailed than the previous one. Another frequent method is the brainstorming process as a system for the risks identification and quantification, in which staff involved experienced engineering and senior officer’s judgment (Baker, et al., 1999). Similarly, other authors such as Bing, Akintoye, & Edwards (2005) , and Heravi & Hajihosseini (2013) have focused on summarizing the positive and extensive experience of countries like Australia, India and the United Kingdom respectively. Recent studies as those conducted by Chan, et al (2011), Hwang, et al (2012), and Wang, et al (2004) based the development of their research in countries that are just implementing the PPP scheme as China, Singapore, and developing countries such as Chile and Mexico. These researches reach similar conclusions about the need for a risk allocation model on PPP projects implementation. To achieve a risk allocation model, they run the methodology used by Bing, et al (2005) . This development is based on a questionnaire of three sections. In the first part is evaluated the personal knowledge about the PPP subject and its influence and membership within the construction industry. In the second section it is established the risk assessment asked. This is done through an evaluation system 1 to 5, wherein the scale represents: 1 = totally assumes the public sector, 2 = mostly assumes by the public sector, 3 = equally shared by public- private, 4 = mostly assumed by the private sector and 5 = fully assumes by the private sector. As a result from the preview studies, 72 risks in PPP projects were initially identified.

After the risk identification from literature review, a specific selection process was conducted through two steps:

Pre-selection from repetition in previous studies: the type of risks that had been previously studied in different countries was analyzed and summarized by recording the frequency in which each risk appeared in one of the studies identified. The risk that appeared in more than 5 studies was pre-selected. Thus, 27 definitive risks where selected to be quantitatively categorized.

Table 1: 72 Risks identified on the literature review

RA1	*Unstable government*	*RA19*	*legal/regulatory framework*	*RA37*	*High finance costs*	*RA55*	*Technological risk*
RA2	*Expropriation of assets*	*RA20*	*contract variation*	*RA38*	*Residual risk*	*RA56*	*Operation default*
RA3	*Poor public decision-making*	*RA21*	*Immature juristic system*	*RA39*	*Delay in project approvals*	*RA57*	*Organization and co-ordination risk*
RA4	*Strong political opposition/hostility*	*RA22*	*Improper of contract*	*RA40*	*Design deficiency*	*RA58*	*Inadequate distribution of risks*
RA5	*support from government*	*RA23*	*standard model for agreement*	*RA41*	*engineering techniques*	*RA59*	*distribution of authority*
RA6	*Corruption and bribery*	*RA24*	*Inability of concessionaire*	*RA42*	*Scope variation*	*RA60*	*Differences in working method*
RA7	*Government's intervention*	*RA25*	*private provision of public services*	*RA43*	*Workmanship*	*RA61*	*Lack of commitment from either partner*
RA8	*Government's reliability*	*RA26*	*Level of public opposition*	*RA44*	*Construction cost overrun*	*RA62*	*Private investor change*
RA9	*government support network*	*RA27*	*Market demand change*	*RA45*	*Construction time delay*	*RA63*	*Third Party Tort Liability*
RA10	*Termination of concession*	*RA28*	*Force majeure*	*RA46*	*Material/labor availability*	*RA64*	*Staff Crises*
RA11	*Inflation rate volatility*	*RA29*	*Geotechnical conditions*	*RA47*	*Poor quality workmanship*	*RA65*	*Competition (exclusive right)*
RA12	*Interest rate volatility*	*RA30*	*Weather*	*RA48*	*Insolvency of sub-contractors*	*RA66*	*Tarif change*
RA13	*Influential economic events*	*RA31*	*Environment*	*RA49*	*Site safety and security*	*RA67*	*Payment risk*
RA14	*Foreign exchange and convertibility*	*RA32*	*Land acquisition)*	*RA50*	*Operation cost overrun*	*RA68*	*Lack of consortium expertise*
RA15	*Financial risk*	*RA33*	*Uncompetitive tender*	*RA51*	*Operational revenues*	*RA69*	*Subjective evaluation*
RA16	*Legislation change*	*RA34*	*experience in PPP projects*	*RA52*	*Low operating productivity*	*RA70*	*Insufficient financial audit*
RA17	*Change in tax regulation*	*RA35*	*Availability in finance*	*RA53*	*Maintenance costs higher*	*RA71*	*Construction/operation change*
RA18	*Industrial regulatory change*	*RA36*	*Financial attraction*	*RA54*	*Maintenance more frequent*	*RA72*	*Intellection property*

Final selection, Multi-Attribute Utility Theory MAUT: Each risk was analyzed on the basis of 5 criterions, objectively quantifying them when possible and subjectively qualifying them by a pool of 6 experts in a focus group session. A percentage weight was assigned to each criteria and each risk was evaluate against every criteria through a scale of relevancy 1 to 9.

A. Scientific literature relevance: frequency of appearance previously outlined was taken into account. For this criteria was defined a weight of 25%.
B. National impact: each risk is placed within the national context. That is, the applicability to the reality of the Colombian construction industry is sought. For this criteria was defined a weight of 10%.

C. Applicability to social infrastructure: In this criterion is evaluated the degree of risk for the development of social infrastructure projects such as schools, hospitals, government buildings, plant sewage treatment, etc. For this criteria was defined a weight of 20%.
D. Public-private relationship and allocation: This criterion aims to capture the concerns about risk allocation. That is to say, questions whether the risk has a tendency to be adopted by default to any of the (public or private) agents or risk allocation is a real unknown quantity. This section was given a special importance because these are the risks that the study aims to concentrate. For this criteria was defined a weight of 20%.
E. Value For Money (VFM) impact (Economic viability for the public sector): Since the risks are significant in the economic analysis of the project and the VFM, it is taking the economic risk into the account associated with each risk. For this criteria was defined a weight of 25%.

After this evaluation, the importance of each risk was calculated as the sum of the multiplication of the percentage weight by the scale of relevancy. Thereafter, the average of the all risks weight was determined. Finally, 17 risks were located over the average and these were selected as the most relevant risks that affect the successful implementation of PPP on the issue of social infrastructure projects these risks are presented in Table 2.

5.2 Risk assessment proposal

Most of the studies reviewed based on the generation of a questionnaire which is directed at people with experience in the construction industry, in the public sector, private sector and academy. However, the main problem of these questionnaires is the low response rate. Roughly, the response rate is around 20% and 40% (Akintoye, 2000). Consequently, the amount of sent questionnaires needed for effective data analysis represents a serious problem. Additionally, it is not always possible to guaranty the reliability and quality of responses. Therefore, it is often proposed to conduct a number of structured interviews to characters with high experience and knowledge on PPP in the specific context where the risk management process is taking place.

The interviews have to be made to PPP experts from the academia, public sector and private sector. The involvement of academia is essential. As manifested Osipova & Erikson (2013), the best method to achieve agreement on the management of risk is with the incursion of the academic world to determine an optimal method where several opinions about risk management, are combined. Likewise, it is important to involve some private sector agents and governmental organizations who have exercised the function of regulatory body of the PPP's. Within the national framework, it is suggested the involvement of the National Planning Department, the Ministry of Finance and the Ministry of Education.

The interview will be divided into three stages, such as the questionnaire division given by Chou, et al. (2012):

The first stage involves a socialization and context with the interviewee. Initially, it will be explained to the person to conduct the study, the objectives, the methodology followed in the interview and the importance of the study. Similarly, in this part some specific data will be asked to the interviewee to evaluate the credibility of his answers in the following stages. The necessary data to request are: Sector in which works (public, private or academic), and years of work experience in construction projects and projects under PPP mode.

Table 2: Selected risks

Risk	***Group membership***	***Definition***
Expropriation of assets	*Governmental*	*Given political, social or economic pressures, the government take ownership of the project without proper compensation to private.*
Corruption	*Governmental*	*Selection and development of projects under illicit schemes and decisions to promote other interests.*
Inflation rate	*Macroeconomic*	*Unexpected and significant changes in interest rates and inflation, due to immature economy and a local non-consolidated market.*
Interest rates	*Macroeconomic*	
Legislative changes	*Legal*	*Vulnerability to a change in government regulations, including tax policies, which affect income or established project costs from the viability stage.*
Tax regulation changes	*Legal*	
Demanding market	*Social*	*Inadequate methods for determining demand stage project operation and maintenance requirement.*
Environment	*Environment*	*Public regulation with high requests on the environmental impact of the project.*
Land acquisition (availability)	*Project selection*	*Difficulty in time and / or costs to acquire the land needed for the project.*
Residual risk	*Residual*	*It reflects the probability of finding unexpected adverse situations.*
Delay in project approval and permits	*Residual*	*Difficulty in obtaining documents required for a legal framework for the proper development of the project.*
Operation cost overrun	*Operation*	*Higher costs than expected in the operation stage.*
Public private coordination	*Operation*	*Lack of coordination and coherence between public and private.*
Low experience in PPP projects	*Project selection*	*Low national experience in the development of social infrastructure projects under PPP scheme.*
Absence of a legal framework.	*Legal*	*Inappropriate or contradictory legal framework to the development of projects under PPP scheme.*
maintenance costs	*Operation*	*Higher than expected costs in maintenance of assets.*
Technological risk	*Operation*	*Project vulnerability to technological disadvantages and therefore the presence of a constant need to update.*

The second stage involves the assessment of previously identified risks. To perform this method, three important aspects must be considered. First, a dictionary of risks to ask must be prepared if the respondent does not easily recognize the applicability of risk in a PPP project. Second, it is recommended that the respondent, with the aim of further analysis, give an opinion about the role of these risks in social infrastructure and economic infrastructure. To facilitate this discussion, the risks should be asked in the context of an important project (hypothetical or real) in public politics. That is an important current project is introduced like a complex of schools or hospitals and it is compared against the development of a concessioner highway. Finally, assess their responses on a scale of 1-5, where the scale represents 1 = totally assume for the public sector, 2

= most assumes for public sector, 3 = equally shared by the public and private sector, 4 = assumed mostly by the private sector and 5 = fully assumes the private sector.

The last step is a final stage of completion where it is located different questions related to the future of PPPs in social infrastructure. For example, you can ask:

· What is the next step for PPPs in social infrastructure evolve?
· Do you believe that PPPs in social infrastructure will become of the magnitude and importance of the concession highways?
· How important is the PPP scheme to satisfy social public policies?

6. Conclusions

This study is divided into two parts. In the first part, the benefits of the implementation, develop and evolve of PPP contract scheme is exposed. Beyond the typical discussion of PPP efficiency gains and cost reduction, this study defines PPP as a government instrument to carry out projects of national importance. Given the nature and characteristics of the projects, PPP acts as a central hub for the establishment of a national policy in the medium and long term, which seeks an economic, social and environmental well-being and, ultimately, an axis of development and productive transformation.

The last part analyses the importance of risk management and the role of risk allocation through international experiences of private investment in social infrastructure. Formerly a proposal for the process of risk allocation for social infrastructure projects in Colombia is developed. In order to do so, an extensive literature review about the risks involved in the development of PPP projects was made. In this research, a list of 72 risk was obtained on the basis of their relevance in reviewed literature and subsequently narrowed down to 17 critical risks using multi-criteria analysis. Five evaluation criteria were used: frequency of appearance in reviewed literature, national impact, criticality in social infrastructure, public-private definition and economic impact.

Lastly, an expert opinion evaluation to effectively allocate risks is suggested. Given the low response rate of questionnaires, the development of semi-structured interviews to a selected group of experts from the industry, the public sector and the academy is proposed as an alternative.

For the purposes of validating and enhancing this model, it is suggested that further research focuses on the selection of a representative project sample in Colombia to implement the risk allocation process proposed in this research and evaluate the feasibility of the development of this type of projects under the PPP scheme on the basis of the concept of Value For Money. The resultant adjusted proposal should be implemented in Colombian social infrastructure policies.

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Clients' Perception on Risk Sharing in Construction Projects

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Abstract

Risk Sharing is a concept of equitable allocation of identifiable and quantifiable risks at pre-contract stage, followed by their dynamic management at post contract stage, for which general/flexibility provisions should be made in the contract conditions, because not all risks are foreseeable/predictable and/or quantifiable at the planning stage. Moreover, risks may change with project progress: some risks may become more critical, some other risks may disappear, while some other risks may need some degree of joint efforts of contracting parties for their effective management. The objective is to minimize the risk and total cost of risk to a project, not necessarily the costs to each party separately. On the basis of such conceptualization, the present paper summarizes the outcomes of a questionnaire survey that examined the perceptions of 48 respondents from construction clients in Brunei on present and preferred sharing of 28 common risk items, as well as the criticality (or severity index) of those risk items in terms of their importance and frequency of occurrences. The respondents have considerably differing perceptions of risk allocation, with extreme divergence in most of the risk items. Despite such divergence, respondents have demonstrated a general enthusiasm towards shared or joint management of risks as they opted for about 18-53% of expected shared risks. Three risk items were identified as 'most important' in terms of their importance index, with the most of the remaining risk items are 'more important'. No risk item was verified as 'most critical', but most of the items were 'more critical'. Moreover, there seem to be no clearly identifiable relationship between the degree of risk sharing and critical index of the risk items. The outcomes are expected to allow the clients to better formulate construction contracts to effectively manage construction risks. It is also expected to further allow a better understanding of dynamic risk management and the need for proactive contracting in construction.

Keywords: Construction industry, proactive contracting, risk allocation, risk sharing, risk importance

1. Introduction

One of the principles of risk allocation is that the party best able to manage a risk should bear the risk. However, clients are seen to exculpate risks to contractors, especially in the traditional procurement regimes, without considering if contractors can manage those risks. Contractors too assume those risks, without considering if they can manage those risks, in order to do business, and survive (Ahmed *et al.* 1999). Obviously, contractors may better manage some of the risks, but clients may better manage some other risks, and some other risks may better be shared or managed jointly by clients and contractors. The goal of optimal risk management should be to (a) "minimize risk – whomever risk it may be" (ASCE 1979), and (b) minimize the total cost of risks to a project, not necessarily the costs to each party separately (CII 1993).

Construction risks are often project specific, and allocated to different parties through definitive contract conditions, on the basis of information available at the time of contracting. However, the nature and extent of such project-specific risks can only be realistically appreciated at later stages during the project execution. The nature and extent of risks may change along with project progress. New risks may emerge and existing risks may disappear or change in importance or be re-allocated. Any such changes may also ease or aggravate some other risks. Moreover, some of the risks may occur more frequently than some others, and some of the risks may have more impact on project objectives than some others. Some of these risks may also need to be shared between contracting parties or managed using the combined efforts of contracting parties for their effective management. Therefore, proper and exhaustive allocation of risks cannot be achieved through contract conditions alone. Instead, what needs to be done, is to equitably allocate all identifiable and quantifiable risks at pre-contract stage, on the basis of available information. This needs to be coupled with some flexibility crafted in the contract documents, in order to allow proactive appreciation of any changes to those allocated risks, identify any new risks, assess or re-assess them, re-allocate and/or share those risks and jointly manage them with the collaborative efforts of major contract parties at post contract stage, using a joint risk management (JRM) strategy, and as the situation requires (Rahman and Kumaraswamy 2002).

Two previous studies in this area were conducted by Hartman et al. (1997) in Canada, and Rahman and his collaborators in Hong Kong (Rahman 2003, Rahman and Kumaraswamy 2002, 2004). The Canadian investigation compared perceptions on present and preferred allocation of risk. In addition to that, the Hong Kong study addressed attitudinal aspects of contract parties towards the suitability of any shared parts of any risks leading to a probable JRM model. The present study goes further from these two studies and investigates both present and preferred risk sharing arrangements between client and contractor, as well as attempts to assess criticality of various risk items in terms of their frequency and impact on project objectives.

2. Methodology

The overall research project was designed with literature review, and two surveys. The present paper summarises the interim outcomes of the study, on the basis of first questionnaire survey, which was focused on respondents from cliental organisations only. The objectives of this paper are twofold:

- To compare the perceptions on present and preferred risk allocation between clients, contractors, and ‘shared’ between them; and
- To assess criticality of various risk items in terms of their frequency and impact on project objectives.

Data was collected using a structured questionnaire survey. The questionnaire was carefully designed to meet the above objectives, pilot-tested by two industry experts, and improved based on the opinions obtained from the experts. There were four sections in the questionnaire. Section One included an ‘introduction’ clarifying the risk sharing concept and solicited experience based opinions of the respondents. Section Two was designed to collect respondents’ information for the survey sample composition. Section three contained an inventory of 28 risk items. All the 28 risk items have been shown in their entirety in Tables 2 – 5. The risk items were mainly sourced from Rahman and Kumaraswamy (2002), but adjusted to suit local situations and to meet the opinions obtained from two experts during the pilot test. Most of the risk items that were identified and verified in this manner, are also commonly reflected in standard forms of construction contracts, since risks are allegedly allocated through the conditions of contract. The respondents were requested to reflect their opinions on the above mentioned 28 risks in terms of their perceptions of present and preferred risk allocation in conventional construction contracts, i.e. what percentage of a particular risk presently lies or they prefer to be:

1. with the client (X, from 0 to 100);
2. with the contractor (Y, from 0 to 100); and
3. shared between the client and the contractor (Z, from 0 to 100); in such a way that the sum of X, Y and Z equals to 100.

Section four contained the same 28 risk items and was designed to collect information on their frequency of occurrence and importance or impact, if they occur. Respondents were asked to assess and write scores on a scale from 1 to 5: 1 being the ‘least frequent/important’ and 5 being the most frequent/important. Additional spaces, to both the inventory of risk items in sections 3-4, were provided requesting respondents to add any risk items if they think important, and to assess the same. Moreover, blank space was also kept at the end of the questionnaire to allow the respondents to provide any comments / suggestion on effective risk management in general.

Public Works Department (PWD) of the government of Brunei Darussalam assisted in distributing the questionnaire to its officers and collecting the responses from them. As such, 48 responsive responses were received, with an average total work experience of 10.13 years, and average experience directly in construction of 9.38 years, as shown in table 1. This may relate to the quality of the data, as they are considered to reflect the experiential knowledge of the respondents. During the time of the survey, respondents were working on an array of positions, and with various kinds of managerial (e.g. project manager, assistant project manager, quantity surveyor, site supervision, and contract manager) and engineering type of responsibilities (e.g.

structural designer/ engineer, architects, architectural designer, and quantity surveyor). There were 17 engineering, and 29 managerial respondents. Two respondents did not mention their designation and/or nature of job. The data may therefore be considered to represent the public sector of Brunei, both in terms of coverage of works related to public services, and types of job, i.e. nature of experience of the responses.

Table 1: Summary of respondents' profile

Description of information	*Total sample*	*Engineering*	*Managerial*
Responses received	*48*	*17*	*29*
Average Total work Experience (years)	*10.13*	*9.38*	*10.57*
Minimum work experience (years)	*1*	*1*	*1.4*
Maximum work experience (years)	*27*	*25*	*27*
Average experience in construction (years)	*8.33*	*8.06*	*8.5*
Minimum experience in construction (years)	*1*	*1*	*1*
Maximum experience in construction (years)	*27*	*25*	*27*

3. Perception of risk allocation

Responses on risk allocation directly indicated the percentages of risk related to each risk item that is perceived to lie with the client, contractor and shared between them. The analysis was done by arithmetically averaging these figures for each risk item, separately within the total sample of 48 responses, as well as within each group based on nature of job (e.g. engineering and managerial). However, this paper presents summary results only, hence only the outcomes from the total sample are presented.

Table 2 shows perceptions of risk in percentage terms that presently lies with clients for the total sample of 48 responses, along with the respective standard deviations (SDs), minimum scores and maximum scores. It is seen that, except for the two risk items, minimum scores for all the risk items are zero, meaning clients are not allocated any risk on these items. On the other hand, 17 risk items have 100% scores, meaning clients have the entire amount of risks of those items. The maximum score of the remaining 11 risk items vary from 50% to 90%. On the whole 16 items have extreme divergence (i.e. minimum zero and maximum 100). Such diverse minimum and maximum scores produced averages from 19.0% to 52.1%, along with high standard deviations (SDs), which in turn also indicate a wide spectrum of responses. Although not shown here, similar pattern of responses (i.e. general diversity with extreme divergence on most of the risk items) was observed for the rest of the options on risk allocation, both for present allocation and preferred allocation. Such a widespread divergence within the same contract party (i.e. client) may relate to their superficial involvement in preparing and managing contracts, and resulting in to a kind of subconscious demotivation or disinterest, as consultants prepare and manage contracts for them. Such divergence may well arise from varied personal experiences and therefore highlight a need for cooperative learning as well.

Table 2: Average perceptions of present allocation of risks with clients (in % terms)

Risk ID	*Risk description*	*Average*	*SD*	*Minimum*	*Maximum*
F-01	*Acts of God/nature*	*39.7*	*35.2*	*0*	*100*
F-02	*Change in scope of work*	*43.9*	*23.2*	*10*	*100*
F-03	*Change order evaluation & negotiation*	*39.5*	*15.6*	*10*	*80*
F-04	*Changes in codes and regulations*	*32.7*	*23.3*	*0*	*100*
F-05	*Discrepancies / Conflicts in documents*	*29.5*	*19.8*	*0*	*80*
F-06	*Contractor competency*	*32.0*	*26.6*	*0*	*100*
F-07	*Cost of legal processes*	*31.2*	*23.8*	*0*	*80*
F-08	*Defective design*	*51.9*	*26.5*	*0*	*100*
F-09	*Long lead time / Delay in payments*	*35.1*	*24.9*	*0*	*100*
F-10	*Delays in resolving contractual issues*	*52.1*	*23.2*	*0*	*100*
F-11	*Delays in resolving disputes*	*45.9*	*20.0*	*0*	*100*
F-12	*Environmental hazards (project area)*	*39.7*	*28.5*	*0*	*100*
F-13	*Financial failure of client (Owner)*	*40.3*	*30.5*	*0*	*100*
F-14	*Financial failure of contractor*	*41.1*	*30.6*	*0*	*90*
F-15	*Indemnification and hold harmless*	*33.5*	*26.6*	*0*	*100*
F-16	*Inflation and exchange rates*	*25.3*	*27.4*	*0*	*90*
F-17	*Labor quota / problems*	*19.0*	*15.8*	*0*	*50*
F-18	*Availability of equipment*	*25.0*	*21.5*	*0*	*80*
F-19	*Labor and equipment productivity*	*17.9*	*17.8*	*0*	*70*
F-20	*Material and equipment quality*	*30.8*	*24.6*	*0*	*90*
F-21	*Permit and ordinance*	*26.2*	*21.5*	*0*	*100*
F-22	*Quality of work / Workmanship*	*49.7*	*32.8*	*0*	*100*
F-23	*Safety at site / Health & Safety*	*21.1*	*16.5*	*0*	*80*
F-24	*Site access upon contract award*	*36.5*	*32.6*	*0*	*100*
F-25	*Subcontractor failure*	*23.4*	*21.4*	*0*	*100*
F-26	*Third party delays*	*32.8*	*29.1*	*0*	*100*
F-27	*Unforeseen site/ ground conditions*	*37.1*	*19.6*	*0*	*100*
F-28	*Availability of materials*	*31.3*	*28.6*	*0*	*95*

Table 3 shows the difference between average ‘present shared’ allocation with that of ‘expected shared’ allocation, along with the ranks for differences in shared allocation. Negative sign indicates increase in allocation. All the risk items are seen to have increased in ‘shared allocation’ of varying degrees. Nine items (ranks 20-28) are seen to have increased shared allocation of risks by less than 10% only. However, 13 (ranks 7-19) items increased by 10-20%, and remaining six items (ranks 1-6) increased by 21-30%. These increases occurred from reduced expected allocation either to both parties; or to one party but with resulting reduced expected allocation.

Table 3: Comparison of present and expected risk allocation

Risk items	*Expected allocation*		*Difference between present and expected allocation*	
	Shared	*Rank*	*Shared*	*Rank*
F16: Inflation and exchange rates	*51.1*	*2*	*-24.5*	*1*
F15: Indemnification and hold harmless	*53.0*	*1*	*-24.2*	*2*
F02: Change in scope of work	*37.0*	*8*	*-23.8*	*3*
F05: Discrepancies / Conflicts in documents	*46.3*	*4*	*-23.8*	*4*
F27: Unforeseen site/ ground conditions	*39.6*	*5*	*-21.6*	*5*
F21: Permit and ordinance	*38.8*	*6*	*-21.1*	*6*
F13: Financial failure of client (Owner)	*35.5*	*9*	*-19.6*	*7*
F20: Material and equipment quality	*33.6*	*13*	*-19.5*	*8*
F28: Availability of materials	*33.4*	*15*	*-18.0*	*9*
F17: Labor quota / problems	*30.2*	*17*	*-17.6*	*10*
F03: Change order evaluation & negotiation	*34.7*	*10*	*-17.1*	*11*
F04: Changes in codes and regulations	*49.6*	*3*	*-16.0*	*12*
F22: Quality of work / Workmanship	*27.4*	*21*	*-15.0*	*13*
F09: Long lead time / Delay in payments	*30.6*	*16*	*-15.0*	*14*
F18: Availability of equipment	*27.3*	*22*	*-14.3*	*15*
F19: Labor and equipment productivity	*26.9*	*23*	*-13.9*	*16*
F24: Site access upon contract award	*28.7*	*19*	*-13.0*	*17*
F23: Safety at site / Health & Safety	*25.6*	*24*	*-12.1*	*18*
F25: Subcontractor failure	*24.0*	*25*	*-11.5*	*19*
F26: Third party delays	*34.7*	*12*	*-8.7*	*20*
F08: Defective design	*27.8*	*20*	*-8.4*	*21*
F06: Contractor competency	*28.8*	*18*	*-6.6*	*22*
F01: Acts of God/nature	*37.1*	*7*	*-6.3*	*23*
F12: Environmental hazards (project area)	*33.5*	*14*	*-5.8*	*24*
F14: Financial failure of contractor	*18.3*	*27*	*-5.1*	*25*
F11: Delays in resolving disputes	*17.9*	*28*	*-4.1*	*26*
F10: Delays in resolving contractual issues	*19.7*	*26*	*-2.9*	*27*
F07: Cost of legal processes	*34.7*	*10*	*-0.1*	*28*

‘Expected shared’ allocation of risks are seen to range from 17.9% to as high as 53%. On the whole, two risk items are seen to be shared by above 50%, two risk items by 40-50%, 13 risk items (ranks 5-17) by 30-40%, eight risk items (ranks 18-25) by 20-30% and three risk items are by less than 20% with the least one of 17.9%. Such a higher degree of expected sharing of risks may indicate respondents’ general enthusiasm towards joint management of risks in general, which might have been influenced by elsewhere, or simply form their consciousness. This may be indicative of attitudinal changes of the public sector towards embracing ‘modern’ contracts.

4. Criticality of risk items

Table 4 summarises the count of responses on ‘frequency of occurrences’ of the risk items that was asked in section four of the questionnaire.

Table 4: Count of responses on frequency of occurrence

Risk Items	*Count 1*	*Count 2*	*Count 3*	*Count 4*	*Count 5*
F01: Acts of God/nature	*13*	*14*	*9*	*10*	*2*
F02: Change in scope of work	*1*	*5*	*17*	*13*	*12*
F03: Change order evaluation & negotiation	*6*	*8*	*22*	*7*	*4*
F04: Changes in codes and regulations	*19*	*16*	*11*	*1*	*1*
F05: Discrepancies / Conflicts in documents	*3*	*13*	*15*	*14*	*3*
F06: Contractor competency	*3*	*7*	*20*	*14*	*4*
F07: Cost of legal processes	*12*	*18*	*13*	*3*	*1*
F08: Defective design	*7*	*15*	*18*	*8*	*0*
F09: Long lead time / Delay in payments	*1*	*2*	*20*	*19*	*6*
F10: Delays in resolving contractual issues	*1*	*12*	*21*	*11*	*3*
F11: Delays in resolving disputes	*3*	*11*	*22*	*11*	*0*
F12: Environmental hazards (project area)	*11*	*14*	*17*	*6*	*0*
F13: failure of client (Owner)	*22*	*8*	*13*	*3*	*2*
F14: Financial failure of contractor	*4*	*4*	*23*	*15*	*2*
F15: Indemnification and hold harmless	*10*	*12*	*19*	*3*	*0*
F16: Inflation and exchange rates	*21*	*11*	*15*	*1*	*0*
F17: Labor quota / problems	*7*	*12*	*21*	*6*	*2*
F18: Availability of equipment	*4*	*13*	*19*	*10*	*2*
F19: Labor and equipment productivity	*3*	*13*	*23*	*7*	*2*
F20: Material and equipment quality	*0*	*13*	*21*	*11*	*3*
F21: Permit and ordinance	*6*	*23*	*14*	*4*	*1*
F22: Quality of work / Workmanship	*1*	*4*	*17*	*16*	*10*
F23: Safety at site / Health & Safety	*1*	*4*	*15*	*19*	*9*
F24: Site access upon contract award	*6*	*15*	*21*	*4*	*2*
F25: Subcontractor failure	*5*	*14*	*19*	*9*	*1*
F26: Third party delays	*4*	*19*	*17*	*4*	*4*
F27: Unforeseen site/ ground conditions	*3*	*9*	*20*	*13*	*3*
F28: Availability of materials	*5*	*16*	*16*	*9*	*2*

Respondents gave their opinion on frequency of occurrences, and importance or impact on project objectives, of the 28 risk items on a scale from 1 to 5: 1 being the 'least frequent/important' and 5 being the 'most frequent/important'. As such, the column labelled with 'Count 1' shows the number of respondents who scored 1. Similarly, the column 'Count 2' shows the number of respondents who scored 2, and so on. As seen from the table, all the risk items have scores from 1 to 5, except a few. Similar pattern of responses was also received for 'importance or impact' of various risk items on project objectives, using the same scale of 1 to 5. For comparison purposes, all such responses were calculated in to a single representative score of 'frequency index' (FI) and 'importance index" (II) (Lim and Alum 1995) as:

Frequency (or Importance) Index = $(5n_5 + 4n_4 + 3n_3 + 2n_2 + n_1) / \{5(n_1 + n_2 + n_3 + n_4 + n_5)\}$

where,

- n_1 the number of respondents who scored 1 or "least frequent / important",
- n_2 the number of respondents who scored 2 or "less frequent / important",
- n_3 the number of respondents who scored 3 or "frequent / important",
- n_4 the number of respondents who scored "more frequent / important", and
- n_5 the number of respondents who scored 1 or "most frequent / important".

The above two indices were then converted in to an overall index called "Severity Index" (SI), by multiplying the frequency index and importance index. The severity index was used to rank the overall implication of each risk item on project objectives.

Severity Index = Frequency Index X Importance Index.

As used in this study, FI and II $\geq$ 0.8 was considered 'most frequent / important', between 0.60-.80 'more frequent/important', between 0.4-0.6 'frequent / important', between 0.2-0.4 'less frequent/important', and $\leq$ 0.2 'least frequent / important' or negligible. For SI $\geq$ 0.64 most critical, between 0.36-.64 more critical, between 0.16-0.36 critical, and $\leq$0.16 less critical.

Table 5 shows the above three indices of 28 risk items, along with their respective ranks, arranged in order of the rank of severity index. Health and safety, change in scope of work, workmanship and delay in payments are seen as the most frequent risk items with ranks from 1-4. These are also seen as the top-ranked risk items in terms of importance indices. At the bottom of the table, ranks of different risk items in the two category are seen closer, but not exactly of same rank. For example, 'cost of legal processes' ranks 25 as per its frequency index, compared to rank 26 as per importance index. 'Inflation and exchange rates' ranks 28 in both category, but 'permit and ordinance' ranks 22 and 25 respectively. Similar pattern is also seen around the middle of the table. Thus, both the indices may be taken to be considered to form similar pattern in terms of their ranks. However, their ranges are different.

For example, the range of frequency indices is 0.729 to 0.383, compared to importance indices of 0.854 to 0.525. However, 10 risk items are seen more frequent, 16 risk items are frequent, and only two risk items are less frequent. On the other hand, three risk items are seen as most important, 21 risk items are more important and four risk items are important. These resulted in to no risk item in the category of 'most critical', but 18 risk items as 'more critical' and 10 risk items are critical.

Table 5: Comparison of criticality of different risk items

Risk item	*Frequency*		*Impact*		*Severity*	
	Index	*Rank*	*Index*	*Rank*	*Index*	*Rank*
F23: Safety at site / Health & Safety	*0.729*	*1*	*0.854*	*1*	*0.623*	*1*
F02: Change in scope of work	*0.725*	*2*	*0.821*	*2*	*0.595*	*2*
F22: Quality of work / Workmanship	*0.725*	*2*	*0.800*	*3*	*0.580*	*3*
F09: Long lead time / Delay in payments	*0.713*	*4*	*0.763*	*5*	*0.543*	*4*
F27: Unforeseen site/ ground conditions	*0.617*	*7*	*0.775*	*4*	*0.478*	*5*
F06: Contractor competency	*0.638*	*5*	*0.746*	*8*	*0.475*	*6*
F14: Financial failure of contractor	*0.629*	*6*	*0.750*	*7*	*0.472*	*7*
F05: Discrepancies / Conflicts in documents	*0.604*	*10*	*0.763*	*5*	*0.461*	*8*
F20: Material and equipment quality	*0.617*	*7*	*0.729*	*10*	*0.450*	*9*
F10: Delays in resolving contractual issues	*0.613*	*9*	*0.717*	*13*	*0.439*	*10*
F11: Delays in resolving disputes	*0.574*	*12*	*0.719*	*12*	*0.413*	*11*
F25: Subcontractor failure	*0.546*	*15*	*0.733*	*9*	*0.400*	*12*
F18: Availability of equipment	*0.571*	*13*	*0.679*	*16*	*0.388*	*13*
F28: Availability of materials	*0.546*	*15*	*0.708*	*14*	*0.387*	*14*
F03: Change order evaluation & negotiation	*0.579*	*11*	*0.663*	*19*	*0.383*	*15*
F26: Third party delays	*0.538*	*17*	*0.700*	*15*	*0.376*	*16*
F08: Defective design	*0.513*	*20*	*0.729*	*10*	*0.374*	*17*
F19: Labor & equipment productivity	*0.567*	*14*	*0.658*	*20*	*0.373*	*18*
F24: Site access upon contract award	*0.521*	*19*	*0.675*	*17*	*0.352*	*19*
F01: Acts of God/nature	*0.492*	*21*	*0.667*	*18*	*0.328*	*20*
F17: Labor quota / problems	*0.533*	*18*	*0.613*	*22*	*0.327*	*21*
F12: Environmental hazards (project area)	*0.475*	*23*	*0.654*	*21*	*0.311*	*22*
F21: Permit and ordinance	*0.479*	*22*	*0.575*	*25*	*0.276*	*23*
F13: Financial failure of client (Owner)	*0.413*	*26*	*0.613*	*22*	*0.253*	*24*
F07: Cost of legal processes	*0.443*	*25*	*0.570*	*26*	*0.252*	*25*
F15: Indemnification and hold harmless	*0.468*	*24*	*0.536*	*27*	*0.251*	*26*
F04: Changes in codes & regulations	*0.388*	*27*	*0.608*	*24*	*0.236*	*27*
F16: Inflation and exchange rates	*0.383*	*28*	*0.525*	*28*	*0.201*	*28*

A further examination indicates that the degree of criticality (i.e. rank of SI) is less likely to have any strong relationship with the degree of 'expected shared risk'. For example, a few risk items have the same or closer ranks in both category: unforeseen site conditions' and 'site access' rank 5 and 19 respectively, in both category. 'Availability of materials' ranks 14 in SI, but ranks 15 in the other category. Some factors seem to be inversely related. For example, the three least ranked risk items in terms of SI tops the list in terms of expected shared risk. They are: indemnification and hold harmless, changes in codes and regulations, and inflation and exchange rate. Factors that may be loosely considered in this group are health & safety (ranks 1 and 24), workmanship (ranks 3 and 21), contractor competency (ranks 6 and 18), third party delays (ranks 16 and 12), acts of God (ranks 20 and 7), and permits and ordinances (ranks 23 and 6). The remaining risk items seem to form no clearly identifiable pattern.

5. Conclusions

This interim report on an ongoing study attempted to estimate the present and expected risk allocation profile, and was focused on construction clients. Both incorporated a provision for risk sharing, i.e. to identify the attitude towards a strategy for joint management of risks, possibly in a teamwork based collaborative manner. It is seen that the contracting parties had inherently different perceptions, and extremely opposite in most of the cases (i.e. 0% and 100%), of both present and expected allocation of risks, although they all work for public clients. Such diverse perception might have shaped from diverse individual experiences that may be bad or good. Nevertheless, they indicate the need for a cooperative learning. Interestingly, a markedly positive attitude towards shared management of risk was observed. Most of the respondents opted for risk sharing between 18% - 53% for all of the 28 risk items used in the survey. In doing so, respondents generally reduced the present risk liabilities of either one or both of the contracting parties (i.e. contractors and clients). This may be an indicator of the long awaited paradigm shift from the existing traditional construction industry environment towards a friendly and teamwork based culture. This result seems to support the argument that most of the risks need joint efforts of varying degrees from both contracting parties for their effective management.

This survey also identified the criticality of different risk items, which lacks to have any identifiable pattern of relationships with the degree of their sharing. All these are expected to help clients to better appreciate the impacts of different risk items and suitable approaches for their effective management. The next step of this study is to extend the survey to contractors and consultants, to tap their opinion in the first place, and then identifying a set of strategies for wider adoption of risk sharing in construction.

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Extra Contractual Concerns and Their Contractual Consequences in the Near East: The Turkish Experience

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Abstract

While there seems to be a vast literature on the administration of construction contracts, we have yet to understand the complexities of extra contractual concerns and their contractual consequences, especially in the Near East. Pre-conceived biases, expectations and perceptions of obligations and intricate behavioural patterns are often the sources of confusion and poorly functioning contractual relationships.

The present paper will attempt to shed some light on some of these issues, drawing on observations of cases from Turkey and the Turkish contracting experience overseas. The method adopted can be best described as "participant observation" through the authors' intensive involvement with contractual claims as experts and consultants.

The main focus of the paper is the identification of reciprocal and one-sided patterns of contractual behaviour of Turkish employers and contractors operating in the Near East. Reciprocal patterns are those exhibited by both employers and contractors and include "honeymoon patterns" and obscure documentation practices. One sided patterns include employers' and contractors' practices, such as deliberate preservation of ambiguity in contracts and contractual behaviour, fears of violating public welfare, fears of being included in the "Black List", fears of challenging prominent main contractors and "face value" issues, resulting in complex adversarial relationships, complicated disputes and, occasionally unexpected outcomes. The paper discusses these patterns from a performance perspective and concludes with a set of recommendations for further research into contractual behaviour.

Keywords: Construction contracts, Near East, disputes, relational governance, survival

1. Introduction

The ENR Sourcebook is an annual publication that offers rankings of international contractors and design firms based on contracting revenues generated abroad. ENR Sourcebook's figures include prime contracts, subcontracts, design –build contracts, construction management-at-risk contracts and shares of joint ventures.

ENR's "The World's Top 250 International Contractors" list published in August 2015, based on 2014 figures, included 43 Turkish contractors. Turkey kept its second position in the list after China for the eighth year. The total revenues of the 43 Turkish companies placed on the ENR list increased by 43.4 percent to $29.3 billion in 2014 compared to the previous year. Thus, the total share of Turkish companies, which was 3.8 percent in 2013, increased to 5.6 percent in 2014 (The 2015 The Top 250 International Contractors 101-200, 2015).

Construction has played a significant role in the economic development of Turkey since the 70's , currently accounting for 5.9 % of GDP. The share of GDP attributable to construction may be as high as 30% if the impact of the construction sector on other sectors of the economy are taken into consideration according to a report by the European International Contractors (FIEC Construction Activity in Europe ,2015).

Turkish contractors undertook approximately 7500 projects in 103 countries between 1972-2014 (6 months). The total value of these projects is estimated around 285 billion USD (Türk Yurtdışı Müteahhitlik Hizmetleri, 2014).

The foregoing seems to be a success story. The realities of construction contracting are, of course, more complex. The sheer size of the overseas market is not an indicator of high performance by itself. Only one Turkish design firm took place in the ENR Top 100 International Design Firms list (ENR bases Top Design Firm rankings on total revenue of design services from projects within their region during the previous calendar year. Firms are also ranked by design specialties and disciplines)

Turkish construction projects are characterized by adversarial relationships, confrontational disputes, abandonment, early termination, contractual deadlocks, low satisfaction and other complex issues. The present paper shall not attempt to analyse the competitive advantage of Turkish construction firms, as this has been undertaken by many researchers (Giritli et, al., 1990, Günhan and Arditi, 2005, Özorhon et al. 2010, Batmaz et. al, 2010). Instead the paper shall try to identify patterns of behaviour prevailing in contractual relations in Turkey and the Near East, drawing on the authors' experiences as expert witnesses and claim consultants over a period of twenty years in the Turkish construction sector. In addition, the paper shall attempt to raise questions about best contract administration practices, firm survival and firm performance.

The cases examined were observed during the authors' involvement with construction claims over a period of twenty years. As such, the method approximates participant observation in the sense that the researchers have shared the activities of the parties.

The paper describes patterns of observed behaviour and provides a brief discussion of non-legal sanctions and rewards exercised by the parties. Raising questions of sustainability in the long run, the paper concludes with suggestions for further qualitative and longitudinal studies to offer insights into contractual behaviour.

2.Turkish Contractors in the Near East

2.1 Brief History

Most of the Turkish contractors moved into the Middle Eastern market in the late 70's as subcontractors following a recession. By the early 80's most were working as prime contractors. Between 1978 and 1987, about 60% of the value of work undertaken came from Libya and 31% from Saudi Arabia (Giritli et. al. p. 417). At that period, opportunities of work were created by several mechanisms, including soft loans (government to government loans), joint economic cooperation systems (such as the Turkish Libyan and Turkish –Iraqi Joint Economic Cooperation Agreements), barter agreements and military construction projects. Turkish contractors gained considerable competitive advantage through the operation of these mechanisms (Sözen, 1998).

The situation, however, started to change by mid-80s. There were several reasons behind the transition, including the saturation of the Saudi Arabian market, the influx of South Korean, Pakistani, Chinese and Bangladeshi firms with highly competitive labour costs and governmental supports (such as tax breaks), while the end of the barter agreements with Libya generated cash flow problems and the crisis that eventually led to the Gulf War created adverse conditions for Turkish contractor firms (Sözen, 1998).

The decline in the overseas market resulted in insolvency: 23 of the 50 contractor firms studied by Sözen in the years 1981-82 had closed down by 1992 (Sözen, 1992; Sözen, 1998).Risk taking and competitive firms had entered new markets, e.g. the Russian federation and the Turkic Republics, whereas firms that had put all their eggs in one basket (e.g. firms concentrating activities in Libya or the domestic market) were forced out of business.

Following the economic crisis of 2001, the volume of contractual activity overseas increased sharply. The explanatory factors offered were the following:

- The decline of domestic investments following the economic crisis in 2001 resulted in abnormally low offers
- Creation of opportunities overseas by booming oil prices
- Accumulation of overseas expertise and entrepreneurial learning

The leading markets since 2013 have been Turkmenistan, Russian Federation, Azerbaijan, Iraq, Kazakhstan, Algeria, Saudi Arabia, Angola, Libya and Kuwait.

2.2 Background

The authors' experiences as expert witnesses and claim consultants in the construction sector indicate that contractual relationships of Turkish contractors in the Near East are characterized by a lack of trust in the other party (employer or subcontractor) crystallizing in:

- Mistrust in the other party, confrontational attitudes, adversarial atmosphere;
- Deterioration of employer-main contractor/ main contractor-subcontractor working relationships;
- Disappointment and dissatisfaction with DAB decisions, arbitral awards and court decisions;
- Relinquishment of contractual rights because of insufficient or non-disclosable contract documentation;
- Inertia in pursuing claims because of "black list" exposure;
- Prolonged dispute resolution processes or contractual deadlocks;
- Dependence on foreign design and technological know-how in complex, multidisciplinary EPC projects.

Yet, the survival of Turkish firms in the Near Eastern market deserves an objective explanation. There are a number of rival theories about the survival of firms in organisation theory. "Liability of newness" and "liability of adolescence" models have found widespread empirical support (Freeman, Carroll et al., 1983; Bruderl, Preisendorfen et al.1992, Bruderl and Schussler, 1990).

Among models based on firm dynamics, the most influential is perhaps the passive learning theory by Jovanovich, who contends that the longer a firm operates in a market, the more it learns and the more efficient it becomes (Jovanovich, 1982). The basic assumption in the passive learning model is that firms learn without engaging in active learning effort, e.g. research and development.

Frankish et al (2007) offer an alternative but interesting explanation: It is possible that entrepreneurs do not learn:" *Here, even if business success is a chance event, an individual who continues to buy tickets for the lottery will enhance their probability of being successful at some point in time. It does not mean that they have 'learnt to play the lottery'. It merely means they have bought more tickets."* (Frankish et. al. 2007, p.4).

As to the role of unwritten codes of conduct that powerfully affect inter-firm behaviour Macaulay, in his classic article argues that "*Not only are contracts and contract law not needed in many situations, their use may have, or may be thought to have, undesirable consequences*." (Macaulay, 1963, p.64). Macaulay's argument has lent support to the relational governance literature associated with trust (Poppo, 2002). The underlying argument is that formal contractual relations and enforcement of contractual obligations undermine exchange relationships based on trust, whereas relational governance reduces friction between the parties, increasing flexibility and adaptability.

One of the most important questions that needs to be addressed is whether Turkish contractors have passively learned behavioural patterns that somehow fit with the contracting environment in the Near East despite active engagement in R&D and investment in trust. The answer to this question is not simple and certainly deserves empirical investigation. Even then, this is a shaky foundation and there would be problems of measurement in an empirical investigation.

3. Observed Patterns of Behaviour

The following section shall attempt to identify observed reciprocal and one sided patterns in contract performance. Reciprocal patterns are those shared by employers and contractors. One sided patterns seem peculiar to employers or contractors.

3.3 Reciprocal Patterns

Honeymoons

Like any social relationship, the contractual relationship is likely to experience a honeymoon period during the early phases of contract performance. This period is typically characterized by leniency in contractual enforcements, goodwill, trust and tolerance of contractual breaches.

Almost all contracts set out obligations and responsibilities of the parties relative to performance and claim notices. Claim notice provisions describe procedures that must be strictly followed in notifying the other party before claims can be pursued. Likewise these provisions typically include deadlines for notification, known as time bars.

Similarly contracts contain provisions that any changes made to a contract are ineffective unless made in writing and signed by or on behalf of both parties. This is known as the variation clause and aims to prevent oral variations

At the honeymoon stage, however, both parties are disinclined to require strict compliance with contractual provisions: time bars are often overlooked and oral change orders are executed. This is a widely observed behavioural pattern and is interpreted by both parties as an exhibition of mutual goodwill. There is nothing inherently wrong with this approach as long as the relationship endures within an amicable atmosphere. However, the honeymoons typically do not last long and mutual goodwill eventually evolves into “constructive acceptance”.

During the execution of a large scale infrastructure project under FIDIC Silver Book in Istanbul, time bars were ignored by the contractor and late submission of notices was accepted by the public authority employer during the initial stages of contract performance. At a late stage when the relationship between the parties deteriorated into an antagonistic one, the employer refused a late notice by the contractor based on employer’s rights under clause 20.1, which stipulated that any claim to time or money would be lost if there was no notice within the specified time limit. The contractor took the employer’s determination to the Dispute Adjudication Board, with supporting evidence that previous late notices had been accepted by the employer earlier. The DAB interpreted this as constructive acceptance against the employer.

Duplicate or non-disclosable documentation

Most projects produce duplicate documentation. The reason for this anomaly is the difficulty in obtaining approval of authorities having jurisdiction over the design documents or frequent changes in legislation. The basic intention of the parties is to comply with existing codes, while reserving the potential to make alterations to a scheme after it has been granted planning approval. In a majority of cases duplicate drawings are preserved, one official, the other non-official. In a potential claim situation, however, submission of documents can present a problem, since only official documentation may be submitted to a court or an arbitral tribunal. Duplicate documentation poses difficulties in filing claims, as a party can only claim what she/he can demonstrate transparently.

In a recent case, a contractor was barred from claiming site office and head office overheads for a standby period of 9 months because of non-disclosable documentation.

Another case demonstrates the impasse reached by the parties .A widely used contractual arrangement in Turkey is financing of construction costs by sharing independent units between the employer and the contractor. During the construction of high rise a mixed-used luxury building located close to the centre of Istanbul under a similar arrangement, the landowner/employer and the contractor had a disagreement about the appropriation of areas and spatial arrangements. There were considerable discrepancies between the official projects that had obtained planning consents and the actual drawings. The actual drawings included alterations beyond the scope of permission. This incongruity presented a major obstacle in taking the disagreement to court and the disagreement still remains unsolved.

3.4 Employer’s Patterns

Ambiguity

Aoki and Allison (2005) argue that it may not always be desirable for all parties to a social relationship to account precisely and accurately for actions. The authors use the term ambiguity in its sense of admitting multiple interpretations. Thus, ambiguity is created to provide personal space in social relationships.

Creation of ambiguity is a pervasive pattern in contractual relations. The employer usually refrains from approving contractual documents to provide “contractual space” in a reflex action that functions to reserve future defences.

During the performance of a large scale project under FIDIC Silver Book in Istanbul, the employer never officially approved the work programme submitted by the contractor. Thus, there was no baseline schedule that is typically intended to measure and control project activities. The absence of a baseline became a major problem during the resolution of a major time extension claim.

Public welfare concerns

Liability for public welfare offences is a major determinant of contractual behaviour for the public employer in Turkey. The public authority is particularly sensitive to cost claims filed by the contractor, while granting extension of time is not a major issue. Cost claims in compensable delay cases can be a serious cause of concern for public employers.

The proliferation of DAB referrals by the contractor was a phenomenon that took us years to understand. Ultimately it turned out that the contractor was encouraged by the employer to take money claims to the Dispute Boards, as complying with a Board decision was less risky for the employer than granting entitlement to cost through an employer's determination.

In one particular case, where the contractor proposed a value engineering solution that reduced cost at the expense of quality, the proposal had to be accepted by the contracting public authority. In the final account, protection of the public fisc mattered in a government audit. The regulatory government audit mind set is difficult to understand and accountability for costs can be interpreted as a public welfare offence.

Grossly one sided contracts

Employers (clients and main contractors) tend to drive the contractor/subcontractor into a corner by means of grossly one-sided contracts that minimize employer risks while imposing onerous terms on the contractor. These contracts are characterized by exclusions of damages, disclaimers for the owner and limitations of remedies for contractors. The question is, of course, why a contractor/subcontractor would ever sign such a a burdensome contract. Surprisingly, both parties are of the opinion that (unstructured interviews of the authors) that nothing eventually happens because when the contractor fails to strictly comply with a particular provision of a contract, the employer often delays its attempts to enforce such provision. The employer is well aware that severe losses may force a contractor out of business, resulting in a failure to complete the work, with the inevitable delays, and the attendant delays, high monetary and non-monetary costs on the parties.

3.5 Contractor's Patterns

Black List concerns

Contractors working with the public employer or powerful private employers are generally disinclined to file or pursue claims in fearful anticipation of being included in the "black list" which implies serious problems in securing future contracts. In compensable delay situations, time extension claims are fairly well tolerated by the employer, whereas money claims are risky for the procurement of future projects from the same employer.

A Turkish contractor working for a Middle Eastern employer under FIDIC was terminated for convenience. Under FIDIC conditions, the employer is not allowed to terminate the contract in order to execute the works himself or to arrange for the works to be executed by another contractor. In this particular case, however, the employer did outsource the remaining works to another contractor. The reaction of the terminated contractor was “to remain silent”. Eventually, the terminated contractor was awarded another contract by the employer.

In another case where an eminent Turkish main contractor and a Turkish subcontractor were working on a project in Azerbaijan, the main contractor breached the subcontract repeatedly. The subcontractor refrained from raising claims for a considerable amount of time. Finally when it did bring the matter to international arbitration, there were problems in finding experts to provide an expert report in favour of the subcontractor. The subcontractor sought amicable settlement and the matter eventually faded off.

Saving “face”

Contractors and subcontractors alike display ambivalent attitudes toward powerful clients. Contract administration manuals generally provide templates for different kinds of claims, such as: “ *We hereby give notice in accordance with Sub-Clause ....of the Conditions, that during the execution of our Works, we have encountered adverse physical conditions in the form of …………………. located …………………….. which in our opinion was Unforeseeable because……………………….. We will be maintaining such contemporary records as we believe necessary or may be required by you, to substantiate our additional costs/and support our request for an extension of time pursuant to Sub-Clause....”.* However, the standard claim template is too aggressive for the Turkish contractor.

Notices served under contracts have to be worded carefully in order to refrain from offending the employer. As a result, the standard claim letter is unassertive and maintains a degree of ambiguity as to the consequences of the claim.

“*The employer’s representative is offended and turns his head when we meet on the site just because we filed a claim against the employer although we were fully entitled to do so*” ,complained a contractor once while admitting that he had similarly been outraged by a subcontractor filing a (rightful) claim and never awarded a subcontract to the same firm again.

4. Discussion

The motive for the present paper was the authors’ failure to understand and interpret the results of contractual actions or inactions of the parties and to draw straightforward conclusions from them.

The foregoing observations certainly do not depict best practices in contract administration. Yet the survival of Turkish contractor firms in the international market deserves attention and empirical investigation.

The observations suggest that relational governance and contractual enforcements do not always complement each other. It is true that Turkish contractors and employers frequently call upon or depend upon non-legal sanctions (black list threats) and rewards (securing future contracts by remaining silent in potential claim situations).This may be interpreted as "passive learning" and probably has contributed to the building of stable market ties in the Near East, but the question is whether reliance on non-legal sanctions or rewards is a sustainable behavioural pattern in the long run.

Many key questions remain unanswered. For instance why is the formal execution of contracts been substituted by relational governance without the expected positive effects on exchange performance and cooperation? Or put more simply, why do the parties rely on non-legal sanctions or rewards in the absence of trust? What then is good performance in the administration of construction contracts if the intended benefits are not realised? Or have the Turkish contractors have simply bought more tickets in a lottery?

Cognitive biases of the parties are affected by the environment in which they occur. This is why interactions and influences of organisational culture and climate also need to be taken into account.

5. Conclusions

In this paper, we have sought to raise a number of research questions related to how contractual relations are understood and performed in the working practice of Turkish contractors at home and in the Near Eastern market. Obviously, the paper is based on non- systematic observations of the authors and as such, has important limitations that imply caution in generalizing the findings. In this sense, although the study falls short of developing a formal diagnostic tool it draws a picture of a complex situation. The study, being of an exploratory and interpretive nature, raises a number of opportunities for future research, both in terms of theory development and interpretation of contractual relations.

Further work is clearly needed to explore the relationship among the features of governance that support contractual relations. Further research can thus shed light on the dynamics of interfirm behaviour, sharing and exchange in the construction sector. Qualitative and longitudinal studies carried out could offer insights into these complex mechanisms. Understanding of organisational cultures could also provide great insights into why certain behaviours do and do not emerge.

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Legal Developments in Relation to Concurrent Delay: The Position of the English and Scottish Courts

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Abstract

In the UK over the last 50 years, legal developments in relation to extensions of time and/or monetary compensation for delays in construction and engineering projects, have been both cautious and incremental. In order to contend with the practical difficulties inherent in these industries, the courts have established various common law concepts and principles. The efficacy of many of those principles remains to a degree intractable, perhaps none more so than those relating to concurrent delays. Abstracted from wider doctoral research into how extension of time and/or monetary claims are dealt with in the UK courts, this paper explores the concept of concurrent delays and explains (through analysis of case law and legal commentary) how recent court decisions have, in effect, confirmed a doctrinal split between English and Scots Law. The paper also identifies the reasons for those differences, and poses further questions which require to be investigated and addressed, in order to move towards a more satisfactory and consistent approach as to how the UK courts deal with concurrent delay. Unless and until more is done to stabilise the common law concepts and principles relating to concurrent delay, such as arriving at a definitive working definition, determine conclusively the ratio for adopting the dominant cause test (or otherwise), adequately clarify why the prevention principle should (or should not) prevail, elaborate on critical path methodologies and justify which approach to causation to apply and why, then confusion over how concurrent delay will be dealt with by the judiciary will remain unsettled. Perhaps the most expeditious and pragmatic way to settle issues relating to concurrent delay should, in the first instance, be dealt with in the various standard forms of contract. This is justified as a reliance on common law principles to provide an equitable solution to concurrent delays, has had limited success. Indeed the current approach has witnessed UK judges struggling to harmonise their decisions, given under differing contract conditions and compounded by often opaque evidential constraints on projects which are factually complex. It is suggested that until concurrent delay clauses are incorporated into the standard forms, the current approach engendered by the courts, will be susceptible to imprecise, unreliable and incorrect judgements, which may not reflect the original contractual intentions of the parties.

Keywords: Construction law, prevention principle, **c**oncurrency, apportionment

1. Introduction

Complex building and engineering projects are susceptible to delays. In 2008 the Chartered Institute of Building conducted a survey of more than two thousand schemes and found that over two thirds, were delayed beyond the original completion date, and around a fifth of those projects were late by over 3 months[1]. There are a myriad of reasons why construction projects are delayed such as: labour shortages, contractor errors, poor management, employer variations to the original work scope, unforeseen ground conditions, design delays/omissions and adverse weather conditions. The list is interminable.

In construction and engineering projects, delays can be divided into both excusable delays (either with or without compensation), or culpable or non-excusable delays. Excusable delays are the contractual responsibility of the employer and entitle the contractor to an extension of time, and/or compensation depending on the event and the specific contract terms. Culpable or non-excusable delays are the contractual responsibility of the contractor, and do not entitle the contractor to an extension of time or any compensation.

Where excusable delays are identified, the standard forms of construction and engineering contracts such as the JCT, NEC and FIDIC suites, entitle the contractor, under certain criteria and conditions, a right to an extension of time and/or compensation. By definition, an extension of time clause revises the original contract completion date set out in the contract, which has been affected by delaying events which are the contractual responsibility of the employer.

Extension of time clauses protect and provide, a benefit to both the contractor and the employer. They are primarily regarded as being a benefit to the employer in that *"it establishes a new contract completion date, and prevents time for completion of the works becoming 'at large"*[2]. They are also a benefit to the contractor as they *"relieve the contractor of liability for damages for delay (usually LD's)"*[3]

Notwithstanding the standard forms attempts to provide the parties with cohesive guidance and clear obligations with respect to the management of delays and/or the associated compensation, unfortunately they are often unable to deal effectively with many of the inherent complexities which exist in construction and engineering projects of scale. In consequence, there have been various common law interventions, where the courts have been compelled to establish various dicta and principles and formulate dicta, necessitated by the limitations of the standard forms. An area where both the standard forms of contract, and the common law have struggled to provide unanimity, is in relation to concurrent delay[4] (hereinafter referred to as 'concurrency').

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[1] Chartered Institute of Building Website: http://www.ciob.org/insight/timep-management.htm, based on the CIOB Report titled *Managing the Risk of Delayed Completion in the 21st Century* conducted between December 2007 and January 2008.

[2] The Society of Construction Law, Delay and Disruption Protocol, Oct 2002, p. 10

[3] ibid

[4] David Barry, *Concurrent Delay in Construction Law: Lord Drummond Young's Volte Face*, 2011 27 Const.L.J, issue 3. p 1.

Recent jurisprudential developments in the UK have revealed a steady departure in how the English and Scottish courts deal with concurrency. Indeed in 2012, Mr Justice Akenhead took the opportunity to review the relevant body of precedent on this matter and provided an obiter commentary, as to the English courts approach to concurrency, and how it now departs from the Scottish courts approach:-

"The two schools of thought, which currently might be described as the English and the Scottish schools, are the English approach that the Contractor is entitled to a full extension of time for the delay caused by the two or more events (provided that one of them is a Relevant Event) and the Scottish approach which is that the Contractor only gets a reasonably apportioned part of the concurrently caused delay.[5]*"*

2. Concurrency, a moveable feast?

In the UK, despite a wealth of judicial and professional commentary on the subject, a definitive and workable definition of what constitutes concurrent delay in construction and engineering projects and how it is measured in practice, remains elusive[6]. Learned debate centres on whether concurrency exists where delay events begin at the same time in the project, begin and end at the same time, overlap at the same time, or, as it has been suggested, *"…need not involve delays felt at the same time"*[7]. Indeed the last 15 years or so have seen many and varied definitions from both the courts and legal commentators alike, none of which have been universally accepted[8]. The difficulty in arriving at a definitive definition has not, however, been a barrier to the courts commenting upon issues of concurrency.

Current literature identifies, at a somewhat summary level, the jurisprudential reasoning as to the underlying reasons why the English and Scottish courts have arrived at their requisite positions[9]. However it is suggested that more should and could be done to challenge the common law principles / concepts relied upon, such as Prevention, Dominant Cause, The Malmaison Approach, Apportionment and Causation, and in particular how those principles interplay with one another in practical terms.

It is important to note that the key common law developments in the UK, in relation to concurrency, have in general, been based on various iterations of the Joint Council Tribunal

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[5] *Walter Lilly & Company Limited v Giles Patrick Cyril McKay and DMW Developments Limited* [2012] EWHC 1773 (TCC) – need to get paragraph.

[6] Mattew Cocklin, *International Approaches to the Legal Analysis of Concurrent Delay: Is there a solution for English Law*, A paper based on the first prize entry in the Hudson Prize essay competition 2012, presented to a meeting of the Society of Construction law in London on 9th April 2013 p 1.

[7] Franco Mastrandrea *Concurrent delay: an alternative proposal for attributing responsibility*, CLJ 2014 Vol 30 (3) p 173-181 and Lord Osborne's view in *City Inn Limited v Shepherd Construction Limited* [2010] CSIH 68 CA101/00, para 49

[8] Lord Osborne in *City Inn Limited v Shepherd Construction Limited* [2010] CSIH 68 CA101/00 at para 49 provides some guidance on what concurrent delaying events may mean.

[9] Please refer to references (at p.12) for various commentaries.

('JCT') Standard Forms of Contract[10]. Therefore, it is worth reiterating John Marrin QC's guidance on common law approaches to concurrency when he said:

"….there is one truth which can scarcely be over-emphasised. The answers to the questions raised will depend on the terms of the contract which governs the relationship between the parties."[11]

Finally, it is also significant that, despite a plethora of literature and obiter commentary, the Scottish case of City Inn v Shepherd[12] is somewhat remarkably, the only reported construction case where concurrency was actually found to exist.

3. Concurrency in the English Courts: The Current Position

Perhaps the most widely accepted definition of concurrency in England, first proposed by John Marrin QC, in 2002[13], referred to in Keating on Construction Contracts[14] and echoed in the case of Adyard Abu Dhabi v SD Marine Services[15], is as follows:

"the expression 'concurrent delay' is used to denote a period of project overrun which is caused by two or more effective causes of delay which are of approximately equal causative potency"

There are three important points that can be derived from this definition:-

- The *"two or more effective causes of delay",* must relate to both employer[16] and contractor events for concurrency to exist[17];
- The causes do not have to be concurrent in time; and
- Where on examination, the effective causes of delay are not of "*approximate equal causative potency"*, i.e. one is effective and the other is not, the minor cause will be treated as not causative[18]. Where an event has greater causative potency, notwithstanding it may be co-critical[19], it has sometimes been referred to as the dominant event or cause. Whether the use of the 'dominant cause' to separate causes, which do not have equal

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[10]JCT is the English version of the Standard Forms, the Scottish equivalent is the Scottish Standard Building Contracts ('SBCC').

[11]John Marrin QC *Concurrent Delay Revisited*, A paper presented to the Society of Construction Law at a meeting in London on 4th December 2012, p 19

[12]*City Inn Ltd v Shepherd Construction Limited* [2007] CSOH 190

[13]John Marrin QC *Concurrent Delay*, A paper given at a meeting of the Society of Construction in London on 5th February 2002, p 3

[14]*Keating on Construction Contracts*, Chapter 8, Section 3, Sub-section (c), para 8-025.

[15]*Adyard Abu Dhabi v SD Marine Services* [2011] EWHC 848 (Comm), [2011] 384, 136 Con LR 190, para 277.

[16]Causes of employer delay are known as Relevant Events in JCT Contracts. See note 28 below.

[17]*Walter Lilly & Co Ltd v MacKay & DMW Ltd* [2012] EWHC 1773, [2012] BLR 503, para 366.

[18]John Marrin, note 11, page 3.

[19]Co-critical – both delay events are identified on the critical path and have the same effect on the completion date when either one is omitted, often calculated using Critical Path Analysis Techniques.

causative potency, but could still be deemed effective causes of the delay, is still good law in England has been subject to increasing debate[20].

The genesis of the current English approach to concurrency was first established in 1999, in the case of Henry Boot v Malmaison, where Mr Justice Dyson J (as he was then) stated:-

"… it is agreed that if there are two concurrent causes of delay, one of which is a relevant event, and the other is not, then the contractor is entitled to an extension of time for the period of delay caused by the relevant event notwithstanding the concurrent effect of the other event."[21]

This approach, commonly referred to as the 'Malmaison Approach', has been adopted in subsequent English cases[22], culminating in what can be considered the most recent decision in the UK courts, Walter Lilley v McKay, where Mr Justice Akenhead said, *obiter* [23]:

"…I am clearly of the view that, where there is an extension of time clause such as that agreed upon in this case and where delay is caused by two or more effective causes, one of which entitles the Contractor to an extension of time as being a Relevant Event, the Contractor is entitled to a full extension of time. Part of the logic of this is that many of the Relevant Events would otherwise amount to acts of prevention and that it would be wrong in principle to construe Clause 25 on the basis that the Contractor should be denied a full extension of time in those circumstances. More importantly however, there is a straight contractual interpretation of Clause 25 which points very strongly in favour of the view that, provided that the Relevant Events can be shown to have delayed the Works, the Contractor is entitled to an extension of time for the whole period of delay caused by the Relevant Events in question…The fact that the Architect has to award a "fair and reasonable" extension does not imply that there should be some apportionment in the case of concurrent delays. The test is primarily a causation one.[24]

Therefore in terms of *'delay'* to the works, where concurrency is deemed to exist, the contractor will be entitled to an extension of time to completion for that period, notwithstanding his own delays which may also have delayed completion of the works by the same period.

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[20]Support for the dominant cause test is found in *Keating on Contracts* 9th Edition, Chapter 8, Section 3, Sub-section (c) 8-022, and *City Inn v Shepherd Construction Ltd* [2010] CSIH 68, [2010] BLR 473, para 42. However there has been increasing criticism of whether the dominant test is still applicable in England, Jeremy Winter, Matthew Totman and Sunil Mawkin, *Concurrent Delay 2011 at* http://www.whitepaperdocuments.co.uk/index.php?option=com_docman&task=doc_download&gid=1544&Itemid=2 and John Marrin QC note 11 page 13, Vincent Moran QC *Causation in Construction Law: The Demise of the 'Dominant Cause' Test?,* A paper presented to the Society of Construction law at meetings in reading 8th May and Glasgow on 15th May 2014.

[21] *Henry Boot Construction (UK) Ltd v Malmaison Hotel (Manchester) Ltd* (1999) 70 Con LR 32, para 13

[22] *Steria Ltd v Sigma Wireless Communications Ltd* [2008] EWHC 3454, *De Beers UK Ltd v Atos Origin IT Services UK Ltd* [2010] EWHC 3276, [2011] BLR 274, 134 Con LR 151, *Adyard Abu Dhabi v SD Marine* Services [2011] BLR 384, *Walter Lilly & Co Ltd v MacKay & DMW Ltd* [2012] EWHC 1773, [2012] BLR 503.

[23] In relation a contract let under a JCT Standard Form of Building Contract 1998 Edition, Private without Quantities (with various amendments)

[24] Walter Lilly, note 5, para 370

How the contractor's *'loss and expense'* associated with concurrent delay, is to be dealt with by the English courts, was clarified in De Beers V Atos Origin, where Mr Justice Edwards-Stuart said:

"The general rule in construction and engineering cases is that where there is concurrent delay to completion caused by matters for which both employer and contractor are responsible, the contractor is entitled to an extension of time but he cannot recover in respect of the loss caused by the delay." [25] [emphasis added]

Taking precedent into consideration, the following statements can be concluded as to how the English courts will deal with concurrent delay and the associated loss and expense:

- Where there are two or more effective causes of delay which are the contractual responsibility of both the employer and the contractor, but have unequal causative potency the dominant cause may prevail. Marrin QC, however argues that the lack of judicial support, among other things, may provide room for doubt as to whether the dominant cause approach would be adopted by the English Courts[26].
- Where there are two or more effective causes of delay, which are the contractual responsibility of both the employer and the contractor, and have equal causative potency, then the contractor will be awarded an extension of time for the concurrent delay. The reasoning behind Mr Justice Akenhead's decision is two-fold:-
    - Firstly, that to deny the contractor an extension of time would amount to an act of prevention[27]; and
    - Secondly, the contract expressly provides that the contractor is entitled to an extension of time, for a Relevant Event[28]. There is nothing in the contract, which states that the contractor will be denied an extension of time, should he be responsible for a concurrent delaying event.
- Where there are two or more effective causes of delay, which are the contractual responsibility of both the employer and the contractor, and have equal causative potency, then the contractor will not be entitled to claim loss and expense for that period[29]. The logic here is that the contractor cannot recover damages, because he would have suffered the same loss and expense due to the delays for which he is responsible[30]. Loss and expense in this instance would generally take the form of prolongation costs, such as site management, site accommodation, transportation and the like.

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[25] *De Beers v Atos Origin IT Services UK Ltd* [2011] BLR 274, para 177.
[26] Marrin note 12 p. 13.
[27] See p. 5 above – Mr Justice Akenhead's decision in Walter Lilly – note 24 refers..
[28] Relevant Events are risk events which are the contractual responsibility of the employer, and depending on the circumstances, allow the contractor extensions of time, and or monetary compensation. The specific term 'Relevant Event' is particular to the JCT Standard Forms of Contract, but can and often is, understood in a similar manner, in any of the standard forms, where events/actions are the contractual responsibility of the employer.
[29]This is relevant if the contractor cannot satisfy the "but-for test" of causation that his losses would not have occurred in any event during the concurrent period. Keating on Contracts, Section 5, para 9-062.
[30] De Beers, note 25 para 178.

4. Concurrency in the Scottish Courts: The Current Position

In light of recent case law, it is considered that the closest current definition of concurrency as it is understood in Scotland defined in the case of City Inn, is as follows: "*true concurrency between a relevant event and a contractor default, in the sense that both existed simultaneously, regardless of which started first…*"[31]. However in the appeal to the Inner House to this decision, Lord Osbourne widened the definition of "true concurrency" by saying: "*the focus of attention has moved, rightly in my opinion, from events themselves and their points and durations in time to their consequence upon the completion of the works*".[32]

Until 2004, there was no material inconsistency in how the Scottish and English courts dealt with concurrent delay and/or the associated loss and expense. However Lord Drummond Young's judgement in John Doyle Construction v Laing Management (Scotland) began what is now seen, as a departure between the Scottish and English courts.[33] Although predominantly known as a case concerning global claims, the learned judge had some interesting and diverging opinions on losses incurred due to concurrent delay: "*…even if it cannot be said that events for which the employer is responsible are the dominant cause of the loss, it may be possible to apportion the loss between the causes for which the employer is responsible and other causes.*"[34][emphasis added]

In England, at that time, in light of the Malmaison decision, the contractor was deemed disentitled to any loss or expense associated with events which were concurrent. It was not until 2007, in the seminal case of City Inn v Shepherd Construction, that a Scottish court was clear that it was taking a different approach from that in the English courts. Lord Drummond Young (now a pivotal figure on this matter) had some difficulties in agreeing with the English courts view on how concurrency should be dealt with[35], both in terms of loss and expense and extension of time claims. Considering mostly English precedent and taking some guidance from the US courts, he said:

In terms of dominance: "*I agree that it may be possible to show that either a relevant event or a contractor's risk event is the dominant cause of that delay, and in such a case that event should be treated as the cause of the delay*"[36]

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[31] City Inn, note 12, para 18.
[32] City Inn, note 8, para 52
[33] *John Doyle Construction Ltd v Laing Management (Scotland)* Ltd [2004] S.C.L.R. 872 B.L.R. 295
[34] ibid, para 16.
[35] His difficulties were based on Judge Richard Seymour QC's decision in *Royal Brompton Hospital NHS Trust v Hammond* (No.7), (2001) 76 Con LR 148 at paragraph 31, where he had suggested that should a contractor already be in culpable delay, and an employer's Relevant Event arises (such a inclement weather), is concurrent for a period of time, but does not affect completion, then the Relevant Event should not be considered. Lord Drummond Young, said *"It should not matter whether the shortage of labour developed, for example, two days before or two days after the start of a substantial period of inclement weather, in either case the two matters operate concurrently to delay completion of the works."*
[36] City Inn, note 12, para 21. His support for the dominant cause approach is found in Leyland Shipping Company Ltd v Norwich Union Fire Insurance Society Ltd [1918] AC 350.

In terms of delay: *"Where true concurrency between a relevant event and a contractor default, in the sense that both existed simultaneously, regardless of which started first, it may be appropriate to apportion responsibility for the delay between the two causes, obviously, however, the basis for such apportionment must be fair and reasonable"* [37]

In terms of loss and expense[38]: *"In this respect the decision in John Doyle Construction Ltd v Laing Management (Scotland) Ltd, supra, may be relevant. In that case it is recognised at paragraphs [16]-[18] that in an appropriate case where loss is caused by both events for which the employer is responsible and events for which the contractor is responsible it is possible to apportion the loss between the two causes. In my opinion that should be done in the present case."*[39]

His judgement was affirmed by a majority in the Inner House of the Court of Session[40], notwithstanding a dissenting view from Lord Carloway.

Taking current precedent into consideration, the following statements can be concluded as to how the Scottish courts will deal with concurrency, both from a delay, and loss and expense perspective[41]:-

- Where there are two or more effective causes of delay, which are the contractual responsibility of both the employer and the contractor, and have <u>unequal</u> causative potency, the dominant cause <u>will</u> prevail.
- Where there are two or more effective causes of delay, which are the contractual responsibility of both the employer and the contractor, and have <u>equal</u> causative potency, again the dominant cause will prevail and it <u>may</u> be appropriate that the delays will be apportioned between the parties. On analysis of Lord Drummond Young's decision, the reasoning behind his position is as follows:-
    - Contrary to Judge Seymour QC's view in Royal Brompton, the employer event and the contractor event, do not have to happen simultaneously and both should be treated as concurrent causes whichever happened first[42].
    - The architect should exercise his judgement to determine what has delayed the works, on a fair and reasonable basis[43]. Precisely what is fair and reasonable must turn on the facts and circumstances of the case. [44]
    - Apportionment is supported by US law[45,] where he referred to a Board of Contract Appeals case which stated:- *"Where a contractor finishes late partly*

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[37] City Inn, note 12 para 18.
[38] In this instance, prolongation costs.
[39] City Inn, note 12 para 166.
[40] City Inn, note 8.
[41] Note to facilitate a comparison, the phrasing of concurrency in this instance has been chosen, to be consistent with the conclusions drawn from the English courts.
[42] City Inn, note 12.
[43] Lord Drummond Young attaches "”considerable importance to these words", see note 12, para 20.
[44] City Inn, note 12, para 18. The *"fair and reasonable"* approach is taken from clause 25 of the JCT Conditions, (Private Conditions with Quantities) (1980 edition), with amendments.
[45] *Chas. I. Cunningham Co*, IBCA 60, 57-2 BCA P1541 (1957) the Board of Contract Appeals.

because of a cause that is excusable under this provision and partly because of a cause that is not, it is the duty of the contracting officer to make, if at all feasible, a fair apportionment of the extent to which completion of the job was delayed by each of the two causes, and to grant an extension of time commensurate with his determination of the extent to which the failure to finish on time was attributable to the excusable one."

- Causation in practise works in a complex manner, in ways that does not permit the easy separation of causes, meaning the Architect or court must apply judgement, which can take the form of apportionment.[46]
- When an apportionment exercise for delay is carried out, the methodology is similar to that found in contributory negligence among joint wrongdoers.[47]
- Contrary to significant emphasis being placed from the English courts, he does not consider the principle of prevention in any meaningful detail.

- Where there are two or more effective causes of delay, which are the contractual responsibility of both the employer and the contractor, and have equal causative potency, then the losses may be apportioned between the parties[48]. The logic being similar to that adopted for concurrent delays.

5. Discussion

Taking the foregoing into consideration, it is evident that there are inconsistencies in how the Scottish and English Courts approach the matter of concurrency. In order to find a more consistent and satisfactory direction for both jurisdictions, requires further research and discussion into the following areas:

- **Definitions:** Unless and until a definitive definition of concurrency can be commonly understood by both the English or Scottish courts, then it is likely that difficulties in relation to concurrent delay will prevail. For example, it is still to be understood in practice whether *"true concurrency"*[49] i.e. employer and contractor delay events which overlap in time, as defined in City Inn, will be dealt with any differently to employer and contractor delay events which do not overlap in time, neither of which is dominant, but act together to delay the completion date. If the employer and contractor events are deemed concurrent because they do not overlap in time, but in *effect* cause delay to the completion date, why are these not merely delay events that are calculated as part of the delay analysis. Furthermore, why would they be deemed *"concurrent"* at all?
- **Dominant Cause v Effective Cause:** The advancement of the "*effective cause*" approach in England, may suggest the demise of the dominant cause test, although this remains unconfirmed. It is suggested however, that it is possible in many instances for experienced construction professionals and the courts, to identify the dominant cause

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[46] City Inn, note 12, para 22.
[47] City Inn, note 12, para 158.
[48] Although Lord Drummond Young stated that prolongation *costs "need not automatically follow success in a claim for extension of time"*, note 12, para 166
[49] City Inn, note 8 para 50.

between two events which may appear to have approximate equal causative potency, and appear co-critical in the programme. It is important to maintain a differentiation, because if dominance can be established, then it may be the parties could have chosen alternative mitigation strategies, to avoid their delays impacting the completion date. If that is the case, it is suggested that there is no reason, why the dominant cause approach is not adopted in the first instance. It is also respectfully suggested, that the term *"effective cause"*, is too general in description, which may only confuse matters when applied practically. Concurrency should only exist, it is suggested, once dominance cannot be established.

- **Prevention Principle:** In England, prevention is the first of two ratios in support of the Malmaison Approach; however there are conflicting judgments as to whether prevention actually exists in relation to concurrent delays[50]. In Scotland, there is ongoing debate as to whether the judge's ability to apportion concurrent delay and/or loss actually offends this principle in any event?
- **Express terms of the Contract:** In England the second and main ratio, in support of the Malmaison Approach centres on a literal interpretation of the contract (at least a JCT contract), which expressly allows an extension of time for employers Relevant Events. However, it must be explored as to why the architect or contract administrator should be precluded from taking other events (not expressly stated) into consideration, which also have an impact on the completion date. One must consider the original intention of the parties, and what would the outcome be for standard forms of contract, other than the JCT suite, which requires the architect to act fairly and reasonably? In Scotland it would appear that in evaluating concurrent delay and its effects on the completion date, the architect should do what is fair and reasonable, taking into consideration Relevant Events and events which are not expressly stated in the contract.
- **Causation:** The standard causation criteria, commonly referred to as *"but for analysis"* is suspended adopting the Malmaison Approach in England, and is also suspended in Scotland if the dominant cause approach is accepted. It must be asked, have the courts decided suspend the standard criteria for causation as a matter of Policy, if so on what basis?
- **Contributory Negligence:** The apportionment of concurrency in Scotland has been likened to contributory negligence between (joint wrongdoers (tortfeasors)[51]. There are conflicting arguments as to why a similar approach cannot be adopted in the law of Contract, which require further analysis?
- **Obiter commentary:** As mentioned previously, apart from one reported construction case, both English and Scottish courts commentary on concurrency has been given in obiter dicta. Indeed in City Inn, the judge merely suggested that apportionment *"may"* be appropriate. It is obvious therefore that the issue of concurrency is far from settled, and divergence between the English and Scottish courts may not be as immobile as is generally considered?

[50] *Jerram Falkus Construction Ltd v Fenice Investments Inc* (No 4) [2011] EWHC 1935 (TCC), [2011] BLR 644, 138 Con LR 21, [2011] CILL 3072.
[51] City Inn, note 12, para 158.

- **CPA: Programme Analysis / CPA**. It is inadequate to consider the legal understanding and application of concurrency without considering the forms of delay analysis which may be adopted to evidence same. It is imperative that more should be done to align how the legal principles will actually work in practise.
- **Redrafting of the Standard Forms:** Workable definitions could and should be provided by the standard forms of contract, such as JCT, NEC3 or FIDIC suites[52]. Admittedly, it is possible that the definitions of concurrency when included in the standard forms may be different[53], but at least the parties would have more certainty on what terms they were entering into. Furthermore it would be helpful if the delay analysis methodology was outlined, because it is an integral and perhaps inseparable element in analysing delays to completion.
- **Policy considerations:** Given the relatively low profit margins of contractors of scale, it may be of benefit to acquire a deeper understanding of whether in matters of concurrency, is it fairer to award time, but no money, or apportion both time and money. For example in general, liquidated damages would be considerably higher than prolongation costs, should that influence the decision making process?
- **Hybrid Solution:** Considering all of the above, is there a viable argument to suggest that the contractor is entitled to an extension of time, but only a proportion of the money for concurrent delays? This is significant because, by way of example, if a project overruns because of a number of employer events, but only one contractor event, then there is no incentive or control for the contractor to mitigate his delays, if he is in the knowledge that he will not be able to recover or reduce his prolongation costs in any event, due to delays caused by concurrent employer events. A form of pacing delay which brings its own complexities.

6. Conclusions

This paper has identified the jurisprudential differences between the English and Scottish Courts, and how they may deal with concurrent delay in construction and engineering projects in the future, and how these differences manifest themselves in the decision making process.

It is essential that first and foremost the parties involved in construction and engineering projects, must refer to the particular terms of their contract, to understand their immediate rights and obligations in relation to how concurrency is to be administered. More often than not, the parties will have contracted using one of the standard forms, which are in general silent on how concurrency is to be dealt with. In consequence, divergences in how the English and Scottish courts deal with concurrency, will prevail and common law solutions will have limited efficacy. It is suggested that unless and until the aforementioned considerations are addressed, it is likely that problems articulating and measuring concurrency will persist for the foreseeable future.

[52] Currently the only standard form of contract to define concurrency is found in the CIOB Complex Contract Conditions, 2013.

[53] Indeed the current common law differences on concurrency between the Scottish and English Courts may require a departure between the JCT suite in England and its SBCC equivalent in Scotland.

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Selection of Delay Analysis Methods in Construction Projects

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Abstract

Delays in construction projects may seem to be easy to analyze, however, in many cases, the process is complex and difficult. As a result, many methods were developed for analysing project delays. With projects varying in nature and complexity and the availability of several delay analysis methods (DAMs) that produce different results for the same project and set of facts, conflicts started arising in projects over which DAM should be used and why. This paper examines the commonly used DAMs in construction projects and the factors that could influence the decision as to the selection of the appropriate delay analysis method adopted by Contractors.

The analysis of five case studies found that there is agreement on what is considered acceptable framework of performing delay analysis by Contractors. The research found support for using the Time Impact Analysis (TIA) Method, as this was considered the most reliable and acceptable method to Contractors in UAE. The main factors affecting the selection of the DAM were the attitude of the opponent party, experience of the delay analyst, complexity of the project, stage of the project at the time of performing the analysis, and the available time and cost for performing the analysis.

Keywords: Delay analysis, extension of time, claims, selection factors, time impact analysis

1. Introduction

Delays are commonly in many construction projects and researchers. Braimah and Ndekugri, (2008) argued that it is rare that a project finishes without time overruns. Delay analysis methods (DAMs) are essential tools for assessing the effect/impact of a delay, particularly in complex projects. While there is an agreement over the possible approaches to analyze the delay, there appears to be a disagreement over which DAM is the most appropriate or preferred, if any. Researchers have concluded that there is no one DAM than can be universally applied (Arditi & Pattanakitchamroon, 2006).

Researchers identified multiple factors affecting the selection of the DAMs. The most recognized work in relation to delay and disruption are that of the Society of Construction Law (SCL) delay and disruption protocol (SCL, 2002) and the American Institute of Advancement of Cost Engineering International (AACEI) recommended practice 29R-03 (AACEI, 2011). Both documents provide invaluable information as to delay analysis types and selection factors. However, they do not provide sufficient guidance as to how such factors influence the selection and application of the DAMs. D'Onofrio (2015) reviewed the work of both SCL and AACEI and concluded that the preferred DAM is the Time Impact Analysis (TIA). This view, however, was undermined by the issue of Rider 1 to the SCL delay and disruption protocol (SCL, 2015), which excluded the preference of the TIA method and encouraged the utilization of the factual based methods, particularly for analyzing delays at a time distant from the event.

The aim of this research is to investigate the most appreciate DAM, if any, and the relevant influencing factors for selection and acceptance. The research main objectives are to identify the main factors influencing the selection process, the commonly used and most acceptable DAM(s).

2. Delay Analysis and DAMs

One of the early decisions the delay analysts have to make before selecting a DAM is whether to perform a forward perspective or backward retrospective path calculations. This decision is influenced by initial factors such as the timing of performing the analysis and its purpose (Kao and Yang, 2009) which in turn would influence the decision of whether to follow an observational or a modelling approach of the delay (SCL, 2002).

Some methods, such as the TIA are categorized as complex while some others, such as the Impacted As Planned (IAP) are considered as simple methods. Complex in this context means requiring analysts to have certain level of experience, the necessary records and willingness to invest significant effort into the exercise (Braimah & Ndekugri , 2008). Therefore, each of the DAMs can be performed to a different level of detail; such detail level is influenced by the availability of the records as well as the time, money and resources available to perform the analysis (Braimah & Ndekugri, 2008).

There are various types of DAMs that are commonly used in the construction industry.The name and type of the DAM does not really matter as long as the delay analysts explain and justify their selection and performance technique (D'Onofrio, 2015). Yang and Kao (2012) note that none of the existing DAMs are perfect as they all require assumptions and contains theoretical forecasts and subjective assessments.

SCL (2002) and Arditi and Pattanakitchamroon (2006) suggested that four methods are the most common in the construction industry which are the As Planned vs. As built Windows Analysis (APvAB), Impacted as Planned (IAP), collapsed as Built (CAB) and the Time Impact Analysis (TIA) method. *APvAB* compares the planned activities (Baseline) with the as built activities. Yusuwan and Adnan (2013) describe it as the most preferred method as it is simple and produces fair and reasonable results. SCL (2015) recommends using this method when performing the analysis distant from the event. Its main features are that it does not present a complex analysis, rely on the baseline network, or require any computerised software, however, it is based on heavy subjective views and assumptions. While this method is relatively easy to perform, it requires analysts to have relevant experience and it may not be sufficient to deal with concurrent delays or the dynamic nature of critical path (Braimah and Ndekugri, 2008). The APvAB method requires a baseline and an as-built schedule or as-built records. It might be suitable for simple and complex cases. SCL (2015) also refers to the Longest Path Analysis method as something similar, but different in that it requires as built schedule and looks at the delay at one point whereas the APvAP may utilise any available as built records and can be performed in window periods.

IAP method simply influences all delay events on the baseline schedule in a prospective way on the assumption that the baseline logic, sequence and durations have not changed (Arditi & Pattanakitchamroon, 2006). IAP may be sufficient to predict future delays but it will not give adequate results when analysing on-going or completed projects (Braimah & Ndekugri, 2008). Kao and Yang (2009) suggested alternative names for the IAP method: 'as planned', 'what-if', impacted baseline schedule', 'as planned plus delay analysis' and the 'affected baseline schedule' methods. The IAP method requires a baseline schedule and knowledge of the delay events and it is not recommended for complex cases and completed projects.

Collapsed/'But for' As-Built Analysis method analyses the delay using the final as built schedule or creating one including all network logic along with all delay events and their impacts and then start excluding the impact of the delay events to see what would have been the case but for such delay events (Braimah and Ndekugri, 2008). This method is moderately complex and requires an as-built schedule and knowledge of the delay events. It is suitable for complex cases but cannot deal with concurrency issues and the changing nature of the critical path.

TIA is a dynamic method that allows for initially creating a separate sub-network for each of the events, which can be agreed between the parties, and then these subnets can be inserted into the project-updated schedules in each relevant time-period. In the final time-period, there will be a fully impacted schedule containing all delay events and considering all as built data (SCL, 2002). SCL (2002) considers TIA as the preferred method but not when the case of analysis is distant from the events (SCL, 2015). It considers project delays regardless of the originator or the type of the delay and encourages the parties to keep good records and to update the project schedule on regular basis. However, is that the method requires complex analysis and effort and a substantial time to perform. As such, its use will be highly depended on the availability and the quality of the project records (Arditi & Pattanakitchamroon, 2006). Williams (2003) described three other methods in a way similar to the TIA, which are the windows analysis, snapshot analysis and the time impact technique. They are effectively the same but with different ways of looking at the delay events, delay effect, window periods and project progress. The TIA, however, differs from the Contemporaneous Windows Analysis method in that the latter is observational method that does not require modelling or impacting the delay events as it follows the "effect and cause" approach rather than the "Cause and effect" approach. In summary, the review of the literature recommendations (table 1) supports the use of TIA except when projects have poor records or when there are limitations on time and budget for the analysis.

Table 1: Summary of delay analysis methods

Nr.	Method	Brief Description
1	As-Planned vs. As-Built APvAB)	Observation of the difference between an as-planned and an as built schedule
2	Impact As-Planned (IAP)	It is based on the theory that the completion date can be determined by adding the delays into the as-planned schedule.
3	Collapsed As-Built (CAP)	Effects of delays are ''subtracted'' from an as-built schedule to determine what would have occurred but for the delay events.
4	Time Impact Analysis (TIA)	Assumes that delay impacts to a project can be assessed by running a series of analyses on schedule updates.

3. Main Selection Factors

Before selecting a DAM, questions should be asked as to which DAM can produce the desired outcome and whether the project circumstances are suitable for performing such method (Williams, 2003). Braimah and Ndekugri (2008), SCL (2002) and AACEI (2011) identified several factors affecting the selection of the appropriate DAM by delay analysts.

Data, Information and Records Available focus attention on the type and level of available project data that could heavily affect the selection and application of a DAM. However, the reliance on the project records varies between the DAMs. Records may include correspondence, progress reports, meeting minutes, site inspection records, transmittal sheets, videos, photos and others (Braimah & Ndekugri, 2008). None of the DAMs would give valid results if the project records were incorrect or invalid. Not surprising that more than 70% of the delay analysis effort is usually exerted in gathering and organizing the information (Arditi & Pattanakitchamroon, 2006). ***Baseline, Availability Quality and Features*** is the second in importance after the availability of proper records. Having a proper baseline schedule reflecting the original intentions of how and when to perform the works is essential to perform the delay analysis, regardless of the selected method (Arditi & Pattanakitchamroon, 2006). ***Contractual Obligations and the Attitude of the Opponent Party****;* a DAM might be specified in the Contract documents or agreed by the parties. It may also be influenced by the applicable legislation. This may limit the analyst choices as to the section of the DAM (Braimah & Ndekugri, 2008 and SCL, 2002). The attitude of the opponent party may not affect the application of the DAM, but it must be considered by delay analysts before selecting a DAM. If the opponent party, for example Is willing to accept liability, a fair and simple method maybe sufficient (Braimah & Ndekugri, 2008). ***Project Nature, Complexity and Circumstances;*** the characteristics of the projects such as the size, design, duration, cost and complexity will heavily influence the selection of the DAM. However, the effect in two different ways. Complex and large projects may require a complex DAM to be able to analyse the delays. However, in some cases, the project might be too complex or has unnecessary complex information which may require a less sophisticated method to analyse the delay (Braimah & Ndekugri, 2008). ***Nature, Type and Number of the Delay Events***; Delays are usually categorised based on liability to Compensable, Excusable and non-excusable delays. The type of project delay affects the selection of the DAM as some methods are unable to analyse multiple liability events (SCL, 2002). ***Skills of the Analysts*** and abilities could influence the selection of the DAM as some methods require complex analysis and certain level of experience, particularly when it comes to making reasonable assumptions, subjective views, interpretations and understandings (SCL 2002; 2014, AACEI, 2011). ***Time, cost and Resource Constrains for Performing the Analysis***; claims are usually governed by certain resources, budget, time and milestones. This must be taken into account before selecting the DAM. There is a huge variance on the level effort required to perform each of the DAMs Cost proportionality should be considered when selecting the DAM. The more complex the DAM is, the more effort is required and the more expensive it will be. (Arditi & Pattanakitchamroon, 2006). ***Capabilities, Shortcomings and Strength Points of the Method***; depending on the project circumstances, the analysis will have to choose a Dam that is capable of producing the desired results. For example, the IAP method cannot deal with concurrency issues while the TIA can (Arditi & Pattanakitchamroon, 2006). ***Status of Project and Point of Time;*** delay analysis can be performed at any point of time before, during or after completion of the project. However, this will heavily influence the section of the DAM. For example, if a forecast of a prospective delay is required, then the IAP method may be appropriate. However, if a retrospective analysis is required and the as built data is available then the other methods such as the CAP or the ABvAP methods would more appropriate. In cases where the project is still running and a real time delay analysis is required, then the TIA method may be the best (SCL, 2015). ***Concurrent delays, Disruption and Acceleration Issues; w***hen multiple delay events with multiple potential liabilities for the delay exist in a project, complex analysis might be required. This would affect the analyst's selection of the DAM as, for example, simple methods such as the IAP cannot delay with such complex issues (Williams, 2003). ***Purpose and Reasons for Delay Analysis;*** Braimah and Ndekugri (2008) note that the purpose of the delay analysis will influence the selection of the delay analysis methodologies. Purposes of analysis are usually extension of time, prolongation cost, and acceleration and disruption entitlements. Depending on each method capabilities, the selection should then be made. For example, if acceleration entitlement is the purpose of the analysis, methods such as the impacted as planned or the collapsed as built may not serve the purpose. However, methods such as the TIA may effectively present the acceleration measures. ***Ownership of the Float, Software Used and Scheduling Settings;*** the ownership of the project float affects the criticality of the activities. While the float is commonly owned by the project, sometimes this is not the case. It is therefore essential that the delay analysis gets this cleared out and even try to get the consent of the parties on the ownership of the project float before selecting the DAM (Arditi & Pattanakitchamroon, 2006). Various scheduling software programmes in the market allow for scheduling large number of tasks and activities using the CPM logic. Such software contains various options that affect the calculation and determination of the critical path. Specific attention to software settings such as the scheduling options: retained logic and progress override is needed. In-progress updates, such scheduling option would make huge difference on the critical path as it would allow activities to schedule out of sequence (Arditi & Pattanakitchamroon, 2006).

4. Research Method

The research analyzed five case studies of construction projects in UAE. The decision to use case studies approach is driven by the need to engage the key actors, mainly delay analysists, and develop a detail understanding of the dynamics of the decision making process that determines the method as well as the process adopted for delay analysis. The projects were selected using the researcher contacts to ensure cooperation and overcome sensitivity about disclosing details of what many organizations consider confidential. A wide range of similarities and differences were identified between the analyzed case studies. The case studies were driven by three main questions; how the decision was made on the method to assess delays, what were the key factors that have influenced this choice and in what way has the selected method enabled or impeded the effort to assess delays more effectively and achieve the desired results. Table 2 is a brief summary of the case studies, interviewees and the used DAM.

Table 2: Summary of case studies

Project	Interviewee	Used Method(s)
A (5 Stars Hotel)(65M US$)	A1 (Project Planner)	IAP
	A2 (External Consultant)	Float Mapping
	A3 (External Consultant)	TIA
B (International High School) (120M US$)	B1 (Project Planner)	IAP
	B2 (Project Planner)	TIA
C (Highway Road) (113M US$)	C1 (Project Planner)	TIA
D (Sewage Treatment Plant) (1.5B US$)	D1 (External Consultant)	ABvAP
E (Residential Tower) (25M US$)	F1(Project Planner)	IAP

In terms of the common DAMs, the TIA method is more common in the sample. The interesting fact is that the IAP method, although criticized by the researchers, according to the case studies, it is still commonly used. The float mapping method was used in one of the projects but did not deliver the desired results due to its over-complexity and lack of ability to deal with concurrent delays. Similarly, the As Built vs As Planned method was used in one of the case studies and, exactly as suggested by Arditi and Pattanakitchamroon (2006), was not successful because it is not yet popular and clients seems to have doubts about its abilities and results.

Figure 1, shows the research developed selection process for the DAMs. The process is dependent on the selection of a delay analyst having the appropriate experience which would influence the choice DAM. The process addresses all the relevant factors and the potential effects of such factors; however, it does not provide specific instruction for the selection of the DAM as such decision requires the analyst’s subjective view.

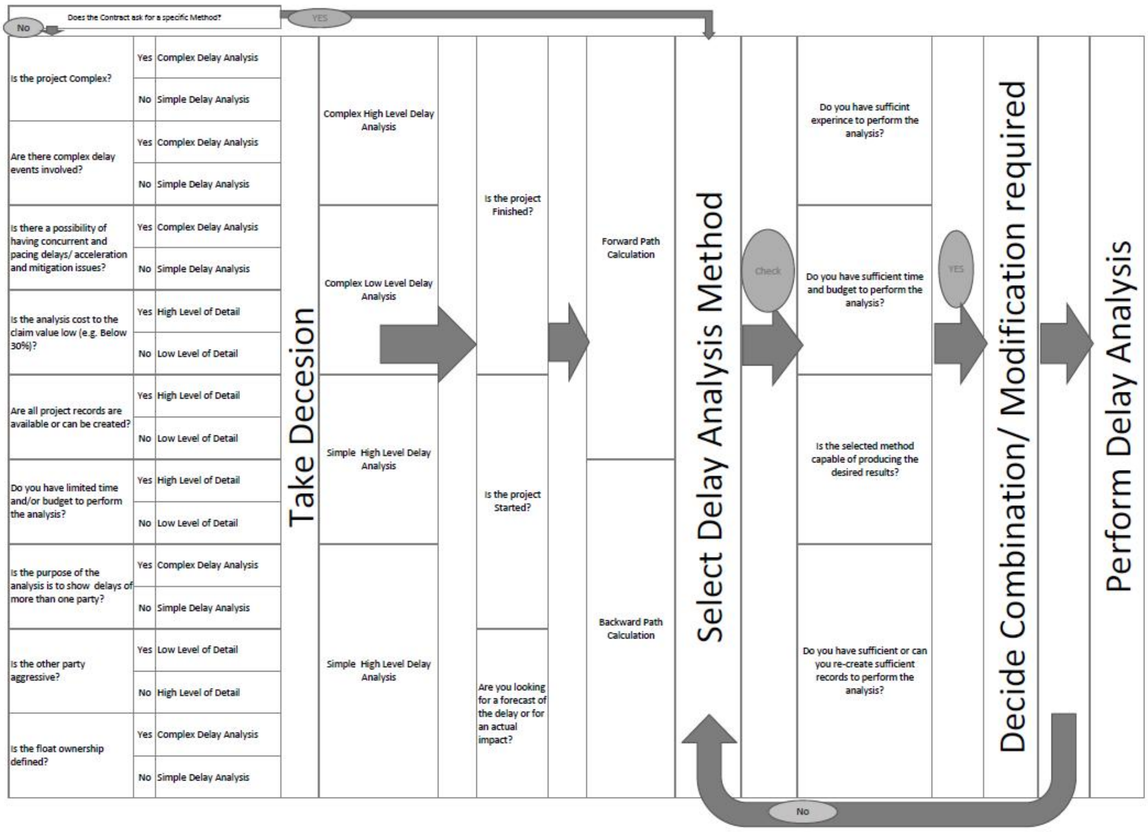

Figure 1: Selection process of delay analysis methods

5. Analysis and Discussion

The analysis of the case studies has shown that the main factors influencing selection of DAMs were the availability of records, the time available to perform the analysis, the attitude of the other party, the contractual requirements and the actual status of the project at the time of performing the analysis. The main factors that were found to be influencing the acceptance of the method were the attitude of opponent party and the purpose of the delay analysis which were highlighted by Braimah and Ndekugri (2008). An important finding however was that the selection of the method itself is a subjective decision of analysts based on their own understanding, interpretation and appreciation of the various factors. Interestingly, the reputation and the impartiality of delay analysts were found to be the main driver for accepting the delay analysis. Such factor was not directly addressed in the literature review although clients seem to be strongly influenced by such factor when making their decision.

There is an agreement that the first factor to check is that if the contract documents specify which DAM should be used. Although SCL (2002) suggests that new forms of contract nowadays specify the DAM, this was not the case in any of the projects examined in this study. The primary factors for the selection of the DAM were the availability of project records, the time available for performing the analysis and the point of time of time of the analysis. The interviewees also viewed the availability of an adequate baseline schedule, as part of the project records, as an essential element for performing the delay analysis.

Only one of the interviewees gave great importance to the experience of the delay analyst while others viewed it as a secondary factor. This could be because he was performing the float mapping method which is not a common method and may require special experience. SCL (2002)) emphasize on the importance of this factor as it may affect both the decision of selection of the method and the results of the analysis. Cost and time limitations are viewed as a constraint for both the selection of the delay analysis method and the level of detail of the analysis. Contractors seem to tend to utilize IAP Method, not only because it gives them favorable results, but also because it requires the least time and effort. Although SCL (2015) notes that the actual status of the project and the time of performing the analysis are the main factors, it appears that in practice they are secondary. Table 3 below, however, provides a summary recommendations, based on the reviewed literature and conducted interviews, that may assist delay analysts while deciding which DAM to utilize.

Table 3: Summary of recommendations (1-2)

Factor	*Conditions/ Circumstances*	*Recommended Method(s), listed on priority basis*
Records availability, accessibility and Quality	Baseline only	IAP
	As Built only	CAB
	Baseline and As Built	CAB OR ABvAP
	Baseline, periodic updates and As	TIA OR CAB OR ABvAP
Contractual Requirements	Specific Method	Specified Method OR Challenge with Justifications
Complexity of Project and Delay Events	Simple	TIA/ low level of detail (LD) OR Any Method/
	Complex	TIA/ High level of detail (HD) OR Complex Method/ HD
Skills of the Analyst	Expert	Perform Analysis
	Intermediate/Beginner	Get Support OR Refuse Job
The attitude of the opponent party	Lean	TIA/ LD OR Any Method/ LD
	Aggressive	TIA / HD OR Any Method/ HD
Time, Resource and Budget Constrains	High	TIA / LD OR Any Method/ LD OR Challenge Constrain(s)
	Law	TIA / HD OR Any Method/HD
	Complex	Complex/ HD

Factor	*Conditions/ Circumstances*	*Recommended Method(s), listed on priority basis*
Capabilities of the	Simple	Simple/ LD
Time of Performing Analysis	Before Start	IAP OR forward calculation method
	During Construction	TIA OR dynamic method
	After Completion	TIA OR CAB Or ABvAP OR dynamic
Concurrency, disruption and	Present	TIA OR Factual Based / HD
	Not Present	TIA /LD OR other simple method
Purpose of the Delay Analysis	Complex	TIA /HD OR modified version
	Simple	TIA /LD OR other simple method
Ownership of Project Float	Disagreed/Complex Apportionment	TIA /HD OR any complex method
	Agreed/Simple Apportionment	TIA / LD OR other simple method
Scheduling Settings	Special Settings/Constrains	TIA /HD OR complex method
	Common Settings/Constrains	TIA/LD OR other simple method

6. Conclusions

The challenge that most construction projects face is to deal with delays when they appear efficiently and effectively to be able to put the project back on track. This research reviewed the key literature on the topic and set case studies of the projects in the UAE to examine how the decisions to select a DAM and the factors influencing such a decision. The main finding of the research is that two DAMs, IAP and TIA, are dominant in the UAE construction industry with evidence that TIA is the most favoured by Clients. The availability of project records, the availability and quality of the baseline schedule, the actual status of the project and the time of performing the analysis are the primary factors that analysts consider when selecting a DAM. The results also showed that the selection of the DAM is subjective influenced by the delay analyst experience, knowledge and understanding. This is a new factor that can be aligned with the ‘skills of the analyst’ factor. Time and budget limitation are important factors. That would limit the work of the delay analyst who will have resist the pressure to compromise on quality and details as this may affect the accuracy, fairness and reasonableness of the delay analysis results. In summary, the research demonstrated that although the advantages and disadvantages of each of the DAMs are clear, the appropriateness of using any method remains influenced by the analysists personal views and judgment of the project events and their understanding of the appropriateness of the different DAMS.

The ability of the research to generalize its findings may be argued to be limited to the selected case studies. However, the depth of analysis and established trust between the researcher and the interviewees would give credit to the findings that provide a useful insight in such important and sensitive issues.

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Statutory Adjudication of Payment Claim Disputes in Australia Affected by On-Going Scrutiny by Courts and Changes to the Legislation

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Abstract

The object of statutory adjudication in NSW and Queensland is to ensure that a party, who performed construction work for another party, is able to recover payment. It is intended that payment would be made on an interim basis, pending final resolution. However, the NSW Supreme Court has viewed adjudicators as tribunals, proceeded to judicially review adjudication determinations and provided relief in the nature of *certiorari* to quash an adjudication determination where there has been jurisdictional error. This power to quash an adjudication determination was initially rejected but subsequently re-confirmed by the NSW Court of Appeal.

The recent amendments of the NSW and Queensland security of payment legislation have significantly modified the operation of the adjudication process. The main purpose of the amendments in NSW was to put in place an orderly regime of cash flow from principals, through to head contractors and subcontractors, and to create retention trusts in high value projects, to improve security of payment to parties who carry out construction work. In contrast, the purpose of the Queensland amendments was firstly to improve efficiency of distributing adjudication applications to qualified adjudicators through an office of the Adjudication Registrar of the Queensland Building and Construction Commission (QBCC) and secondly, to correct the perceived bias that adjudication of large payment claims within the short statutory time lines, disadvantaged respondents. To that end, the amendments introduced a two tier adjudication process for 'simple' claims of $750,000.00 or less and for 'complex' claims of over $750,000.00. Respondents are now able to raise further reasons for withholding payment during the adjudication process and the parties to an adjudication have more time to make submissions to the adjudicator.

The main objective of this paper is to critically assess, based on the published information, the case law, and the data obtained from the QBCC Registrar, the NSW Government and the Adjudication Research and Reporting Unit (ARRU) of the University of NSW, the performance of the recent amendments of the NSW and Queensland security of payment legislation.

Keywords: Adjudication, payment claims, amendments, NSW, Queensland

1. Introduction

In the first part of this paper, the brief history of the security of payment legislation in the Australian construction industry will be outlined, with a particular emphasis placed on the NSW Act, in relation to the evolution of the adjudication law. In the following parts, the recent amendments to the NSW and Queensland Acts will be outlined and the authors will attempt to assess the impact of the amendments on the performance of the adjudication process.

2. History of statutory adjudication in Australia

The *Building and Construction Industry Security of Payment Act 1999,* which commenced in New South Wales on 26 March 2000 (the NSW Act or the Act), was an outcome of the Cole Royal Commission into the conduct and practice of the construction industry in the late 1990's. The objective of the Cole Royal Commission was to review the conduct and practices employed in the Australian construction industry in view of a high rate of insolvencies, particularly among subcontractors, who are the main source of labour and who undertake work, which represents 75% of the total project value (Cole, 2003).

The NSW Act was the first legislation in Australia, which aimed at providing security of payment for parties who carry out construction work or supply related goods and services under a construction contract by way of a rapid statutory adjudication process. It followed the introduction of the *Housing Grants, Construction and Regeneration Act 1996* (UK) (the UK model) but it adopted a different path to the UK model. The NSW Act was taken up by Victoria in its *Building and Construction Industry Security of Payment Act 2002*. Significant amendments were made to the NSW and the Victorian Acts in 2002 and 2007 respectively to remove the option of respondents providing security in lieu of paying the adjudicated amount. Under the amended Victorian Act, claims for damages and delay damages are expressly excluded as are some disputed variations.

Queensland, in 2004, and South Australia, Tasmania and Australian Capital Territory, in 2009, adopted the amended NSW Act with minor changes. This became known as the eastern model as it generally operates in the eastern States of Australia. The eastern model is characterised by the rapid adjudication of payment claim disputes, where only a party (a claimant), who carried out construction work, may apply for adjudication.

Western Australia and the Northern Territory introduced their own security of payment legislation under *Construction Contracts Act 2004* and *Construction Contracts (Security of Payments) Act 2004* respectively. These Acts were based on the UK model and are commonly referred to as the western model, under which either party to a dispute may apply for adjudication. Timelines for submissions are longer than in the eastern model. The reason for narrowing down the scope of this paper to the eastern model and in particular, to the recently amended legislation in NSW and Queensland, is that data on the performance of the adjudication process in these two States is more readily available.

The intent of the original NSW Act was to ensure that a party, who carried out construction work or supplied related goods and services under a construction contract, received payment by way of a rapid adjudication process, pending the final resolution of the dispute by arbitration or litigation. However, the Act was found not to provide security of payment, as intended, as the respondent, instead of making payment of the adjudicated amount, could provide security for payment in the form of a bank guarantee or a deposit into a trust account pending the final resolution of the dispute. The outcome of this was that despite being successful in adjudication, the subcontractor received no payment and its cash flow was adversely affected.

The amendments introduced in 2002 re-affirmed the original intent of the Act and made it much more effective in providing security of payment by:

- empowering Authorised Nominating Authorities (ANAs), who collect adjudication applications and appoint adjudicators, to issue an adjudication certificate, which, when filed in a Court of competent jurisdiction, becomes an enforceable judgment for debt;
- preventing the respondent, in challenging an adjudication determination in a Court, to raise any cross-claims or any defence in relation to matters arising under the construction contract; and
- requiring the respondent to pay the adjudicated amount.

The effectiveness of the amendments was reflected in a sharp increase in a number of adjudication application, as reported by Uher & Brand (2005a). However, this period is also characterised by an increase in challenges to adjudication determinations in the NSW Supreme Court. In *Musico & Ors v Davenport & Ors* [2003] NSWSC 977 (‘*Musico*’), McDougall J viewed the adjudicator as a tribunal with power to make determinations that, although not final, are binding on the parties. On that basis, in paragraph [54] in *Musico*, McDougall J held that the Court had power under s.69 of the *Supreme Court Act 1970* to provide relief in the nature of *certiorari* to quash an adjudication determination where jurisdictional error is shown. This was contrary to the object of the Act in that the intended role of an adjudicator was that of a mere certifier.

Subsequently, in *Brodyn Pty Ltd trading as Time Cost and Quality v Philip Davenport & Ors* [2004] NSWCA 394 (‘*Brodyn’*) the Court of Appeal reversed the decision in *Musico,* to the extent that relief in the nature of *certiorari* to quash an adjudication determination that is not void, is not available, and that the only relief available was by declaration and injunction if a determination is void. The Court of Appeal provided guidelines as to the basic and essential requirements for a valid adjudication determination. These were: the existence of a construction contract, valid service of a payment claim and an adjudication application, and the adjudicator determining the adjudication application in accordance with the Act. The Court of Appeal held that a determination is void where the adjudicator acts outside its jurisdiction, including where the adjudicator does not exercise its power under the Act in a ‘bona fide’ manner and where it denies natural justice to a party.

The period post *Brodyn* is characterised by a further increase in the number of adjudication applications as reported by Uher & Brand (2005a), which reached the peak in or around 2005. This is verified by empirical studies by Brand & Uher (2004) and Uher & Brand (2005b), and by reports issued by the NSW Government and the ARRU. While generally complying with the principles decided in *Brodyn*, the Courts set aside many determinations for a variety of jurisdiction related reasons including denial of natural justice, abuse of process, issue estoppel, a payment claim being related to multiple contracts, not satisfying the contract pre-conditions of payment or not being referrable to a valid reference date, invalid service of documents and an adjudicator failing to apply an active process of intellectual engagement.

In *Chase Oyster Bar v Hamo Industries* [2010] NSWCA 190 [*Chase Oyster Bar*], the NSW Court of Appeal revised the decision in *Brodyn*. The Court, found that the adjudicator was a tribunal, and the NSW Supreme Court had power to provide relief in the nature of *certiorari* to quash an adjudication determination. As the laws now stands, adjudication determinations may be quashed by the NSW Supreme Court, where there has been a jurisdictional error of law and where an adjudicator denies natural justice to a party. However, this decision did not change the finding in *Musico* that judicial review of an adjudicator's decision is not available on basis of non-jurisdictional error of law.

The decisions of the NSW Courts have, to a large extent, been persuasive in Queensland Courts, nevertheless, the Queensland Supreme Court and the Court of Appeal have, in some instances, handed out decisions, which are contrary to the decisions of the NSW Courts.

3. The 2010 Amendments of the NSW Act and their impact on the operation of the Act

Upon a review of the operation of the Act, in 2010 the NSW Government inserted a new Division 2A into the Act to give greater protection to subcontractors. Prior to this amendment, a claimant (a subcontractor), upon filing an adjudication certificate in a Court, could request the Court to issue a debt certificate under s.7(1A) of the *Contractors' Debts Act*. If served upon the principal, the principal would be required to action the debt certificate by deducting an adjudicated amount from payment to the respondent (a head contractor). The shortcoming of this mechanism was that upon the conclusion of an adjudication process, the principal may have already paid the respondent the full amount of its entitlement so the debt certificate was of no utility.

The new Division 2A of the Act provided, in sections 26A–26F, that a claimant (a subcontractor), who has made an adjudication application, may serve a 'payment withholding request' upon the principal. The principal is then required to retain sufficient money due to the respondent (a head contractor) to cover the claimant's payment claim. This new mechanism, while allowing a subcontractor to issue a payment withholding notice much earlier than under the *Contractors' Debts Act*, does not guarantee payment to the subcontractor in circumstances where the principal has already paid the respondent its payment entitlement. This may well be the reason, why subcontractors, in the authors' personal experience as adjudicators, only infrequently rely upon sections 26A–26F of the Act.

4. The 2013 Amendments of the NSW Act and their impact on the operation of the Act

4.1 Introduction to 2013 amendments

On 9 August 2012, the NSW Government established an inquiry into Construction Industry Insolvency in NSW, headed by Bruce Collins, a Queens Counsel. The impetus was the financial collapse of a number of established building/construction companies. The purpose of the inquiry was to recommend measures to better protect subcontractors from the effects of insolvency of head contractors.

The Final Report was published on 28 January 2013 (Collins, 2003). It made a number of recommendations, some of which were adopted by the NSW Government as the 2013 Amendments of the Act. The most notable amendments will now be briefly discussed.

4.2 Definition of subcontractor, head contractor and principal

Superseded section 4 of the Act provided definitions of various terms including the definition of *claimant* and *respondent*. Amended section 4 introduces, for the first time, definitions of *subcontractor*, *head contractor* and *principal*. This was necessary for the proper interpretation of a new regime for the due date for payment outlined in amended sections 11(1A–1C), trust accounts for retention in section 12A and the supporting statement in section 13(9) of the Act.

A *head contractor* is defined as "*the person who is to carry out construction work or supply related goods and services for the principal under a construction contract (the main contract) and for whom construction work is to be carried out or related goods and services supplied under a construction contract as part of or incidental to the work or goods and services carried out or supplied under the main contract*".

It emerges from this definition that a party cannot be a *head contractor* unless the party enters a construction contract that requires another party to carry out part of the *head contractor's* obligations under the main contract. A *head contractor* must also have at least two construction contracts, one with the *principal* and one with a *subcontractor*. A *head contractor*, whose construction contract bars sub-letting of any part of the contract works, is not a *head contractor* but a *subcontractor*.

While there will always be a subcontractor, given the varied nature of contractual arrangements associated with building/construction projects and the varied nature of roles played by participants to construction contract, Davenport (2014, pp. 2–4) observed that "*in the course of a contract, a* *principal can mutate and cease to be a principal and a subcontractor can mutate and become a head contractor. On any day, you may not know whether a party to a construction contract is a principal, a head contractor, a subcontractor or something else*".

In circumstances, where a subcontractor or a head contractor can both be a claimant, the parties' failure to correctly identify their status could lead to confusion as to whether the claimant is a subcontractor or a head contractor and whether the respondent is a principal, a head contractor or a subcontractor. Although the authors are unaware of any adjudication application falling over due to the failure to properly identify the status of the parties in relation to a construction contract, as noted by Davenport [2014], Rippon & Smiley [2014] and Davenport at el (2015), these new definitions may bring about a real problem for adjudicators to interpret the proper status of the parties.

4.3 Due date for payment

Prior to the 2013 Amendments, the due date for payment was, according to section 11 of the Act, 10 business days after a payment claim was made if a construction contract made no express provision thereof.

The amended section 11 now differentiates between payment by a principal to a head contractor and payment to a subcontractor. Under s.11(1A), the maximum period for payment to a head contractor is 15 business days after a payment claim is made and under s.11(1B), the maximum period for payment to a subcontractor is 30 business days after a payment claim is made.

The rationale for mandating the maximum period of 15 business days for payment to a head contractor is to improve the flow of cash from top of the contractual chain down through the supply chain. This amendment clearly benefits head contractors' cash flow but it may impair the principals' ability to source funds from lenders within the prescribed time frame.

The statutory maximum period of 30 business days for payment to subcontractors is likely to adversely affect the cash flow of subcontractors involved in small value subcontracts, who often enter into subcontracts with no express terms of payment. Prior to the 2013 Amendments, payment was, in those circumstances, due within 10 business days of the date of service of a payment claim. Under the amended section 11(1B), payment is now due some 20 business days later. This amendment may also compel subcontractors to rely on other than the adjudication process to recover payments. While no statistical data is available from either the NSW Government or the ARRU on the impact of this amendment on subcontractors and the adjudication process, the information obtained from one ANA indicates that in the period after the amendment to June 2015, the number of adjudication applications declined by 28%. However, whether this is entirely related to the amendment or to some other factors, is not clear.

Only subcontractors, who may benefit from the amendment, are those, involved in high value subcontracts, where they traditionally receive payment well after the new mandatory period of 30 business days.

4.4 Removal of a notice that a payment claim is made under the Act

Prior to the 2013 Amendments, a payment claim required to be endorsed as a claim under the Act. This ensured that the Act only applied to such endorsed payment claims.

Under the 2013 Amendments, a payment claim under a construction (non-residential) contract is no longer required to state that it is made under the Act.

Facts Sheet 4 (2014), issued by the NSW Government, explains the rationale for this change by asserting that the mandatory endorsement of a payment claim as a claim under the Act, made subcontractors reluctant to use the adjudication process for fear of losing future work. This issue was identified by Brand & Uher (2004) and Uher & Brand (2005b), in analysing the performance of the Act in the first few years, as a potential problem for subcontractors. However, contrary to Facts Sheet 4 (2014), there is no evidence whatsoever that in the past 10 or more years, the endorsement requirement had the effect of intimidating subcontractors.

An unintended side effect of this amendment is that any document may be a valid payment claim under the Act if it satisfies the requirements of section 13(2) of the Act. This will require a respondent to be vigilant and issue a payment schedule in respect of each document, which may be or may appear to be a valid payment claim and which is referrable to a reference date. The failure to do so may expose the respondent to the risk that the claimant would proceed to recover payment as a debt due in any court of competent jurisdiction.

This amendment could also cause a problem for a claimant. This is demonstrated in the following example. In a day to day communication with a respondent, the claimant may issue an email in which it identifies construction work and indicates the amount that the claimant claims to be due. The respondent may construe this email to be a payment claim. Prior to issuing a payment schedule within 10 business days of receiving the email, the claimant issues a regular monthly payment claim. Provided the email satisfies the requirements of section 13(2) of the Act, it would be found to be a valid payment claim. Accordingly, a subsequent monthly payment claim could be a second payment claim referrable to the same reference date. As such, it would be invalid under the Act.

Although no statistical data is available on whether or not this amendment has caused adjudication applications to fall over, the authors have, in their practice as adjudicators, become aware of adjudication applications being found to be invalid due to this issue.

4.5 Mandatory head contractor statement

The 2013 Amendments include, in sections 13(7) and 13(9) of the Act and in section 10 of the Building and Construction Industry Security of Payment Regulation 2008 (amended on 1 May 2015), a new provision, which requires a head contractor to include, with a payment claim served upon the principal, a supporting statement in the form of a declaration to the effect that all subcontractors have been paid all amounts that have become due and payable in relation to the construction work the subject of the payment claim. No such requirement has been placed upon subcontractors making a payment claim against head contractors and no rational for this has been provided by the NSW Government.

This new provision has, according to Facts Sheet 3 (2014), issued by the NSW Government, further improved subcontractors' security of payment by requiring head contractors to make a required declaration of payment to subcontractors at the time of making a payment claim to the principal. Section 13(7) of the Act provides a maximum penalty of $22,000.00 for failure by a head contractor to provide a declaration with a payment claim. Section 13(8) of the Act provides a similar monetary penalty and/or 3 months imprisonment for knowingly providing false or misleading information in a declaration.

No statistics are available at present as to the impact of this new provision on the operation of the Act. However, the authors are of the view that while this provision may improve security of payment of subcontractors, it is less likely to improve the position of sub-subcontractors of a subcontractor who makes a payment claim on the head contractor.

4.5 Trust account for retention moneys

The 2013 Amendments include a new section 12A relating to retention money being held by a head contractor in trust for a subcontractor. It was enlivened by the proclamation on 1 May 2015 of the Building and Construction Industry Security of Payment Regulation 2008. The regulation in section 5 requires head contractors to hold retention money in a trust account for subcontractors, where the head contract value reaches a threshold of $20 million, either at the time when the head contractor entered into a main contract with the principal or when the original main contract value reaches the threshold.

The retention trust created in section 12A of the Act, is not the statutory construction trust recommended in the Collins Inquiry Final Report. The Final Report recommended that any payment by a principal to a head contractor, or by a head contractor to a subcontractor, or by a subcontractor to a sub-subcontractor, for work done or materials supplied by the head contractor, subcontractor or sub-subcontractor, be held on trust where the value of the building project exceeds $1,000,000. This recommendation was to ensure that in case of insolvency of a head contractor or subcontractor, money paid for work done or materials supplied would be protected. The NSW Government's reason for limiting the statutory trust to retention, managed by a head contractor for contracts greater than $20 million in value, is unclear.

This amendment was criticised by the Housing Industry Association (HIA, 2015) on many grounds, including that no reciprocal proposal has been created to quarantine head contractors' retentions held by principals, and that the trust creating, managing and reporting requirements are overly onerous and anticompetitive.

While this new amendment recognises the importance of protecting subcontractors' retention money, it only operates on projects with a value of at least $20 million and in any event, the only guarantee that the retained amount is secured in case of insolvency of a head contractor is that provided by the laws governing trusts. Subcontractors engaged on small value contracts will continue to have their retention money unprotected.

This new amendment has no impact on head contractors if the contract value does not reach $20 million. However, when it is reached, which could occur any time during the execution of the works, head contractors will assume an additional administrative burden in establishing and managing a trust fund in respect of subcontracts entered into after the threshold is reached, and in complying with the reporting requirements. It is likely that at least some head contractors will attempt to negate the impact of amended section 12A of the Act by moving away from cash retention in favour of a bank guarantee. While no empirical data is available at present to verify this, the authors have already experienced, as adjudicators, a shift away from cash retention to bank guarantees in high value contracts between head contractors and subcontractors.

5. Recent amendments to the Queensland Act and their impact on the adjudication process

5.1 Introduction to recent amendments

The intent of a discussion paper titled 'Payment dispute resolution in the Queensland building and construction industry', issued by the Queensland Government in December 2012, was to obtain feedback on the operation of the Building and Construction Industry Payment Act (the BCIPA Act or the Act). It resulted in the release of a Final Report, prepared by Andrew Wallace, on 24 May 2013 (Wallace, 2013). The main recommendations of the Final Report were accepted by the Queensland Government in the form of the 2014 Amendments of the Act. The two most prominent amendments will now be briefly discussed.

5.2 Appointments of adjudicators by the Adjudication Registrar only

Prior to the 2014 Amendments, claimants lodged adjudication applications with privately operated ANAs, who in turn referred the applications to adjudicators on their respective panels.

Under the 2014 Amendments, the responsibility for receiving adjudication applications and for appointing adjudicators now lies with the Adjudication Registrar of the QBCC. The 2014 Amendment in effect abolished the ANAs and centralised the administration of the Act within the

QBCC. This was intended to improve efficiency and effectiveness of the adjudication process, improve the quality of adjudicators through mandatory transitional training and through on-going professional development, and remove perception that some adjudicators and some ANAs were claimant friendly.

While the Wallace Final Report provided no verifiable evidence of inadequate training of adjudicators, the requirement for on-going professional development of adjudicators under the new regime must be viewed a step in the right direction.

It is commonly accepted that greater efficiency of public services can be realised through privatisation. In that context, the decision of the Queensland Government to abolish the ANAs and administer the Act through the QBCC, is a revolutionary step.

The Adjudication Registrar of the QBCC provides, on its website, comprehensive monthly statistics of adjudication applications submitted, adjudication decisions released, certificates issued and adjudication fees charged. In the period from July 2015 to November 2015, 44% of adjudication applications, made under the 2014 Amendments, did not proceed to adjudication for the reason of withdrawal due to invalidity of applications or settlement. In comparison to the same period under the original Act (from July 2014 to November 2014), 26% of adjudication applications did not proceed to adjudication. Whether this indicates that there are gaps in information that the Adjudication Registrar provides to claimants on how to prepare valid applications or the high rate of failed applications is a short term issue related to the transition from the original to the Amended Act, is not clear.

5.2 Dual system of adjudication

Perhaps the most significant change to the Act was the creation of a dual system of adjudication. A claimant must now identify in a payment claim whether the claim is a standard or a complex claim.

A standard claim is a claim with a monetary value of $750,000.00 or less. The time frame for providing a payment schedule and an adjudication application has not changed. However, the time frame for the lodgement of an adjudication response has doubled from 5 to 10 business days. Otherwise, adjudication of payment claims follows much the same path as under the original, unamended Act.

A complex claim is a claim with a monetary value of more than $750,000.00. It is worth noting that it is not necessarily a claim involving complex issues. The only parameter for a claim to be classified as a complex claim is its monetary value.

An adjudication response, issued in response to a complex claim, may include new reasons for withholding payment not previously included in the payment schedule and the claimant has a right of reply to such new reasons. In order to accommodate the claimant’s additional submission and by assuming that a complex claim is multifaceted and wide ranging, the amendment provides a significantly longer time lines for adjudicating a complex claim, which could be in the order of many months. In comparison, the time frame for adjudicating a standard claim is only 30 business days from the day of service of the claim.

Given the significantly different time lines between complex and standard claims, it is likely that claimants would prefer to make standard rather than complex claims in order to secure payment in the shortest possible period. The statistics provided by the Adjudication Registrar indicate that in the period from July 2015 to November 2015, only 12 complex claims or 7.1% of all claims, have been made. It is not possible to directly compare the number of complex claims of over $750,000.00, made under the Amended Act to the same value claims made under the original Act as the Adjudication Registrar's previous statistics classified large claims as claims in access of $500,000.00. Notwithstanding, it is to be noted that in the period from July 2014 to December 2014, just prior to the introduction of the Amended Act, there were 35 or 16.3% of all adjudication decisions related to claims in access of $500,000.00. While the value of some of these claims would have been below $750,000.00, the difference in the percentages is sufficiently large to suggest that high value claims had more frequently been made under the original Act than under the Amended Act.

6. Conclusions

Wide ranging amendments were made to the NSW Act in 2010 and 2013. New provisions were introduced in the form of a payment withholding request, a head contractor's statement and a retention trust to further enhance security of payment of subcontractors. Of these provisions, only a head contractor's statement is likely to achieve the desired objective as a payment withholding request would only provide security of payment in circumstances, where the principal is yet to make payment to the head contractor. The establishment of a retention trust will not enhance security of payment of small subcontractors or those engaged on a project of less than $20 million.

The impact of the amendments on the operation of the adjudication process is not possible to assess objectively for lack of statistical data. In the authors' view, while the amendments are likely to further improve security of payment of claimants and subcontractors in particular, compliance with the new provisions, such as a head contractor's statement and a retention trust, will increase the administration cost of construction contracts.

An unintentional consequence of the removal of the requirement to endorse payment claims as claims under the Act is that documents not intended to be payment claims may in fact qualify to be valid payment claims under the Act. This has already resulted in an intended payment claim being invalid as it was referrable to the same reference date as a valid but unintended payment claim.

The new maximum mandatory date for payment of subcontractors of 30 business days is contrary to the original intent of the Act to provide payment within 10 business days, unless a construction contract allowed for a longer period. This will impact adversely on the cash flow of subcontractors who enter contracts with no payment terms. The data available from one ANA indicates that this amendment may have caused the reduction in the number of adjudication applications made in the post-amendment period.

The 2014 Amendment of the Queensland Act, which abolished privately operated ANAs in favour of having adjudication applications submitted to the Adjudication Registrar of the QBCC, who in turn appoints adjudicators, runs contrary to an established trend of achieving greater efficiency through privatisation. It is much too early to draw conclusions as to whether or not this amendment has achieved any efficiency. The data provided by the Adjudication Registrar indicate that at least, in the short term, more adjudication applications have not proceeded to adjudication for the reasons of either being non-compliant or withdrawn. This may indicate that the Adjudication Registrar does not advise claimants on the process of making valid adjudication applications to the same extent as now abolished privately operated ANAs. Another significant 2014 Amendment of the Queensland Act was the creation of a dual system of adjudication, which provides for claims in excess of $750,000.00 to be adjudicated over a significantly extended period. This will undoubtedly result in an increased cost of adjudicating such claims. The present trend indicates that claimants are averse to making complex claims in excess of $750,000.00.

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Designing Project Management

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Abstract

In this paper we introduce the concept of Designing Project Management. On the basis of our earlier work, we suggest that there is still a gap between what is known from recent project management literature and what project managers can structurally help in the effectiveness of their work. Assuming that project management is a form of solving wicked problems, we propose a designerly way to solve these problems. To this end, we introduce the Project Design Cycle, consisting of the elements Awareness, Design, Performance and Reflection. This cycle has been studied in a purely exploratory study. Result of the study is that these elements are sometimes recognized, sometimes not, that the order of these elements has been hardly recognized, that the difference between Reflection-in-action and Reflection-after-Action has been recognized and a distinction seems to occur between a 'large' Project Design Cycle through the overall project management and a 'small' Project Design Cycle in the daily management. We finally conclude that more training in the cycle is necessary because this will possibly lead to a more effective project management.

Keywords: Project management theory, managing, designing, project management education

1. Introduction

In this paper we introduce the concept of Designing Project Management as a domain specific approach to the management of architectural design and construction projects in an ever changing environment. Much recent research points to the importance of understanding projects, and building projects in particular (Svejvig, 2015), as social systems in which there is a complex interplay and alignment of different goals, meanings, and perspectives (O'leary, 2013). This research suggests that it is important to take the personal, professional and business situations of project partners, commissioners and stakeholders into account when attempting to manage project teams [citation]. Many of the leaders in the rethinking project management (Cicmil, 2006; Hodgson, 2006; Morris, 2013) have come to the conclusion that as yet little of this research has led to significant advances in project management tools, practice, or education. Nor does the so-called classical approach address issues of daily practice or career development of project managers structurally do. In this we believe that current approaches to project management, while containing much essential material are not entirely adequate to the task of helping project managers to carry out their work (Heintz, 2015).

Our purpose is to refocus education from learning the systems of project management to learning how to be a project manager. To do this we propose an approach to project management that is based on the agency of the project manager rather than on the integrity of project management systems. It is not that we believe that the project management systems are irrelevant, but that we place the emphasis on the project manager's agency in selecting tools and actions from those systems and enacting courses of action using them. More specifically, we choose to see project management as a process of designing and enacting courses of action and "preferred situations". In doing so we are shifting attention from project management as an idea to project management "an ostensive (the idea) … [to] a performative (the enactment of the idea) dimension" (Carlgren, 2016).

We call this approach Designing Project Management. The research intention is as much to provide a lens through which to view project management action as to confirm the use of designerly approaches to problem solving by project managers. The educational intention is to offer a model for and an approach to training students in management of design and construction projects in how to enact the systems and theory of project management in the management of complex building projects. Further we believe that this approach will support young project managers in developing their professional capabilities.

This paper discusses the results of a preliminary explorative research project attempting to determine if the elements of the project design cycle can be recognised in the practice of project managers, and to what extent these elements function together as a cycle. The data consists of am interview based case study, and four semi-structured interviews of project managers. We found that the elements were observable, and that while not structured as a formal cycle, a regularity and interdependency between the elements could be observed.

2. Designing project management

2.1 Design in project management

By focussing on the action of the individual project manager we shift the interest from the validity and robustness of project management systems, many of which are aimed at monitoring and enforcement, to the interventions project managers make in steering projects towards successful completion. Such interventions occur at a range of scales from major problems such as development of project organizations to 'smaller' daily problems such as conflicts between project team members. Seen this way, project management is a form of problem solving (Ahern, 2014). These problems may be planning problems, or they may be problems requiring interventions in already ongoing events. Anticipating the current interest in design thinking Herbert Simon connected problem solving in areas such as management with design in areas such as architecture (Simon, 1969) He proposed that design was a approach to general problem solving across a wide range of fields, and defined design as itself "defin[ing] courses of action aimed at changing existing situations into preferred ones." (Simon, 1969) A more recent and more specific definition is: "A design can be defined as a model of an entity-to-be-realized, as an instruction for the next step in the creation process." (Aken, 2007). Indeed project management can be seen as a process of situated inquiry in which the project manager must interrogate the situation he or she finds themselves in, and through processes of sense-making arrive at judgements about, or design, what to do. (Lalonde, 2012)

The recent interest in the application of design thinking to management (Boland, 2004; Martin, 2009; Brown, 2008) has been based on the belief that because of its "liquid and open character" (Boland, 2004), design is an excellent way to approach the more general types of problems encountered in management. Although much of the literature on design thinking in management has drifted away from the earlier work on what Carlgren et al (2016) call designerly thinking, we believe that the distinction will be more limiting than empowering of research and practice in this area.

We therefore draw our inspiration from both the contemporary work on Design Thinking, and the older work on how designers think (Dorst, 1997; Cross, 2006; Lawson, 1997).

Design problems facing design and construction project managers include developing briefs and budgets, composing the design teams, specifying tendering approach and project organization, and creating construction schedules. However, design is also required in order to solve the day-to-day problems that face building project managers. Determining how cope with conflicts between stakeholders or actors, deciding how to bring a jury's deliberations to a close and choose the architect. In each case the project manager must inform him or herself about the current situation, and determine a course of action that is very likely to lead to the desired result. Both kinds of design problems, the mapping out of the future course of the project, and the resolution of day-to-day problems occur under a high level of uncertainty, and in dynamic situations where hidden and exogenous factors will likely play a significant role in driving the project off the current plan. Design thinking is required to find courses of action that will yield the desired results but will be robust across a large range of possible futures.

2.2 The Project Design Cycle

Design whether in the more generalized sense described by Simon, or in the more specific architectural sense, is a cyclical process. In the simplest sense this is a cycle of generate and test (Simon, 1969), but the design cycle also bears similarity to Deming's Plan-Do-Check-Act cycle (Deming, 1952) and the Kolb Learning Cycle: Concrete Experience – Reflective Observation – Abstract Conceptualization – Active Experimentation (Kolb, 2000). These similarities are not coincidental, design and management both rely on learning and feedback from the situation to arrive at better outcomes than might otherwise be realized. For the purposes of illuminating the role of design in building project management the following formulation of the cycle may be most helpful:

Awareness – Design – Performance – Reflection

2.2.1 Awareness

The cycle begins with establishing awareness of the current situation. This awareness encompasses not only the formal project as captured in so called "project information", but also, and importantly, the social situation (situational awareness), including the status and state of the various actors and stakeholders in the project. Awareness of what is going on, who is doing what, etc. Also of intentions, goals, and plans. Awareness also encompasses the determination that 'something needs to be done' i.e. deviation from the intended course of the project in some why. Awareness has a very significant component of sense-making.

2.2.2 Design

Out of awareness flows an understanding of both the current state, a need for change and perhaps a desired outcome. Having determined that action is required, design refers to the shaping of a course of action. Design thinking here is important in its open and free approach to generating alternatives and possibilities. But Design should include both generate and test. A designed course of action is also one that has been in some sense tested.

2.2.3 Performance

The designed course of action must be performed by the project manager. The choice of the word performance refers to the performative aspect of management. It is not just a matter of carrying out the design. A performance is required in that project management requires that one changes people's minds and actions. This requires that one reach them in the same way an actor does. Here we define performance as acting/ putting on a mask to change behaviour.

2.2.4 Reflection

Finally, there is a reflection upon the outcome, attempting to draw any lessons about the designed course of action or its performance that may be useful in the future. We use Reflection in two different senses. In the first sense reflection refers to reflecting in a separate moment after the performance is completed, reflection-after-action. This type of reflection is used by e.g. Deming's (quality) management cycle and Kolb's Experiential Learning cycle (Kolb, 2000). The second sense in which we use reflection is reflection while performing, referring to reflection-in-action, introduced by Schön and defined as thinking about doing something while doing it (Schön, 1983). It is precisely these two approaches of reflection-after-action like Deming and Kolb and reflection-in-action as described by Schön that seem to come forward in the next case.

3. Case: the Vondelpark Pavilion in Amsterdam

3.1 Introducing the case and methodology

The Vondelpark Pavilion is at a magnificent location in the Vondelpark in Amsterdam. Previously, the Pavilion housed a Film Museum, and a café (always packed in the summer), giving the location the reputation of 'a cultural media house', a platform where the creators of art and culture programmes could find a varied audience. The departure of the Film Museum meant that new tenants had to be found – and a second media organization agreed to lease the building. A new restaurant tenant was also found at this time. Due to the change in tenancy and a substantial backlog of maintenance issues, the building had to be substantially rebuilt. The new lease agreements left a very limited time for the renovation. The project management was in the hands of the Project Management Office of the municipality of Amsterdam and consisted of a project manager, assisted by an assistant and a quantity surveyor.

To explore to what extent the Project Design Cycle described above could be recognized in the daily practice of a project manager , a pilot interview covering the Vondelpark Pavilion project was held with the project manager. The data were analysed on four topics: 1. the identification of the elements of the Project Design Cycle, namely Awareness, Design, Performance and Reflection, 2. the sequencing of the elements of the cycle, 3. the difference between Reflection-after-action and Reflection-in-action and 4. the identification of large and small scale cycles during the project. The interviewee was already aware of our work, and for this reason a document was provided ahead of the interview clarifying our then current understanding of the project design cycle. The interview was conducted in Dutch, and translated by the authors.

3.2 Data and Findings

When asked if he could recognize the elements of the PDS in his work for the Vondelpark pavilion, he replied: 'the funny thing about the [PDS] model is that in the last few years with the complex projects I have managed, you start with setting up the project on a rather systemic way – I mean: the money should be okay, planning, organization etc. etc. – then you go along, and things prove to be quite different than you expected. This is not about, for example, whether the schedule is right, but it is about the peoples' perception, what their roles are, and whether they feel good about the objectives; because if [they do] not, they will object or start acting in complicated ways. In the latter case people just don't go along with you, do not act as agreed upon and then you must analyse, you must repair, you must change.'

In the Vondelpark project, at a certain moment different actors had different perceptions of the importance of keeping to the schedule. The schedule was accepted as such, but without sufficient commitment. It was only during the course of the project that the project manager became aware of this problem. Once he became aware of this issue, the project manager attempted several different approaches to getting the team to accept and implement the schedule. Including a 'hard line' strategy developed in consultation with the project manager's employer. All without success. Finally, the project manager determined to approach the issue by trying to understand what the schedule meant to the other actors, he spent two months in conversations between the various actors: *"my question remained; how do I get my team really involved in the plan? For a few months, at the start of a construction meeting, I began to ask every time: how are you? We were able to talk about our concerns, the opportunities we saw and the threats, about how the project was accepted in their organization. Further, a study of sense making[1] in the project seemed to start to bear fruit. People came as reborn out of the conversations that were held in the context of that research. In these conversations they had it made clear for themselves and others what this project was about. Hence they behaved differently during the regular project meetings and the schedule was actually no longer an issue."*

Reflective discussions by the group members during the regular meetings were uncomfortable, but there definitely was reflection during the 'sense making' conversations.

The episode outlined above displays the elements of the Project Design Cycle, but not in a clear sequence. There were Conscious moments of trying to make sense of the situation and then designing a course of action to remedy it. Also smaller cycles imbedded in a large cycle. Trial and error, but with intention. We see the project manager actively expanding his awareness, designing a strategy, trying, and then starting again. There was a 'large' Project Design Cycle from the fuzzy beginning, to the eventual implementation and confirmation of the overall schedule. But there were also 'small' daily

[1] This was a research project conducted by the second author, Louis Lousberg (Lousberg & Pikker, 2015)

cycles in, for example, meetings, in which following daily ‘surprises’ actions are planned, undertaken and given feedback to support the 'large' cycle.

The project manager had the awareness in advance that things could go wrong due to lack of clarity regarding the contract and designed an arrangement on this issue. In the everyday project management however, it seemed different: “*during the construction process, you're more reactive as manager, sometimes the phone rings and you have to solve a problem. However, you notice that there is not only a construction problem, but also from the angry call from the contractor that the structural engineer is not cooperating. And then when I check with the structural engineer it appears that he does not do so because he did not receive an order to do additional work. But, that's pretty standard, I have subsequently called the managing director of the structural engineer to have a coffee and asked him: why do you react so unprofessionally?*”

In this episode, the project manager saw *“no design here: it is a matter of just keep asking questions. Especially during the construction phase you can be direct, because there are simply agreements and everyone should keep them, so you can just say to someone: you’re not doing your job, why is that? It does not really require social skills, it's just being direct and directive. But sometimes you also have to be diplomatic, as in: how do we fix this?”* There appears to be a conscious dealing with problems on the one hand, but otherwise a fairly routine resolution is shown in which, at least not consciously, is designed and performed. It is, one might say, classical project management. Though there seems to be consciously reflecting-in-action.

This was completely different regarding a large ‘surprise’ in the project. *“The surprise with the hotel and catering industry entrepreneur was an exciting one. We had designed a kitchen with a catering consultant and tendered a hotel and catering entrepreneur as a tenant of the restaurant. After which this entrepreneur said: I can’t work in that kitchen. His design for the kitchen which cost not only a 100.000 euro’s more but also had all sorts of consequences for the rest of the construction work. I initially approached this in a hard way: ‘you pay it all by yourself, because you had to say this in the tender procedure’ but finally we settled it on each a half of that amount.”*

In this episode the project manager described his role as: “*first analysing what happens when we would accept this, what impact will this have not only on the building, but also on the costs on the basis of current contracts with e.g. the architect or the consequence for the penalty clause with the contractor at time overrun, in that sense it was complex. I eventually had to talk to the clients. Client B agreed because of the entrepreneurship and employment of this hotel and catering entrepreneur. But before that he summoned them to appear and informed them that this was the last time, otherwise he could leave. Client B picked this up beautifully: the entrepreneur sat shivering on his chair, because first the client made clear that this was the very last time and only finally he presented the deal.”* That was a moment of performance as we have defined in this paper.

Finally, we asked for moments of reflection e.g. at the end of the day. The project manager: *“I have a lot of those moments, especially when things have clashed. Then I ask myself: was this smart or tactical enough by me? I also discuss this often with my colleagues, of which the most important result is that you become aware of things and try out your thoughts. By talking about it, it becomes a kind of reality.”* With the observation that this turns out to be about Reflection-after-action the interview is closed.

4. Interviews with project managers

4.1 Introducing the interviews

After reviewing the pilot interview/case, semi-structured interviews were carried out with four project managers. For these interviews we did not explain the Project Management Design Cycle in advance. Nor were these interviews restricted to a single project. At the beginning of an interview we explained that the research was concerned with establishing what project managers actually do, that we had created a model on the basis of what is known in the literature and that we are now investigating whether the model is adequate. Also, we distinguish between strategic and daily management and that the model might be applicable to both. Interviewees were asked to tell us what they did. Questions followed where necessary to encourage the interviewee to address aspects of the PDS, but without using any of the terminology of the model. Extensive notes were taken from the recordings of the interviews, and the analysis based on these notes.

4.2 The four elements of the cycle

Our opening question at all four project managers was: "what do you do as a project manager?". One of them replied, *"I start with identifying … the program of requirements [including] the environmental factors i.e. stake-holders who can influence the project, feasibility studies, risk analysis, … and then I walk through all management elements. … [then] I start with a Plan of action."* Another project manager described his role as *"determining frames … My role in this is: making it a project. … I look at it from the point of view of project hygiene. My role is very much to agree, capture and make people stuck to their role. … I'm not going to start with a project if I don't have written my own project plan. You need to formulate your own assignment as it were. This includes explicit creation of what I do not. … First you focus the project on what do you want to achieve, then you need to set it up and then you go do."* Just like the project manager of the Vondelpark case, both project managers start with gaining awareness of the project and environment, and then create a Plan of action or determine and establish the frameworks within which the project can be carried out; the first steps in a large project design cycle.

Further, one of the project managers describes how she treats a 'surprise' in the daily work: *"I try to advise the client as well as possible, because in the end it is not my risk, but that of the client. I draw up scenarios, and the client then asks me ' what do you think? '. First, there is a problem signalled, that problem is extensively unravelled on what risks we actually have and there are possible measures (Design), where each choice has all kinds of consequences, up to and including the procurement strategy. So you will have to think about very well."* And another says about 'surprises': *"I manage decision making, by my client, but also by myself. However, if something happens, I always ask myself: 'is this bad, is it an issue? ', because what everyone does when something is an issue – especially in a meeting with techies – is to solve, without thinking at all whether it is necessary. I sharpen the problem in terms of consequences, I see that as my role compared to other team members."* To which another project manager adds: *"Actions such as letting clients choose where the paintings may hang – together with the architect – are deliberately designed [to create support for the project]."*

When asked to elaborate on acting out his role as project manager, one interviewee responded: *"I have been trained to think of yourself as a tool. That is, to be aware of what you can do and what you can't,* *also of how you look, what you're wearing, for example, a suit and sometimes a tie. The rule is that you never are underdressed. "* Another: *"Yes. I act absolutely. For instance, in a meeting where I enter and think about the place where I sit down, and meetings where I say nothing or only two things. What I'm going to do, mainly depends on the others."* And another: *"Sometimes you need some sort of decisiveness. This has to be called a form of bluff sometimes, because you still do not know exactly what's going on."*

Regarding Reflection one interviewee said: *"I think about work when I'm in bed at night. It's about responsibility. Whether did you do things well as a team, or did you have enough control …, did we do things well – you always doubt of course – did we make the right choice, could we have done it not better in another way?"* All four project managers said they think it's important to reflect with colleagues: *"Often this is in conversations with colleagues who were there. We discuss how it went, what the next steps are that we need to take, what those are in six weeks.* … It is sharing what you are going through, that mutual collegiality, that reflection is very important to be able to grow. That you should do as much as possible." Or: *"Moments of reflection are those in which I am away with my assistant on to or off from a meeting. We also here internally with colleagues do very much to exchange knowledge, both structurally at meetings every month as it happens to come across or look for each other, with us is that essential."*

In the interviews all four elements of the Project Design Cycle can be recognized both in large design cycles and in 'surprises' in everyday work. As in the Vondelpark case that they are not always seen by the interviewees to constitute a formal or explicit cycle.

4.3 Content and Support

In addition to the recognition of the PM Design Cycle, the analysis of the data from the four interviews resulted in two additional findings.

1. There seems to be an awareness of to distinct issues: content and support. All project managers report that they have a strategy or plan of action which they enact and against which they measure progress. This was often referred to as [project management] content. In addition to this, three of the interviewees emphasized their work on generating support or enthusiasm (*draagvlakt*) for the project: "For one of our projects we let the Board take a decision on our proposals for their wing. We have lots of support, since we have put a lot of time in it in recent months. So that decision will certainly succeed", as with the user" "Our added value is the creation of support [for the project]. By making people feel that they are heard, making them feel that something is done with the comments they make, even if you do nothing with it, explain why you do nothing, give feedback and as much as possible make them understand that it is going to work." For example let the architect have a say in the selection of technical advisers to have a good click because otherwise everyone sits on his small island" or "to make sure that everyone is heard, for example, despite differences in dominance in terms of personality. And I'm steering in the sense that I always say ' what are *we* going to do now, how will *we* approach this? (-) It is really people work, I'm aware of this increasingly." The latter is typical, there seems to be a dual consciousness in the way project managers look at their work. This dual consciousness seems to consist of content and support. Based on that Plans of approach are made (content) and captured (support) and meetings are led. "A junior project manager has in a great deal of difficulty in following the rhythm of a meeting. A senior project manager actually looks at what happens in a meeting, by which I mean how people respond, whether they are involved, or what they say, or not. A junior project manager has no time to think about how he should steer a meeting. … If it's in a meeting about an ICT-issue and the ICT-man says nothing, then you should think: 'That is not ok'. The way someone says something, or doesn’t say, is almost more important than what he or she says. "

2. That dual awareness has to do with the professional growth as a project manager. In the previous paragraph, a relation was established between the project managers focus on generation of support and the development of a project manager in his or her career. All four interviewees supported this relation. For example: "there comes a time in your career that you come out of the shadow of an experienced project manager into full exposure. … It is important that you gradually develop your soft skills more and more, that you observe how people are most effective." And: "you can be promoted from assistant manager to senior manager if you can look further than just facilitating, if you have an eye for the interests at stake. If you have a kind of independence, and are aware of the risks out there . … It also has to do with your attitude, you shouldn’t be an uncertain little mouse.” And again: "Self-reflection and feedback (Reflection) of your surroundings is an important part in order to grow. If you always make others responsible, you can’t grow. … You have to dare to experiment with management styles to see what work, therefor you need self-reflection.” Beside that dual awareness has to do with professional growth, the last quoted project manager seems to indicate that even in that there is a cycle.

4.4 Education

The interviewees were explicitly asked which characteristics or capabilities distinguished a senior project manager (capable of leading projects independently) form a junior project manager (capable only to assist a senior project manager). In addition to the dual awareness described in the previous section, they consistently identified two things that were key in this distinction 1) the ability to conceive of and enact courses of action independently, 2) the ability to lead or carry a team – to perform with authority. Thus, while the knowledge of project management systems is an important pre-requisite to working as a project manager, it seems to be that it is precisely those capabilities highlighted it in the Project Design Cycle which are key to career development and success as a fully fledged project manager. Indeed, many of the interviewees indicated that as a senior project manager they no longer concerned themselves with monitoring daily progress or operating project management systems.

This points to the importance of preparing young project managers not only for their immediate employment as junior project managers, but also to be able to successfully grow into more senior roles. To do this, we believe that project management education should address issues of design, performance and reflection as integral to project management. We do not necessarily think that project managers trained through the use of the PDS will always follow these steps in practice, rather that by incorporating the PDS into their practice, they will approach the issues of awareness, design, performance, and reflection in a more considered and professional manner.

5. Discussion

The results reported here are only exploratory, and both additional data and analysis will be required to put the findings on a surer footing. What we have tried to do, is determine if the elements of the project design cycle could be identified in the daily practice of project managers, and if these elements occurred in the expected cyclical pattern. This has been done by investigating a pilot case and four comparable interviews with project managers.

The interviews have yielded evidence of all four elements of the Project Design Cycle. However, the complete cycle itself was not observed. Rather groups of elements were reported together, and in the order described in the model, but not the whole cycle. These fragmentary cycles occurred at both large scales and smaller day-to-day scales. There is too little data to show more than the possibility of recognizing these elements and the possibility of consistent relationships between them. Further research will be needed to both firmly establish the ubiquity of the Project Design Cycle elements, their cyclic relationship, and the degree to which project managers use these elements as an explicit method. However, we might speculate that the Project Design Cycle will not be observable ‘in the wild’ as an explicit method. Rather we believe that further research will show that the Project Design Cycle is a formalization of habits of thought and action common among experienced project managers.

Both the literature upon which the Project Design Cycle was based, and the interview results here have suggested that the Project Design Cycle and the behaviour it attempts to capture and (eventually) reinforce are strongly related to a number of important areas of management research – sense-making, methodological pluralism, design thinking and leadership. Further research will be needed, both in the literature and in the field, to explore how each of these processes manifest themselves in the behaviour of project managers and in the Project Design Cycle.

6. Conclusions

In this paper a first exploratory research is conducted into the recognition of the Project Design Cycle in managing building projects. Drawing from literature, the proposed Project Design Cycle consists of Awareness, Design, Performance and Reflection. Subsequently, in an interview with the manager of a complex project followed by comparable interviews with four different project managers we looked for moments in the management of the project to which one or more elements of the cycle may be attributed. The research reveals that: 1) the elements sometimes are and sometimes are not recognized. 2) The sequencing of the elements is barely recognizable. 3) In some moments there is reflection-in-action and sometimes reflection-after-action. 4) In everyday work sometimes management can be described as elements of a 'small' Project Design Cycle and sometimes as elements of a 'large' Project Design Cycle. 5) There seems to be a dual awareness: content and support and 6 That dual awareness has to do with the professional growth as a project manager. Follow-up research will reveal to what extent this can be confirmed and deepened.

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Stakeholder Management Practices to Boost Outcomes of Construction Projects

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Abstract

The role of project managers (PMs) in stakeholder management to boost project outcomes is investigated, by examining the practices that PMs adopt which lead to effective stakeholder management and studying the extent to which effective stakeholder management contributes to better project outcomes. Based on the literature review, a questionnaire containing 39 practices were identified and grouped into 8 categories. Using a survey questionnaire, data were collected from PMs in Singapore's construction industry. Adopting 11 stakeholder management practices could significantly improve the level of effectiveness in managing clients, consultants and/or main contractors, especially those that take into account stakeholders' power. It is also found that managing project stakeholders effectively can improve time performance, quality performance and owner satisfaction. It is recommended that PMs need to set and communicate common goals and objectives, understand stakeholders' interests and consider their power and influence on the project. To manage clients better, PMs need to prioritize stakeholders and develop a stakeholder interest list. The study found that clients prefer to be the sole winner in project disputes, but PMs need to strive for a multi-win solution. PMs need to cultivate skills and methods in managing stakeholders so that conflicts can be resolved in a collaborative and constructive fashion.

Keywords: Project management, stakeholder management, project outcome, construction projects, Singapore

1. Introduction

In a construction project, the stakeholders include the owners and users of facilities, project managers (PMs), facilities managers, designers, shareholders, legal authorities, employees, subcontractors, suppliers, process and service providers, competitors, banks, insurance companies, media, community representatives, neighbours, general public, government establishments, visitors, customers, regional development agencies, the natural environment, the press, pressure groups and civic institutions (Smith and Love, 2004). Leung and Olomolaiye (2010) stated that internal stakeholders, mainly the client, consultants and contractors, are key decision makers who are linked via legal contracts. As stakeholders can influence a project either positively or negatively, their rights, needs and expectations must not be taken lightly (Carroll and Buchholtz, 2006). If stakeholder management is not in place, it may bring about uncertainty and unexpected problems, where stakeholders' disparate actions can harm the project outcome (Aladpoosh et al., 2012).

The aim of the research is to investigate the role of PMs in stakeholder management to boost construction project outcomes. The specific objectives are to: (i) investigate the extent to which PMs practise stakeholder management; (ii) study the extent to which PMs' effectiveness in stakeholder management contributes to better project outcomes; and (iii) examine the practices that PMs adopt which lead to effective stakeholder management.

The scope of research is limited to PMs who work for clients (either as employees or project management consultants) who have managed construction projects in Singapore. These PMs may be working for project clients, architectural, engineering or project management consultancy firms.

2. Brief literature review

Taking into consideration that internal stakeholders are the key decision makers, this research focuses on internal stakeholders that PMs need to manage, namely clients, consultants and main contractors. PMs' effectiveness in managing stakeholders in a construction project is operationalized into effectiveness level in managing clients (Y1); consultants (Y2); and main contractors (Y3). The aim of stakeholder management is to achieve a successful project outcome (McElroy and Mills, 2003). The following variables relating to project outcomes are operationalized following Ling et al. (2009): cost performance (Z1); time performance (Z2); quality performance (Z3); and owner satisfaction (Z4).

Based on the literature review, the possible actions of PMs (X variables, numbered as X1 to X39), and how projects are managed to achieve effective stakeholder management (Y1 to Y3) are identified. It also uses the instrumental approach to identify the connections that exist between the management of stakeholder groups (Y1 to Y3) and the achievement of project goals (Z1 to Z4). The relevant actions that PMs can take in stakeholder management include: defining project missions, goals and milestones (Jergeas et al., 2000); understanding stakeholders' characteristics and exploring their circumstances (Chinyio and Olomolaiye, 2010); assessing stakeholders' behaviour (Freeman et al., 2007); understanding stakeholders' power (Bourne and Walker, 2005); engaging stakeholders (Leung and Olomolaiye, 2010); managing conflicts (Ogunbayo, 2013); and managing corporate social responsibility (Yang et al., 2009).

The literature review has revealed many practices in stakeholder management. The gaps in knowledge are that it is hitherto not known if: PMs are managing stakeholders effectively; adopting certain practices would lead to more effective stakeholder management; and better stakeholder management leads to project success in terms of time, cost, quality and owner satisfaction.

3. Research method

The research design was based on a questionnaire survey. A structured questionnaire was designed as the primary data collection instrument. The questionnaire was divided into three sections. Section A comprised questions to find out the characteristics of the construction project and project outcomes. Cost performance (Z1) was rated on a 5-point scale, anchored as: 1 = overrun budget by > 5%; 3 = cost same as budget; 5 = below budget by > 5%. Time performance (Z2) was also rated on a 5-point scale, anchored as: 1 = late finish by > 5%; 3 = finish on time; and 5 = early finish by > 5%. Product/output quality (Z3) was measured on a 5-point scale, where 1 = expectations not met; 3 = expectations met; and 5 = exceed expectations. Owner satisfaction (Z4) was measured on the 5-point scale where 1 = very low; 3 = neutral and 5 = very high. Respondents were also required to evaluate their level of effectiveness in managing three main stakeholders (clients (Y1), consultants (Y2) and main contractors (Y3)) on a 5-point scale similar to Z4. Section B requested respondents to rate extent to which stakeholder management practices were implemented for the project identified in Section A. These were derived from the literature review on stakeholder management practices, and rated on a 5-point scale, where 1 = not adopted, 3 = adopted about half the time, and 5 = adopted almost all the time. Section C sought information on respondents and their firms.

The population comprised PMs working for clients, or as consultant PMs in project management, architectural or engineering consultancy firms. In Singapore, there is no national registry of PMs, so the size of the population is not known. Random sampling was used to identify PMs from architectural, engineering and project management consultancy firms registered with the Building and Construction Authority's Public Sector Panels of Consultants. A search was also done on GOV.sg and Asiabuilders.com to identify PMs in the government sector and developer firms respectively. To increase the sample size, convenience and snowball sampling methods were also employed. E-mails were sent to firms and individual PMs, with follow-up calls made to these companies requesting for relevant PMs to participate in the survey.

4. Results

A total of 352 surveys were sent out and 43 responses were received. 35 questionnaires were completed comprehensively and used for data analysis. The majority of the respondents are PMs and senior PMs from middle management. They have worked in the construction industry for between 1.5 and 28 years, with an average of 15 years. The majority have more than 15 years of practice. The PMs work in client (public and private) organizations and consultancy firms, with the majority working in the private sector. The PM-respondents reported mainly building projects. The projects range from 415 m^2 to 250,000 m^2, with the average at 44,377 m^2. The majority of the projects cost above S$50 million (S$1 ≈ US$0.72), with a mean of S$106.5 million. Most of the projects took more than two years to be completed. Table 1 shows the projects had significantly poor cost and time performance indicating budget and schedule overruns. The projects had significantly good quality performance (Z3) and owner satisfaction (Z4) In addition, the PMs reported that they were significantly effective in managing clients (Y1), consultants (Y2) and main contractors (Y3).

Table 1: Outcomes of projects and stakeholder management

Code	*Variable*	*Mean*	*T-test*		*Y1*		*Y2*		*Y3*	
			t	*Sig*	r_s	*Sig*	r_s	*Sig*	r_s	*Sig*
Z1	*Cost Performance*	*2.600*	*-1.983*	*.028**	*.211*	*.223*	*.073*	*.677*	*.030*	*.865*
Z2	*Time Performance*	*2.171*	*-5.964*	*.000***	*.394**	*.019*	*.140*	*.422*	*.244*	*.157*
Z3	*Quality Performance*	*3.229*	*2.095*	*.022**	*.409**	*.015*	*.393**	*.019*	*.308*	*.072*
Z4	*Owner Satisfaction*	*3.743*	*5.380*	*.000***	*.344**	*.043*	*.409**	*.015*	*.455***	*.006*
Y1	*Effectiveness in managing Client*	*3.686*	*5.096*	*.000***						
Y2	*Effectiveness in managing Consultants*	*3.771*	*7.069*	*.000***						
Y3	*Effectiveness in managing Main Contractor*	*3.771*	*4.552*	*.000***						

*Notes: ** $p<0.01$; *$p<0.05$. r_s is Correlation coefficient, and sig is 2-tail. Sig for t-test is 1-tail.*

Objective 1 was to investigate the extent to which PMs practised stakeholder management in construction projects. Statistical t-test of the mean was carried out to check whether the population would adopt the practices to a significant extent or otherwise. The t-test results in Table 2 show that among the 39 practices, 34 have been adopted by PMs to a significant extent (mean > 3; t-value positive; and $p< 0.05$), indicating that PMs do actively adopt stakeholder management.

Objective 2 was to study the extent to which PMs' effectiveness in stakeholder management (Y) contributes to better project outcomes (Z). Table 1 shows that time performance (Z2) is significantly correlated with the effectiveness level in managing clients (Y1). When clients are managed more effectively, the project is less likely to have schedule overrun. Table 1 also shows that the effectiveness levels of managing clients (Y1) and consultants (Y2) have significant positive correlations with the output quality of the project (Z3) and owner satisfaction (Z4). This suggests that when PMs manage clients and consultants more effectively, project quality and owner satisfaction may be higher. There are significant positive correlations between owner satisfaction (Z4) and the level of effectiveness in managing project client (Y1), project consultants (Y2) and project main contractor (Y3) (see Table 1). This suggests that by managing all stakeholders more effectively, owners will be more satisfied.

Table 2: T-test and significant correlation results

Code	*Management Practices*	*Mean*	*T-test*		*Y1 (Client)*		*Y2 (Consultants)*		*Y3 (Main contractors)*	
			T-Value	*Sig.*	r_s	*Sig*	r_s	*Sig*	r_s	*Sig*
	Defining Project Missions, Goals and Milestones									
X1	*PM set common goals, objectives and priorities*	*4.171*	*9.809*	*.000*			*.405**	*.016*	*.457**	*.006*
X2	*PM identified clear project missions at different stages*	*3.971*	*6.992*	*.000*						
X3	*PM set project milestones*	*4.114*	*10.445*	*.000*						
X4	*PM communicated intentions and goals effectively to all stakeholders*	*4.200*	*12.154*	*.000*						
	Understanding Stakeholders' Characteristics									
X5	*PM gathered information about stakeholders*	*3.914*	*5.883*	*.000*					*.505***	*.002*
X6	*PM classified stakeholders into various criteria / groups*	*3.314*	*1.540*	*.067*						
X7	*PM prioritized stakeholders*	*2.257*	*-3.599*	*.000*	*.351**	*.039*				
X33	*PM re-conducted stakeholder analysis when there is a change in stakeholders*	*3.943*	*7.691*	*.000*						
	Exploring Stakeholders' Circumstances									
X8	*PM developed a stakeholder interest list and discussed it with team members*	*3.000*	*0.000*	*.500*	*.352**	*.038*			*.444***	*.008*
X9	*PM assessed each stakeholder's needs and constraints to understand the stakeholder's interest*	*3.800*	*5.454*	*.000*						

Code	*Management Practices*	*Mean*	*T-test*		*Y1 (Client)*		*Y2 (Consultants)*		*Y3 (Main contractors)*	
			T-Value	*Sig.*	r_s	*Sig*	r_s	*Sig*	r_s	*Sig*
X10	*PM took stakeholder interests into account in decision making and operations*	*4.057*	*9.150*	*.000*			*.351**	*.039*	*.335**	*.049*
X15	*PM understood stakeholders' circumstances*	*3.943*	*8.728*	*.000*						
X31	*PM formulated different strategies to manage different groups of stakeholders*	*3.743*	*5.158*	*.000*						
X34	*PM understood demands of various stakeholders*	*3.743*	*4.231*	*.000*						
	Assessing Stakeholders' Behaviour									
X11	*PM measured capacity of stakeholders to ascertain their willingness to cooperate with other team members*	*3.486*	*2.764*	*.005*						
X12	*PM understood the range of stakeholder reactions and behaviours*	*4.029*	*9.852*	*.000*						
X32	*PM predicted stakeholders' reaction to strategies and decisions before they are implemented*	*3.229*	*1.276*	*.105*						
	Understanding Stakeholders' Power									
X13	*PM assessed stakeholders' strengths and weaknesses*	*3.600*	*3.340*	*.001*						
X14	*PM explored probable strategies that stakeholders could employ to realize their objectives*	*3.657*	*4.638*	*.000*			*.380**	*.024*	*.369**	*.029*
X16	*PM rated the impact of project strategies on each*	*3.400*	*2.119*	*.021*					*.374**	*.027*

Code	Management Practices	Mean	T-test		Y1 (Client)		Y2 (Consultants)		Y3 (Main contractors)	
			T-Value	Sig.	r_s	Sig	r_s	Sig	r_s	Sig
	stakeholder									
X17	PM understood the power (influence, authority) of each stakeholder	4.229	8.620	.000						
X18	PM understood the urgency faced by stakeholders	4.400	13.715	.000			.394*	.019		
X35	PM implemented strategies depending on the demands of the stakeholders	3.571	3.977	.000			.389*	.021		
	Engaging Stakeholders									
X19	PM ensured effective, regular and planned communication	4.171	10.444	.000						
X20	PM exercised formal forms of communication	4.514	12.766	.000						
X21	PM exercised informal forms of communication	2.657	-1.922	.032						
X22	PM continued to engage with stakeholders when the project met with difficulties	4.257	12.176	.000						
X29	PM developed positive relationships with stakeholders	4.171	11.220	.000						
X30	PM built trust between stakeholders	3.914	6.614	.000						
	Managing Conflicts									
X23	PM identified potential conflicts between stakeholders	3.543	3.932	.000						
X24	PM identified types of conflicts and their causes	3.429	2.983	.003						
X25	PM identified possible coalitions between stakeholders	3.771	5.413	.000						
X26	PM took into account stakeholders' influence before resolving conflicts	3.714	5.122	.000			.354*	.042		

Code	Management Practices	Mean	T-test		Y1 (Client)		Y2 (Consultants)		Y3 (Main contractors)	
			T-Value	Sig.	r_s	Sig	r_s	Sig	r_s	Sig
X27	PM employed suitable conflict resolution strategy	4.086	8.223	.000	-.391*	.020				
X28	PM implemented a multi-win solution	4.143	7.690	.000	-.336*	.048				
	Managing Corporate Social Responsibility									
X36	PM undertook project with a sense of social responsibility	4.086	9.153	.000						
X37	PM exercised utilitarianism – chose actions based on what was best for as many stakeholders as possible	3.943	6.159	.000						
X38	PM managed projects with a sense of duty and in accordance with the law	4.457	11.628	.000			.349*	0.04		
X39	PM implemented stakeholder management with strong awareness of firms' CSR (corporate social responsibility) policies	3.800	4.625	.000						

*Notes: ** $p<0.01$; *$p<0.05$. Sig for t-test is 1-tail. r_s is Correlation coefficient, and sig is 2-tail.*

5. Discussion

Objective 3 was to examine the practices that lead to effective stakeholder management. The results in Table 2 show that there would be significantly more effective management of clients (Y1), consultants (Y2) and main contractors (Y3) when some of the practices are adopted to a higher extent respectively.

Results from Table 4 show that PMs setting common goals, objectives and priorities (X1) is significantly correlated with higher effectiveness in managing consultants (Y2) and main contractors (Y3). Clear indications and directions are necessary to ensure that consultants and main contractors fully understand project requirements, which will safeguard the quality and performance of project deliverables, and improve confidence among project stakeholders (Karlsen et al., 2008).

Table 4 shows a significant positive correlation between PMs gathering information about stakeholders (X5) and the level of effectiveness in managing main contractors (Y3). The result is consistent with Caroll and Buchholtz's (2006) finding on the importance of gathering information on stakeholders' background and role in the project. PMs should embark on aggressive information-gathering of stakeholders, such as their stake, power and influence on the project, as well as any opportunities, challenges and threats that the stakeholders face.

The t-test result in Table 4 shows that PMs do not conduct prioritization of stakeholders (X7) to a significant extent (mean = 2.257, t = -3.599 and p = 0.000), yet this activity is significantly correlated with effectiveness in managing clients (Y1). PMs may not have done this because they took for granted that the client should be given the highest priority, rather than other stakeholders. Taking the t-test and correlation results together, it is recommended that PMs conduct more systematic prioritization of stakeholders. This is important because it allows PMs to deal with the different stakeholders appropriately according to their power and interest in the project. By knowing which stakeholder takes priority, PMs will be able to closely manage those who possess high power and high interest (Kolk and Pinkse, 2006).

Developing a stakeholder interest list and going through it with team members (X8) is not adopted by PMs to a significant extent, yet it is significantly correlated with Y1 and Y3 (see Table 4). PMs may not have consistently carried out X8 because they assumed that stakeholders' interests are similar to project goals. Developing the stakeholder interest list at the early stage of the project will allow the potential impact of stakeholders' vested interests on the project to be identified (Arian and Low, 2005). It is recommended that PMs develop a stakeholder interest list so that they know which stakeholder to pay attention to.

Taking stakeholder interests into account in decision making and operations (X10) was significantly adopted, and X10 also has a significant positive correlation with the level of effectiveness in managing consultants (Y2) and main contractors (Y3). Without considering stakeholders' interests, PMs may make decisions purely based on achieving project objectives (timely completion, within budget and acceptable quality). However, this may frustrate stakeholders who may not cooperate because their interests are not safeguarded.

Exploring probable strategies that stakeholders could employ to realize their objectives (X14) is significantly adopted by PMs, and also have significant positive correlation with the level of effectiveness in managing consultants (Y2) and main contractors (Y3) (see Table 4). As stakeholders may adopt strategies that can help or obstruct an on-going project, it is important for PMs to predict stakeholders' actions as these may have both direct and indirect effect to aid or obstruct the development of a project (Orndoff, 2005).

The result shows that PMs do rate the impact of project strategies on each stakeholder (X16) and this has a significant positive correlation with the level of effectiveness in managing main contractors (Y3). This supports Chinyio and Olomolaiye's (2010) finding that in developing strategies to manage construction projects, PMs have to make assumptions regarding the stakeholders and how project strategies implemented by PMs can impact the level of interest, influence and support of these stakeholders. Stakeholders with higher impact ratings should be handled more carefully.

Understanding the urgency faced by stakeholders (X18) is positively correlated with the level of effectiveness in managing consultants (Y2). Urgency influences the manner and extent to which power is exercised in stakeholder management (Chinyio and Olmolaiye, 2010). When stakeholder claims are given immediate attention it shows that PMs are conscious of a project's time sensitivity in relation to stakeholders (Mitchell et al., 1997).

The practice of implementing strategies which depends on the demands of stakeholders (X35) is positively correlated with managing consultants (Y2) (Table 4). Certain stakeholders may assert their demands and claims, which may not be in the best interest of the project or in line with the client's vision. PMs must be able to handle these stakeholders within project constraints, and devise and implement appropriate strategies to engage and manage them (Leung and Olomolaiye, 2010).

The practice of taking into account stakeholder influence on the project before resolving conflicts (X26) is significantly correlated with the level of effectiveness in managing consultants (Y2) (Table 4). If PMs do not take into account varied stakeholder influence, they may not accord the correct response, and be unable to mitigate any negative stakeholder influence on the project (Aladpoosh et al., 2012).

Table 4 shows that identifying suitable conflict resolution strategies (X27) and implementing a multi-win solution (X28) are negatively correlated with the effectiveness of managing clients (Y1). The results indicate that if PMs identify suitable conflict resolution strategies and/or implement multi-win compromise solutions, clients are not managed effectively. This may be because finding the right conflict resolution strategy requires time, which is a luxury that most projects can ill afford. A multi-win solution can pose a challenge to the project team (Yang et al., 2009), and cause clients to incur additional costs or suffer project delays. Notwithstanding the results, it is recommended that PMs adopt appropriate conflict resolution strategies and resolve conflicts in a collaborative and constructive manner (Moura and Teixeira, 2010) so that the conflict does not escalate to a greater dispute and lawsuit (Ogunbayo, 2013).

Managing projects with a sense of duty and in accordance with the law (X38) is positively correlated with the level of effectiveness in managing consultants (Y2). The results echo Turner and Muller's (2005) emphasis that PMs actions and decisions should be based on rightfulness and integrity. To manage the legal aspect of construction projects effectively, PMs should be familiar with the relevant and most current legislations, and the contractual agreements made between stakeholders.

6. Conclusions

The findings show that when PMs manage clients more effectively, projects will have significantly better time and quality performance and owner satisfaction. Managing consultants and contractors more effectively leads to better owner satisfaction. This study contributes to knowledge by showing specific practices that PMs adopt which are significantly correlated with effective management of stakeholders (see Table 2). Among the many practices, those relating to assessing and taking into account stakeholders' power have the most instances of significant correlation with effective stakeholder management. It was found that consultants and contractors would be managed more effectively when PMs adopt these practices to a greater extent: set common goals, objectives and priorities; take stakeholders' interest into account in decision making; and explore probable strategies that stakeholders could employ to realize their objectives.

The implications of the findings are that PMs need to set clear goals, objectives and priorities so that all stakeholders have the same understanding throughout the whole life cycle of the construction project. As the interests of all stakeholders are of intrinsic value, it is important that the PM is able to reconcile the divergent interests of all stakeholders for the benefit of the project. To do this, PMs should endeavour to understand the different interests of stakeholders and what project success means to each stakeholder. Going through the stakeholder interest list with the project team allows all interests to be explored and understood, and should be done at the start of a project. Additionally, these interests should be well considered in decision making and operations throughout the life cycle of the construction project.

Another novel finding is that clients are perceived to be not well managed when PMs identified suitable conflict resolution strategies and implemented multi-win solutions. The finding suggests that clients prefer to be the sole winner in project disputes, thus putting PMs in a difficult position of having to manage other stakeholders and ensuring projects are completed successfully. Striving for a multi-win solution is challenging and PMs need to cultivate skills and methods in managing stakeholders so that conflicts can be resolved in a collaborative and constructive fashion. This is vital to ensure that any conflicts in the construction project will not be escalated.

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Design and Safety: From the EU Directives to the National Legislation

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Abstract

This contribution wants to examine the relationship between the role of the designer and the role of the safety coordinator in design and construction phase.

EU technical analysis say that the designer plays a key role in the design preparation stage, and is so important in preventing occupational risks on construction sites. In nationals codes the relationship between design and safety it is not so strong.

The chronological path of EU directives dealing with Health and Safety at work in temporary and mobile sites it is analysed, starting from 92/57/EEC till arriving to the later EEC communications on the subject. Contemporary, the national Italian legislation is analysed, from Decree 494/96 till Decree 81/08, with the specific aim to search the connection between the role of designer with respect to the safety in project development. This way it is possible to reconstruct the actual link among architectural design and safety design.

It is thus possible to individuate the weak points in this relationship that lead to a difficult safety management in construction phase; main finding is that the connection between design and safety has been transposed into national standards in very different ways and only through a cultural awareness of the designers on the issues of health and safety objectives of Directive 92/57/EEC will be reached.

Keywords: Safety, design, legislation

1. Introduction

Health and safety issue in construction industry has a great importance. The importance of the theme is ratified by the specific European health and safety on construction sites directives that dictate the guidelines for the state members regulations. All European states are then provided with health and safety legislation concerning construction sites that is related with the common European principles.

Therefore if we analyse the data of accidents in construction industry in the various Member States on the basis of annual Eurostat report, it is possible to note a particularly variable trend within the Member States. The data shared by all European countries is a general decline in accidents: between 2008 and 2012 (latest available consolidated data) accidents in the workplace, in construction industry, had a decrease of 46%. But the fact remains that the number of accidents in construction is considerably higher than that recorded in other economic activities

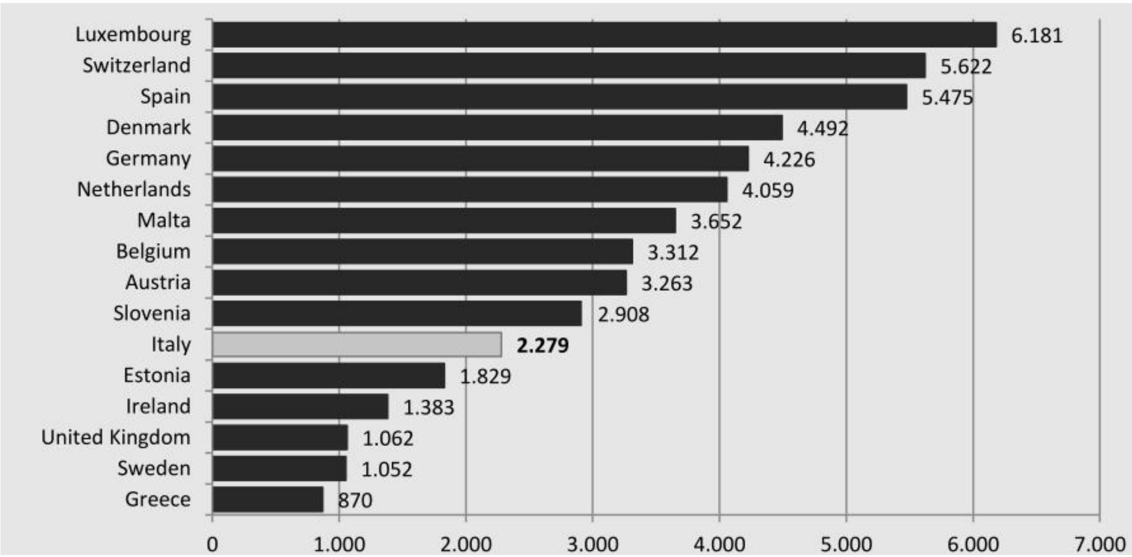

Figure 1: Accidents per 100.000 workers in construction in 2012 (Cresme Ricerche spa, 2014)

The international comparison shows that Italy, in 2012, was well below Germany (4,226) and Spain (5,475). However, considering the most serious accidents, i.e. fatal accidents, Italian ranking radically changes. This may partly be due to the vast spread of the informal economy and the specific entrepreneurial fabric (mainly made up of small and micro enterprises) can lead to under-reporting of less serious accidents.

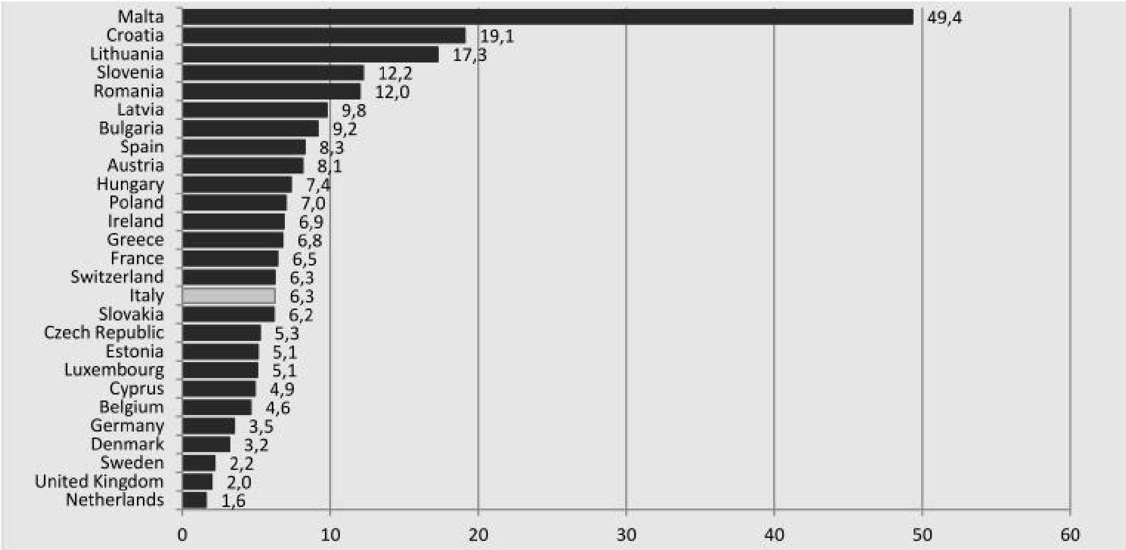

Figure 2: Deadly accidents per 100.000 workers in construction in 2012 (Cresme Ricerche spa, 2014)

The clear disparity in accidents that emerges from the European data, lead us to investigate the path that European directives have made at the moment of their implementation through national legislation. According to Capone et al. (2015), it is interesting to investigate how the European inspiring principles can be found in the texts of Member States laws.

In particular, the question we focus in this paper is on the relationship between the responsibility of the designers of the building and the project and health and safety management. This point of view comes from the importance that the European directives give to the design with respect to health and safety management in construction. EU directives clearly state the importance of the "safety awareness" during various stages of design and, for this reason, remark the Health ad Safety Coordinator involvement in the design phase. Despite of it, in some European countries (i.e. Italy) the involvement of Safety Coordinator in design process is weak, even if national laws theoretically agree with EU directives. For this reason we examine how much national laws are in complete concordance with EU principles basing our analysis on the duties of Designer and Health and Safety Coordinator in Design phase. With the comparison we try to understand possible reasons for such differences in national legislations.

2. EU directive 92/57/CEE and UE Communication 06/11/08

2.1 EU directive 92/57/CEE

Directive 92/57/EEC concerning the minimum safety and health requirements at temporary or mobile constructions sites, since the initial considerations expresses the centrality of architectural choices in determining the safety during construction:

“[…] Whereas unsatisfactory architectural and/or organizational options or poor planning of the works at the project preparation stage have played a role in more than half of the occupational accidents occurring on construction sites in the Community […] “

Right from the initial considerations, the Directive stipulates a direct relationship between the architectural choices and the occurrence of accidents in construction site. Stating that “*it is therefore necessary to improve coordination between the various parties concerned at the project preparation stage and also when the work is being carried out”*, it focuses on the design phase of the work.

Directive brings together again the connections between design and safety:
“Article 4 - Project preparation stage: general principles
The project supervisor, or where appropriate the client, shall take account of the general principles of prevention concerning safety and health […] during the various stages of designing and preparing the project, in particular:
— when architectural, technical and/or organizational aspects are being decided […]”.

The article 4 involves the client, empowering him, and asserts that he also must consider the principles of health and safety at the time of the architectural, technical and organizational choices. Complementing this, the article 5 stipulates the presence of specialized technicians in construction site safety (Health and Safety Coordinators), working since from the design stage.

All the European safety codes are therefore based on the above assumptions. It is interesting to investigate regulatory developments subsequent to 1992 to understand how the relationship between design and safety is inside in the current national standards.

2.2 EU Communication on the practical implementation of Health and Safety at Work Directives 92/57/EEC – 06/11/08

Communication is a European report about the practical implementation of Directive 92/57/EEC in the Member States; it is dated 06/11/08 and represents the state of the art 16 years after the enactment of the directive. Communication follows a Commission undertaking to assess the implementation of the regulatory framework with a view to improve it. It is based mainly on the national reports supplied by the Member States and an independent experts' report analysing implementation of the Directive 92/57/EEC.

The practical implementation of Directive 92/57/EEC

The implementation of the Directive is a complex issue in terms of technical and administrative staff. Member States regularly revise and update their legislation. This explains why in some States the directive has been transposed in a very fragmented of legislation that make it more difficult to assess. It is then revealed differences in national legislation deriving from the previous regulatory framework and from the fact that the Directive lays down minimum requirements and leaves the Member States free to maintain or establish higher levels of protection.

Since the Directive gives all those active on a construction site key roles in prevention, its implementation was therefore assessed in terms of the influence that each group has on prevention of and protection from occupational risks. While the Directive does not refer explicitly to architects, engineers or consultancy firms, this group was evaluated because the designer plays a key role in the project preparation stage, and is so important in preventing occupational risks on construction sites.

It is clear from the report that architects and engineers know the health and safety requirements but do not totally agree with the measures imposed. Some designers are not in favour of the client appointing a coordinator for the design stage as, in their view, this hampers their creative freedom.

While stressing, in some ways, a lack of safety culture in the designers, on the other side it also notes that, when architects and engineers act as coordinators at the design stage, the working conditions on construction sites considerably improve. A specific education in the field of building design is a condition of absolute advantage for the health and safety coordinators. Communication also underlines that preventive health and safety is often not integrated into the project at the design stage because safety conditions during construction and subsequent use and maintenance are not a major factor in design/architectural choices. The designers are thus not adequately involved in health and safety process from national codes.

"There is a long way to go in all the Member States before the culture of prevention effectively takes root at the design stage" (EU Communication 06/11/08).

According to the Communication, it is important in this context that the competent national authorities make an effort to train designers at schools and at university, making prevention a key part of the curriculum

Roles of Health and Safety Coordinators

The Directive does not define the competencies required to act as coordinator, so there are big differences from one Member State to another. Some states have defined the competences and/or skills of coordinators in great detail, sometimes even requiring that they have specific training or a combination of training and experience (i.e. in Italy). The competencies required of coordinators by the Member States to fulfil their duties differ greatly, and so the standard of coordination varies from one Member State to another.

EU communication states that, because project preparation does not take prevention of occupational risks into account before the design is finalised, the lack of planning for prevention has to be remedied at the execution stage. It is to hope a change of attitude in construction industry; if national legislation made it a requirement for prevention measures linked to the subject-matter of the contract to be systematically incorporated into the technical specifications for invitations to tender and in the contract performance clauses and quality contract management by the contracting authorities, this could help to change attitudes in this area.

The communication surveys that a lack of coordination in design affects the quality of the coordinator's work at the execution stage. The result is that on-site coordinators often encounter health and safety problems that are difficult to solve because they are generated from the design itself, because of its morphology and construction techniques. This underlines that safety should be considered a design property which affects itself.

3. European comparison

Here it might be helpful to tell briefly the theme of the relationship between design and safety in the European regulatory framework. The considerations, drawn from Bergagnin et al (2012 and 2013), resulted from a project of the Safety Commission of the Federation of Associations of Engineers of Emilia Romagna in 2012, then continued in 2013. Starting from the comparison between the various national laws transposing the Directive yards 92/57/EEC, aspects related to the main figures involved in the member states Germany, UK, Spain, France and Sweden (Aulin and Capone, 2010) have been analysed. Only these few European countries have been selected because in the academic detailed studies Sweden have been added to the work of Bergagnin et al (2012 and 2013).

Italy is our reference country since in the Italian construction system there is actually a weak position of the Health and Safety Coordinators with respect to the designer position in defining principal stages of the design. The study found that the role and requirements of professional technicians who deal with health and safety vary greatly in European countries. In particular, it was noted that while some EU countries have an approach to the issue very similar to the Italian one (i.e. Germany and Spain), other members (such as France and especially Britain) are significantly different, especially as concerns the design and construction management.

The research method was to deepen investigate the Italian legislation with respect to the EU directives, then, basing on literature studies (Bergagnin et al, Bragadin, Capone), other national legislations have been analysed in order to underline the research theme.

Italy

In Italy the first legislation on health and safety in construction sites declared after the EU directive 92/57/EEC was that the Decree 494/96. With subsequent amendments and additions it was in force until 2008, when it was replaced with Decree 81/08. Health and Safety Coordinator at the Design stage is central in the relationship between design and safety, bond never directly explained.

While in the European Directive are cultural recommendation related to the role and to the operative tools of the Health and Safety Coordinators in Design phase, in the national code specific legal duties and responsibility are assigned to Health and Safety Coordinator at the Design stage. This lead to a strength definition of the Health and Safety Coordinators role in the Decree 81/08 with respect to the EU Directive.

In the following there is a synthesis of the evolution of Italian laws related to the Health and Safety Coordinator at the Design stage:

- Decree 494/96: no substantial differences from the EU Directive about the Health and Safety Coordinator at the Design stage duties. It is important to underline that Health and Safety Coordinator at the Design stage intervention is postponed in the executive design phase.
- Decree 528/99, modify to the Decree 494/96: Health and Safety Coordinator at the Design stage intervene in the generic “design phase”.
- Decree 81/08: not sensible differences from the previous law, except for the coordination of architectural, technical and/or organizational aspects.

At the same time, contents of the Health and Safety Plan evolved; analysing the specific contents of these documents allows us to detect the real competences a Safety Coordinator in Design phase must have with respect to the design. According to Bragadin and Giusti (2015) Health and Safety Coordinator can be seen as a specialized Project Manager and it is important for him to have real designer skills in order to intervene in the whole project.

Article 98 of Decree 81/08 indicates the requirements to be a coordinator: university graduation is not the only requirement, also graduates (surveyor, industrial or agricultural) are in fact admitted to the profession of coordinator. We are so distant from the auspices of the 2008 EU communication in which explicitly refers, as described above, to the design skills of engineers and architects who can assume the role of Health and Safety Coordinator at the Design stage. The debate is as a technician can objectively, without specific design skills, participate in the design phase of the work in relation to the issues of health and safety.

In this context, the stronger link, extremely general and as such address the cultural, is in Article 22 of Decree 81/08, "Obligations of the designers": designers of workplaces should comply with the general principles of prevention in health and safety at the time of design choices. Read extensively, this reminder of the responsibility of the designers – both designers of the building and of the construction site as a workplace - is the strongest bond that the Italian code, only in 2008, re-established with the directive of European origin.

United Kingdom

First aspect of the peculiarity is seen in the great importance that is reserved by the UK Regulations to the concept of design in safety. British standards provide binding obligations of the designer with respect to the safety of the building. In practice, in the UK the designer is required to design the safety of the work for all the people who come in contact with it, by those who realize, the future users and to future maintainers, according to a concept of global security that extends the entire life of the work itself. UK legislation comes to accurately define some technical aspects that the designer has to consider in the design phase, such as the future maintenance of facilities and structures, or cleaning the windows or translucent walls, or how access to areas where there is the risk of falling.

The coordinator is responsible, on behalf of the client, to monitor the work of the designer, making sure that he complies with the safety provisions in order to receive full cooperation on the preparation of the Health and Safety File. The drafting of Health and Safety File, according to EU directives, is charged to the same coordinator.

Health and Safety Coordinator at the Design stage appointment comes even in the process of definition of the levels of design: once prepared the preliminary draft, is not allowed to proceed in the further steps of the design Health and Safety Coordinator at the Design stag is not appointed. Under these conditions, it is clear that the interaction between designer and coordinator proves effective and not fictitious.

Many clear differences are found between the United Kingdom legislation and other European countries including Italy, about the drafting of Health and Safety Plans. In Britain the customer directly provides information in a pre-construction stage, in order inform the designer, the principal contractor and the contracting companies, about the interesting elements regarding the future building, its construction and the construction site.

In UK Health and Safety Coordinator acts decisively and mainly managerial; he is in charge of ensuring the transfer of information between the various parties and the constant updating of proper documents relating to it. Recognizing the importance of the design in the future realization of the building, the UK code make the Health and Safety Coordinator at the Design stage to take a role of "safety consultant" designer and as such works with designer in a nearly equal ratio.

According Bragadin (2011), it can be said that countries like UK, with greater business culture and social sensitivity, while adopting apparently less strict rules have on their side a positive response statistical accident.

Germany

German legislation is very similar to the contents of Title IV of Italian Decree 81/08. On the design phase they are detected small differences from the provisions of Title IV, although it is clear more attention to the verification of the early interaction between the coordinator and designer, with a strong focus also on the contents of the technical dossier ("Document for Future Work").

France

In France there is an insurance system that is mandatory for public procurement and optional (but very useful) for private procurement; this is the so-called "ten year policy posthumously". Insurance institutions have their own technical specialists of the construction industry to grant the insurance. The insurance technics analyse the whole design and can request changes, improvements and any kind of depth, otherwise the denial of insurance coverage. The same procedure is applied to the technics (from design to construction and safety) that must all be covered by insurance. Once implemented, the insurance thus guaranteed the technical quality of the work.

Furthermore, Health and Safety Coordinator in France cannot carry out any other type of appointment within the same building process.

Spain

In Spain Health and Safety Coordinator at the Design stage is appointed only in the case where there are more designers who do not have corporate links between them, or more professionals, or more member firms, or engineering companies. In practice this implies that Health and Safety Coordinator at the Design stage is not almost appointed in the bigger works because often they are carried out by big engineering companies or professional offices.

This law determines an obvious latency in design and programming of safety, in sharp contrast with the objectives of the European Directive, which provides for a special attention to safety since the embryonic stages of the development of design. Since in many cases the Health and Safety Coordinator at the Design stage is not appointed, it is possible that health and safety of the construction is entirely in the hands of designers work.

Sweden

In Sweden Health and Safety Coordinator at the Design stage participates in the planning and lead the preparation and design of project. Health and Safety Coordinator at the Design stage coordinates the preparation and design of project with regard to health and safety to allow participants involved during this stage to take into consideration each other planning and solutions. The coordination should lead to the execution of different parts of the project together with the construction, installation and others that occurs at different time and stage of the project where the risk of ill-health and accident could arise. Health and Safety Coordinator at the Design stage draws up a Health and Safety Plan if it is required before the construction site is set-up.

In table 1 a synthetic comparison among the countries is reported; in the table can be found the Designer Role in Health and Safety in construction and the Health and safety Coordinator involvement in design stages, with respect to the EU principles.

Table 1: A synthetic comparison among the analysed national legislations.

Criterion / *Countries*	*Designer Role in Health and Safety in construction*	*Health and safety Coordinator involvement in design stages*
Italy	*weak, not specific duties or responsibility*	*quite strong but not efficient*
United Kingdom	*very strong*	*weak, only duties of control*
Germany	*weak*	*quite strong*
France	*weak, insurance system*	*weak, insurance system*
Spain	*weak*	*weak*
Sweden	*weak*	*strong*

4. Conclusions

It is clear in this discussion that, despite the common origin (Directive 92/57/EEC), the transposition of the European standard in the different countries was characterized by different hints and in some cases, UK among them, an approach substantially different.

A first objective fact that emerges from the research is the earlier and more intense involvement of the coordinator in the design stage during the project preparation; this takes place in the main European Union countries such as Germany and UK. Especially in UK, the function of Health and Safety Coordinator is purely managerial, having him responsible not only to draw up the Health and Safety Plan but also to control and monitor the activities of the designer. The designer is in fact the main subject invested from the obligation to respect the safety design choices and to provide all necessary information to the coordinator to compile the technical file (Health and Safety File).

An important consequence of the different approach to the safety of European countries, is found in the important role that Health and Safety Coordinator at the Design stage assumes: it has a guiding role to proper design of safety. The Health and Safety Coordinator at the Design stage is given this task with the knowledge that this will translate into lower cost of the work, both during its construction and during its future use.

The comparison shows another obvious fact: the diversity of skills that Health and Safety Coordinator at the Design stage must have. In the main countries is in fact required a high specialization of this figure and some of it expressly forbid to overlap the function of the coordinator with other positions within the same project or construction site. The main EU countries are in fact oriented towards the high specialization of Health and Safety Coordinator.

In conclusion we can say that, from the cross-reading of the rules of the Member States in relation to the European directive, the connection between design and safety has been transposed into national standards in very different ways. This is certainly due to the difference social reality of the construction industry, made by the technicians who work there and by the fabric of businesses, widely variable from state to state.

Starting from the same EU directives, in some countries relationship between duties of the Designers and the duties of Health and Safety Coordinator is strong, in some other is actually very weak. Sometimes the Designer is not even mentioned in the legislation.

In our view and in accordance with the European community indications, the solution to bring the design to the centre of the construction site safety system is to act on the education of the designers, rather than on that of safety specialists. Only through a cultural awareness of the designers on the issues of health and safety we will tend to the actual achievement of one of the objectives of Directive 92/57/EEC: the reduction of architectural and organizational inadequate choices as a cause of accidents on construction site.

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Safety Constructability Improvement Adding Spatial Dimension and Workers' Safety in the Critical Path Method

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Abstract

In this contribution, at first an approach to analyse safety in the construction process is proposed. This approach includes Building Design for Safety (BDS), a specific method to check both constructability and workers' safety of the critical phases in construction process. Safety management in design and construction phases is one of the essential components that can influence the actual achievement of the constructability goal. Compliance with costs and time, necessarily passes through the risk mitigation of the critical activities, this must be done in order to safeguard the quality of the building. Prefiguring the construction process from the design phase, allows us to manage both safety and constructability. We operate within a framework that has to be used in design phase. In the framework, making use of the construction management instruments, we can identify critical activities for the workers' safety during the future construction process. For critical activities characterized by overlapping of time and physical space of construction, the BDS tool is proposed. BDS makes a check both of constructability and safety of the critical construction activities in order to suggest technical and management solutions to mitigate risks. The tool allows the user to identify measures and procedures for risk prevention and protection, with respect to the constructability. BDS has to be performed during the design phase, in order to prefigure the construction process. This way, risk mitigation can be performed according to the constructability goal, safeguarding the building correspondence to the needs of the design. So far, the results achieved concern the BDS application in many real case studies. Future issue are related to the development of the instrument in BIM technology.

Keywords: Constructability, safety, design

1. Introduction

It is within the last fifty years that quantitative methods for project analysis and scheduling have been developed and documented, and particularly those supported with computerization.

Critical Path Method (CPM) has ever since been the dominant methodology for scheduling construction. (Baldwin, 2014)

In this paper a new approach based on the analysis of construction scheduling supported by a construction simulation is proposed and used in order to increase safety constructability in the phase of activities planning.

Such an approach provides a new tool for extending basic activity-based CPM logic adding workers' dimension and optimizing basic scheduling in function of workers' safety. Traditional CPM uses a single layer of logic which operates only between any two activities. Production occurring inside an activity is described only by duration, and there is no recognition of the worker's position in terms of working areas.

Until now the approach of Location-based management assumes that there is value in breaking a project down into smaller locations and using these to plan, analyze and control work as it flows through these locations.

The location-based planning system takes into account activities and tasks, where a task is made up of a sequence of activities in differing locations. Then it uses CPM external logic to define the logic or connection between different activities within locations wherever they occur. However, unlike CPM, the planning system also considers a task's own internal logic, by calculating durations based on quantities and allowing the planner to plan the location sequence and production rate to achieve continuous production.

Starting to carry out a review of the currents practice in the field of Location Based Management Systems (LBMS) a new approach is proposed which generates a logical relationship between working areas and activities and automatically, first, integrates this relationship in the CPM and then manages overlapping activities in terms of risk workers' risk reduction.

This approach comes from the consideration that in construction management, the health and safety is one of the most important element able to influence the entire process-management.

In this perspective it could be useful to remember the close relationship between safety and design (Capone et al., 2015). In safety management, EU Communications refer to architectural, technical and/or organizational choice in order to minimize professional risks. Such choices underline the cooperation needed between designer and safety coordinator at design stage: actually the main issue is related to the effectiveness in reaching the constructability goal.

2. Constructability, design and safety

As referenced by Capone et al. (2015), in the theoretical approach to Constructability the difficulty of designers to lead the construction phases during design phases was straight from the beginning. This opened up to a discussion about the aim to link design phase and construction phase: the results of building's quality are strictly related to the separation/integration between design and construction.

Together with Constructability the development of methods and tools aimed to manage this complex relationship, known as "Constructability", is a strategic resource for the field of Construction management and the progression of this concept shows that the aims could change throughout time depending on many factors such as incidental, environmental, social and economic (Gambatese 2007). According to Russel (1994), the construction time and cost could be depending on the way of running of the relationship between design and workers Healthy and Safety. The aim of directing such factor, according to the Constructability theories, means to find new design tools that aim to manage H&S during the design phase (Gambatese, 2009) (Creaser, 2008) (Taiebat, 2001).

The research line about Constructability has been carried out at two levels of analysis: one is overview level which focuses on the broad picture of Constructability and the other is the practical level, which investigates new tools, created ad hoc, to reach the research objectives. From the relationship between design and safety, the Building Design for Safety (BDS) method has been proposed by Capone (2014). This tool, better explained in Section 4 of the presented paper developed a construction simulation based by starting the activity simulation from the shop drawings. A 2D representation was used to visualize construction operations but the integration of this approach with a construction scheduling tools was not proposed. The presented work first develops a new tool for an automatic re-scheduling of CPM in function of workers' safety and when the tool is not enough proposes BDS as design solution in order to consider safety reasons before construction process starts.

3. Location Based Management System

Location-based management considers there is value in breaking a project down into smaller locations and using these to plan, analyse and control work as it flows through these locations. The location provides a container for project data at a scale which is easy to analyse.

Location-based planning is, in turn, concerned with the process of planning for work to protect production efficiency as work moves through locations. Specifically, the emphasis in location-based planning is to plan for productivity.

Location based methods extend basic activity-based CPM logic to yield an easy-to-use system which possesses the underlying analytic properties of CPM but specifically includes production estimation. This is reached by layered logic which is a simple process of automating the creation of a critical path network by using locations. Traditional CPM uses a single layer of logic while

Location-based planning introduces new layers of logic which add more detail to both the internal task production of the location-based task, and to the external links between tasks.

In this case all the analytic features of CPM are preserved when examining the logic between activities within locations, as activity sequencing is driven by normal CPM algorithms with familiar concepts such as precedence and lags.

In parallel, Location-based control assumes that planning has maximised productivity, found an optimal balance between risk and duration and is feasible to implement.

At least this approach aims to reach a better productivity level without considering how site and workers' conditions change due to overlapping activities and how safety risks increase in construction site.

For this reason the proposed WSiCPM framework, which is explained in section 6, aims to propose a novel approach which consider the integration of CPM with locations but assumes the planning as function of potential hazards which has been calculated using equations depending on different parameters. WSiCPM framework is integrated in a wider framework of design phase as explained in section 5.

4. The method Building Design for Safety (BDS)

The starting point is the idea that the visual simulation is not only a "passive" image of contents, but it is an " active" control in terms of built result. The aim was then to improve the contents of the representation to accentuate its "dynamism", implied in the project. The approach tents to re-elaborate project drawings to clearly express those construction processes implied in the drawings of the constructive details. The approach is to entrust to the design the role of harmonizing different parties. The chosen way is to assess “workers' safety” as the parameter to implement a new tool in order to obtain a safety realizable project. Starting from the representation of construction details, according to Building Design for Safety (BDS), it is possible to simulate the construction of them using the CAD 2D as graphical tool. This can be done through progressive drawings that express the breakdown in construction phases –one phase for each new building product-, chronologically processed and logically related. In these specific drawings are depicted all site facilities (temporary works, machineries and manpower) in order to simulate and verify the real conditions in which it will be the realization. BDS allows both the detailed assessment of safety conditions –by using a traditional risk analysis- for the realization of the item and the Constructability verify of the element itself. It is important that this happen before construction stage, when it is still possible to intervene, where appropriate, with amendments on the project itself. It is possible to find more details on the BDS method in (Capone et al. 2014). The picture below (Figure 2) shows the visual representation of the method.

5. Safety management approach for critical construction phases

In BDS method have been proposed and tested a simulation process of the construction operations, with the specific aim to correct and optimise shopping drawings in order to have a better performance of the building (Capone et al. 2015). After a lot of applications in different case studies, the necessity to consider the “time variable” has appeared, above all in managing interfering activities.

The question should be how to insert BDS method in a wider processual and operative framework, in order to make BDS free from the theoretical, episodic, uneconomical and unrealistic aspect that could have been attributed to it.

To reach this goal the first step was to define an approach that, using the construction management tools, could individuate the critical construction activities in the safety point of view. In professional practice, regarding interfering activities, the Health and Safety (H&S) Coordinator usually gives operative prescriptions to stagger in space and/or in time the interfering activities and gives the instructions to control the efficacy of such prescriptions.

If interfering risks still remain, the H&S Coordinator must determine preventive and protective measures in order to minimise risks.

Nevertheless there are a lot of situations in which is difficult to stagger in space and/or in time the interfering activities preserving together the workers’ safety and the Constructability requirements.

Usually the individuation of critical phases is performed by means of the classical construction management tools; with BDS method we have a closer analysis of the critical phases (Figure 2).

Searching for the applications in which the BDS method could be more effective, we investigated different theories linked with construction management and safety (Baldwin and Bordoli 2014).

The link between design and safety suggested us to improve and optimize visual representation of construction site issues, taking distances from the traditional site layouts in order to improve information and make designer tools more effective.

According to the aforesaid traditional theories, planning techniques such as critical path method (CPM) are useful for analyzing the logic of construction activities, identifying critical activities and producing a model form which it is possible to produce schedules for activities and identify milestone/completion events. From the literature review emerged that CPM helps to clearly identify key contractual dates for the start of the activities on site and completion of construction work. CPM confirms production deadlines and contractual obligation. However,

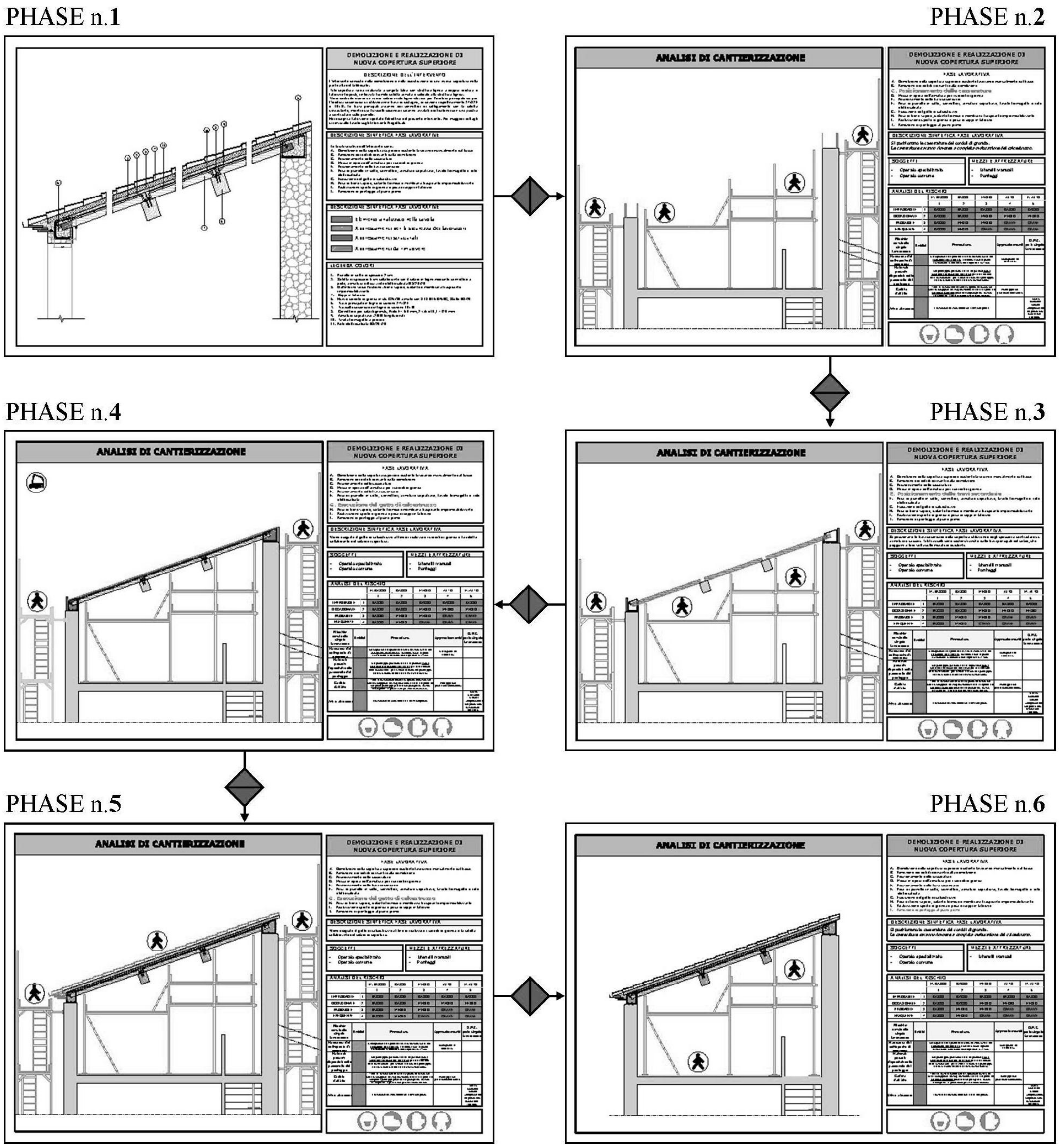


Figure 1: Operative Framework of the BDS procedure for a roof redevelopment (Capone et al. 2014)

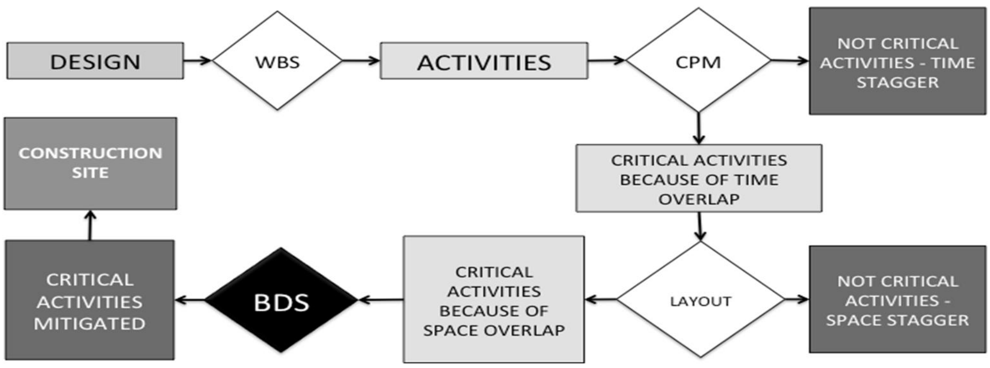


Figure 2: Graphical representation of the approach to safety management of critical construction phases (Capone et al. 2015)

CPM is not the best tools to direct production on site. The great deficiency is the luck of a direct connection between scheduling approach, used for the baseline schedule, and the real site condition. Only introducing the spatial dimension and workers' dimension, considered by BDS method as well, in the traditional construction tools and in CPM planning in this particular case, it could be possible to effectively manage the site conditions.

A step in this direction can be the WSiCPM framework, as in the following it is described.

6. The WSiCPM framework

6.1 The methodology of the WSiCPM framework

An attempt to create a methodology able to incorporate the workers' safety and the spatial dimension into the critical path method (CPM) has been done. Such methodology can be used as a supplemented tool in planning and design phases to identify and remove early the risk of accidents by means of BDS method. The methodology called WSiCPM (Workers Safety into CPM) has been developed to detect time-space-conflicts of activities in order to help health and safety risk assessment in construction management. In WSiCPM framework, a method for qualitative and quantitative risk assessment was programmed and implemented. Probability of potential hazards has been calculated using equations depending on parameters such as: overlapping duration, overlapping working area, number of workers in the observed pair of interfering activities and type of hazard. The severity of the hazard has been estimated analogously, with the compensation of a casualty by insurance companies (through this, the risk can be modified into a monetary value representing the predicted accident cost). Additionally, the framework proposes possible solutions for each pair of interfering activities. BDS has been linked with WSiCPM as a method useful to analyse and resolve health and safety risks in space-time conflicts activities. In figure 3 WSiCPM framework is depicted.

In the following steps the methodology is described using the information from a case study which includes a set of nine different site activities.

6.2 Step 1: Definition of the Overlapping Matrix

This step of the analysis sets out an overlapping matrix which is able to identify and control the *time-overlapping activities* in order to achieve the following aims:

- Organize the analysis of interference activities by way of a pairwise comparison, in order to discuss their interaction;
- To apply the mathematical concept of non-analogue relationship between the two activities of each pair;
- Calculate the overlapping duration of each pair of interfering activities.

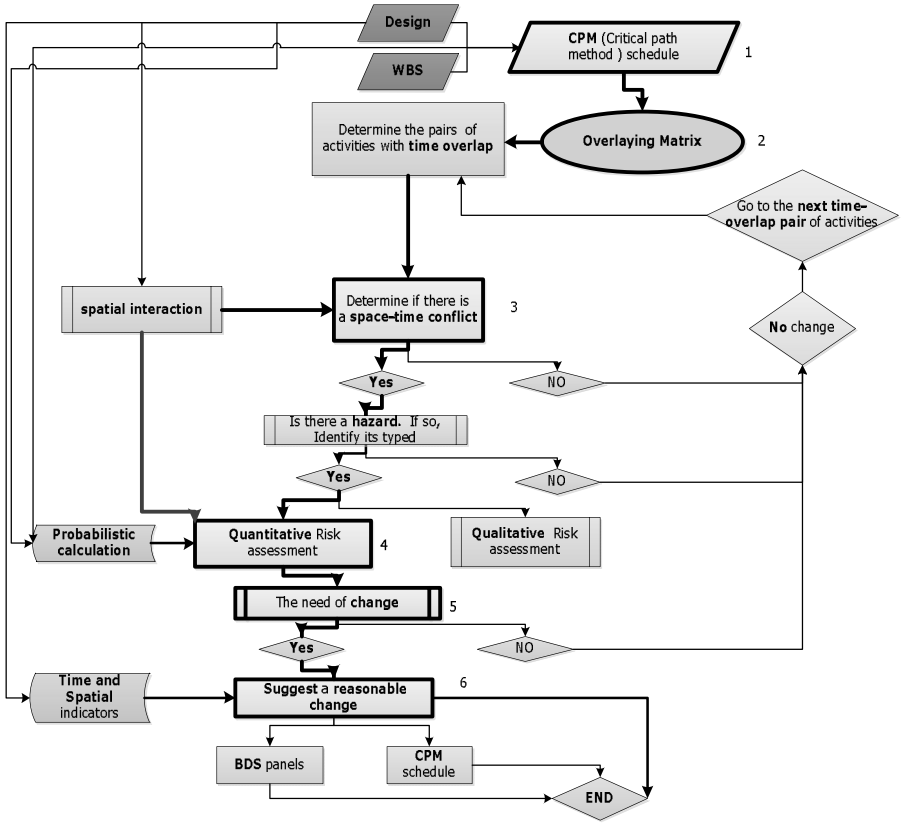
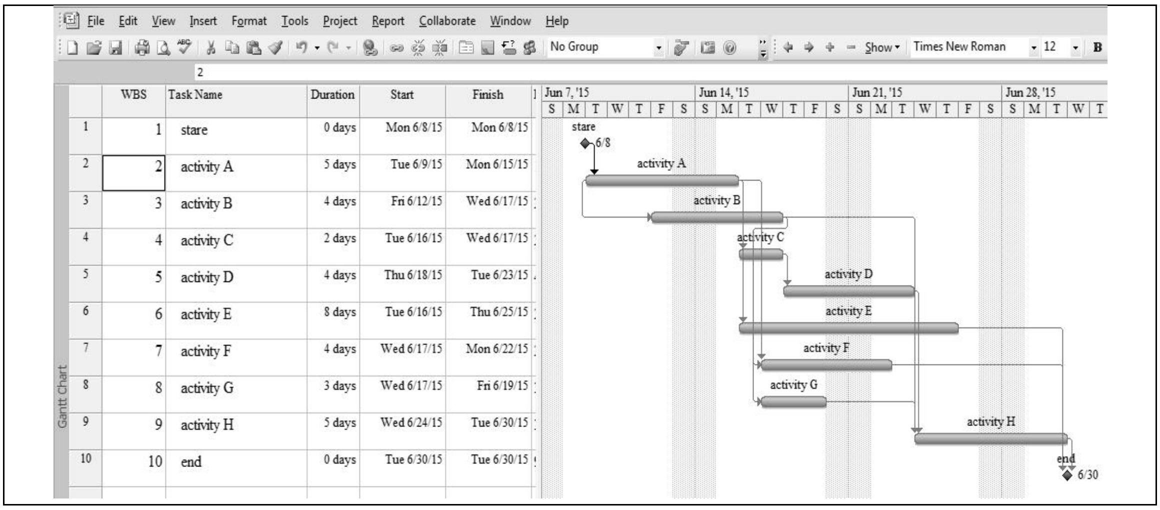


Figure 3: WSiCPM workflow

This is carried out exporting information about the activities' properties (name, duration, finish, dependencies, cost, …) from the baseline schedule CPM (Fig. 4), practically using MS Project Software, to a pre-set database, practically implemented in MS Access Software.

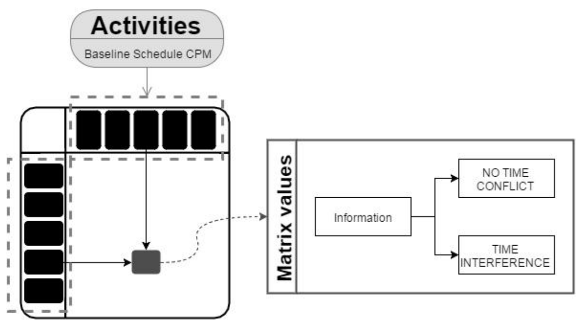


	WBS	Task Name	Duration	Start	Finish
1	1	stare	0 days	Mon 6/8/15	Mon 6/8/15
2	2	activity A	5 days	Tue 6/9/15	Mon 6/15/15
3	3	activity B	4 days	Fri 6/12/15	Wed 6/17/15
4	4	activity C	2 days	Tue 6/16/15	Wed 6/17/15
5	5	activity D	4 days	Thu 6/18/15	Tue 6/23/15
6	6	activity E	8 days	Tue 6/16/15	Thu 6/25/15
7	7	activity F	4 days	Wed 6/17/15	Mon 6/22/15
8	8	activity G	3 days	Wed 6/17/15	Fri 6/19/15
9	9	activity H	5 days	Wed 6/24/15	Tue 6/30/15
10	10	end	0 days	Tue 6/30/15	Tue 6/30/15

Figure 4: Example of the baseline schedule –CPM- taking into account nine activities by using MS PROJECT

The method automatically fills the matrix in using two type of overlapping scenario: "*No conflict*", "*Time interference*". The figure 5 shows the matrix for the proposed case study. After this analysis it's possible to pull the pairs of activities with a time overlap out from the aforesaid matrix.

APPROACH	APPLICATION TO THE CASE STUDY



	A	B	C	D	E	F	G	H
A		Time interfer-ence	No conflict	No conflict	No conflict	No conflict	No conflict	No conflict
B	Time interfer-ence		Time interfer-ence	No conflict	Time interfer-ence	Time interfer-ence	Time interfer-ence	No conflict
C	No conflict	Time interfer-ence		No conflict	Time interfer-ence	Time interfer-ence	Time interfer-ence	No conflict
D	No conflict	No conflict	No conflict		Time interfer-ence	Time interfer-ence	Time interfer-ence	No conflict
E	No conflict	Time interfer-ence	Time interfer-ence	Time interfer-ence		Time interfer-ence	Time interfer-ence	Time interfer-ence
F	No conflict	Time interfer-ence	Time interfer-ence	Time interfer-ence	Time interfer-ence		Time interfer-ence	No conflict
G	No conflict	Time interfer-ence	Time interfer-ence	Time interfer-ence	Time interfer-ence	Time interfer-ence		No conflict
H	No conflict	No conflict	No conflict	No conflict	Time interfer-ence	No conflict	No conflict	

Figure 5: Example of matrix of overlapping

6.3 Step 2: Determination of the space-time-conflicts

According to the framework, after determining the activities with a time overlap, each activity pairs should be processed in order to achieve a double-check: time interaction (as described in the step 1) and spatial interaction as described below, locate the "*space-time conflicts*".

This double-check aims to locate the "*space-time-conflicts*" which mean that there is a spatial interaction between the two activities, even if they are run in separated spaces, since the conflict could be present not only in the activity's work area but also in in the areas connected to each activities. For this reason, referring back to the designer, the method considers four different kind of areas related to each activity and check their interaction as shown in the Figure 6.

If the two activities run in different places without space interface, then space-time-conflict has not occurred as the Figure 6 shows.

6.4 Step 3: Determine the type of hazard and risk assessment

After determining the space-time-conflicts, it is important to know whether a hazard has been created by each space-time-conflict pair of activities. If so, once hazard has been identified, it is necessary to calculate the associated risk.

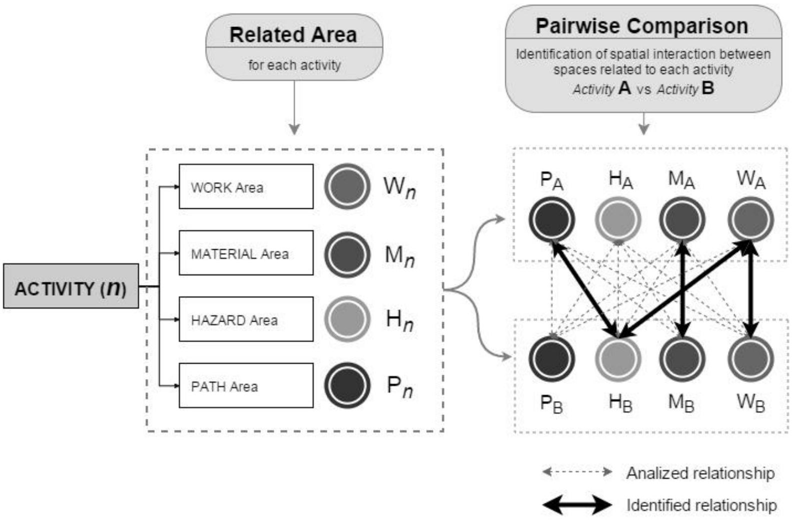


Figure 6: Example of space-time conflicts determination

In WSiCPM a specific quantitative risk assessment has been developed and the risk evaluation is generated by the framework. Inside WSiCPM the probability has been estimated with probabilistic calculation of the time and space probability with respect to the space overlapping areas and the number of workers. The severity of the accidents has been expressed using a method deriving form insurance (monetary quantification of the damage).

6.5 Step 4: Risk response and change request

The WSiCPM framework works like an expert system: the outputs of the quantitative risk assessment, in addition to spatial information and time information from CPM, are the input in this operation. For each space-time hazard conflict pair, the framework suggests a solution.

The framework provides four different kinds of suggestions in order to mitigate risks, helping the decision maker in resolving the conflict.

BDS will be use in WSiCPM to solve the risk situations that cannot be mitigated just with scheduling actions. BDS will be used in case if it would be necessary to have a deep H&S and constructability analysis, coming until the possibility to solve critical situation even by changing the design.

The solutions automatically proposed by WSiCPM are listed as follows.

1- Changing the path

This suggestion is given if there is interference between the hazard area of an activity and the path area of another.

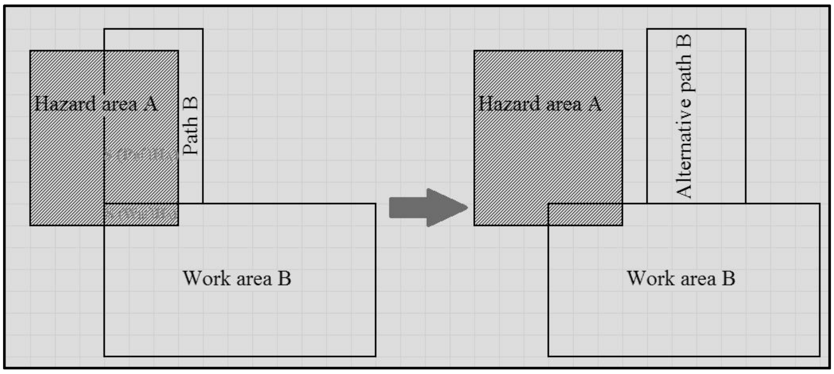


Figure 7: Example of path changing

2- Dividing the areas

This suggestion considers the interference of the hazard area of an activity with the work area of another activity. If this interference is minor with respect to the work area itself and the overlap time is less than the duration of the last activity, taking into account the ability of the last activity to be divided, then the framework will suggest to subdivide it.

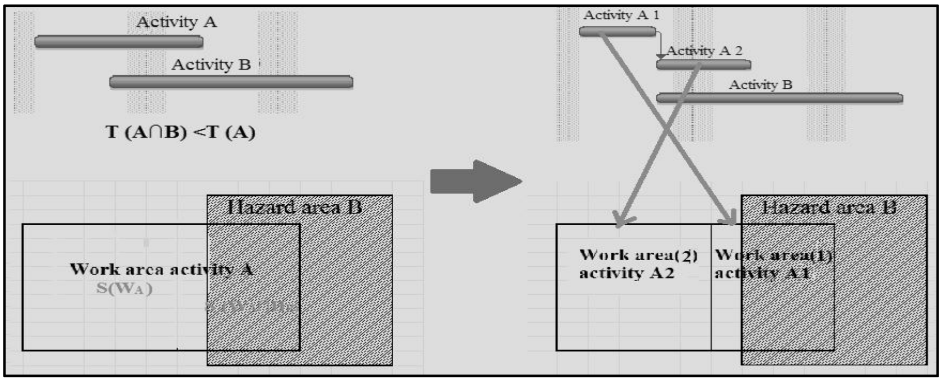


Figure 8: Example of dividing areas

2- Splitting the activity

This suggestion considers that, if the overlap-time is small in comparison with the duration of one of the activities, which can be achieved in two phases and it is not critical, the framework proposes to divide the workload. Thus, the work in the long activity is halted and later continues after the end of the hazard (time dividing).

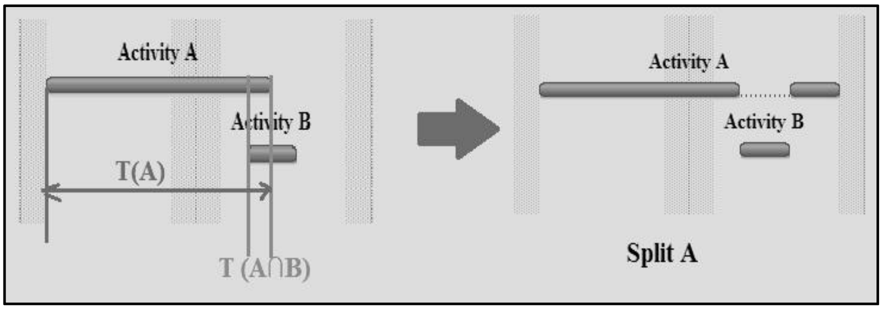


Figure 9: Example of splitting

2- Rescheduling

This suggestion considers that, when the risk is high and the interference of the space is substantial (the two activities take place almost in the same place), and the time overlap is equal to the duration of one of the two activities; re-scheduling the non-critical activities would be the main solution proposed by the framework.

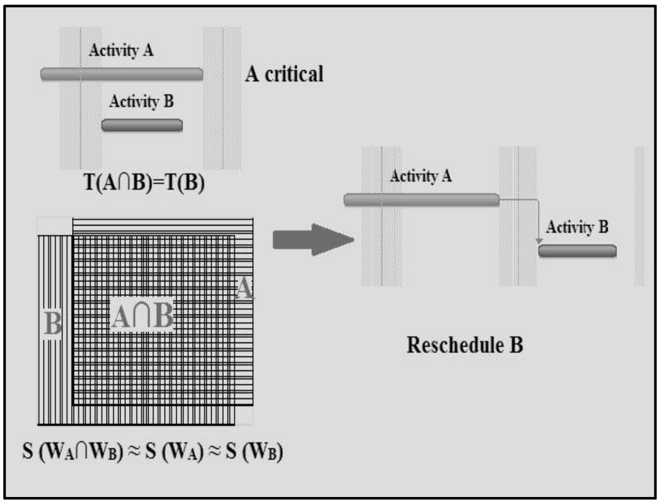


Figure 10: Example of re-scheduling

7. Conclusions

An attempt to propose a framework to analyse, evaluate and solve space-time conflicts with respect to health and safety risk mitigation has been made. If the automate solutions given by the WSiCPM are not suitable for the specific situation, BDS is suggested as the best method to solve the constructability issue mitigating health and safety risk for workers. This way, we tried to individuate acceptance criteria for critical activities overlapping, both in space and in time and then to quantify workers' safety risks.

The analysis, the assessment and the management of health and safety for workers in complex risky activities by using BDS, seems to push future developments in the direction of Building Information Modeling (BIM). In this perspective the research group is working on the implementation of site-analysis in a BIM-environment.

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Resource – Space Charts for Construction Workspace Scheduling

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Abstract

Construction production is typically highly dependent upon space to move, store and fabricate materials and building components, and to perform transformation and assembling activities. Construction planning and scheduling goal is to provide a logical order for activities taking into account safety, space and logic requirements. Construction process scheduling should also incorporate specific features of work-flows of project activities through work spaces. The Location-Based Management System (LBMS) is a recent and innovative method that aims at planning and managing construction projects in a process-oriented way, taking into account activity locations on-site. In an on-going research an improved scheduling method for construction operations has been developed, based on a CPM - Precedence Network plotted on a Resource–Space chart. Space Units of the project work are identified by a Location Breakdown Structure (LBS) like in the LBM System, and project activities are identified by a two dimensions coordinate system based on Resources (i.e. construction crews) and working Spaces (e.g. floors of a multi-storey building). As the Precedence Network is plotted on a resource – space chart, Space Units can be characterized by a maximum resource capacity number for each activity type, thus defining the available space capacity of working crews. In this way project scheduler can verify the quality of the produced schedule during the planning and scheduling process, as dimensions of workspaces and their congestion limits, safety spaces and protection spaces can be easily verified. The method has been tested on a sample project. The proposed scheduling approach can help unexperienced project schedulers to identify specific resource requirements for spaces needed for activities, and to define locations of these spaces and resources on building site. The proposed approach can be useful especially in case of project acceleration and time-cost trade-off, helping the project team to produce an efficient construction schedule.

Keywords: Construction, project scheduling, resource management, precedence network, workspace management

1. Introduction

Construction projects are very specific industrial projects. One of the most important features of construction production is related to the building site. Building construction is an industrial activity in which workers build not only the product but also the working location, i.e. the building site. Therefore, space for construction activities, including materials, machines and fabrication stations, traffic routes, places of construction work and welfare facilities must be designed, organised and planned (Riley, Sanvido, 1997). Construction planning and scheduling has the objective of providing a logical order for activities taking into account safety, space and logic requirements. In particular, it is believed that a construction schedule should focus on space requirements as they can have very important effects on safety and production quality (Akinci, Fischer, Levitt, Carlson, 2002; Ciribini, Galimberti, 2005). Understanding the organization of the various materials, trades, and subcontractors in the project processes is an ability acquired only after years of study and experience. Construction workspace is, at the same time one of the main components and constraints of construction scheduling, due to production context and building product characteristics. So, workspaces are generally difficult to proactively plan and manage, because of the dynamic nature of construction production where site layout and work environment change continuously as processes progresses. Workspaces are key elements of the process model embodied in a schedule, and work-space conflicts prevention is an important feature of a construction schedule. As standard planning and scheduling of a construction project can be achieved through networking techniques, the space – related component of the schedule is difficult to model and to efficiently take into account by an unexperienced project scheduler. Thus, a method to understand schedule workflow and spaces during the scheduling process can be a valuable instrument to achieve project success.

2. Literature review

Many scheduling methods have been proposed in literature in order to improve construction project workspace management with a scheduling model. As crews perform activities from a space unit of the project to another one, it might be advantageous to arrange for such crews to work continuously, without interruptions, thereby preventing idle intervals of equipment and manpower (Selinger, 1980). Riley and Sanvido (1995 and 1997) observed that current space planning in multi-storey building construction is limited to site layout and logistics, and they propose a space planning method that provides a logical order and priority for activities related to their needed spaces. Effectively a construction planner need to: (1) identify the space needed for activities; (2) define locations for these spaces on building floors; (3) develop a sequence of work that defines the order spaces are occupied; (4) identify potential spatial conflicts. Kang et alii (2001) observed that in a multiple repetitive construction project, construction cost and duration are dependent on: number of work areas, proper crew grouping, size of work areas, frequency of repetition of each activity, and provided an heuristic approach to allow optimal construction planning. Yang and Ioannou (2001) proposed a scheduling method with focus on practical concerns in repetitive projects, and implemented in particular the pulling effect in the continuity relationship between activities.

Yi, Lee and Choi (2002) presented a heuristic method for network construction and development for repetitive units project, with the aim of minimizing total project duration by reducing idle time of resources and spaces. Actually the heuristic changes the sequence with which crews complete the scope of work encompassed in each repetitive activity. This approach and general formulation has been applied in earlier and more accurate models (El Rayes and Moselhi, 1998) which guarantee a global optimum solution. Guo (2002) proposed to integrate computer-aided design with scheduling software for the dynamic identification of space conflicts on the jobsite. Work-space types are identified and time-space conflicts are studied. The seminal work of Akinci, Fisher, Levitt and Carlson (2002) investigated the time-space conflicts in construction projects. Six type of spaces required by construction activities were detected and each construction activity requires at least one of these spaces. As activities can have time overlaps, i.e. they can be performed at the same time, time – space conflicts may occur. Ciribini and Galimberti (2005) observed that the H&S Management has widely to deal with working areas and space conflicts. A schedule model should indicate crew workflow directions, space requirements, and spatial buffers between activities. The optimization of the sequences of crews (workflows and production rates) can be done by scheduling work locations. Daewood and Mallasi (2006) and Mallasi (2006) observed that lack of execution pace planning may disrupt the progress of construction activities. Also, spatial congestion can severely reduce the productivity of workers sharing the same workspace, and may cause health and safety hazards to workers. A Critical Space-Time Analysis (CSA) approach is proposed to model and quantify workspace congestion and a computerized tool termed PECASO was developed for workspace management. The basic method suggested by researchers and practitioners for time – space project modeling is the linear scheduling method, flow line or linear planning, integrated with a network model (Kenley and Seppanen, 2010; Russell, Tran & Staub – French, 2014). Kenley and Seppänen (2009, 2010) observed that locations are important in construction because building can be seen as a discrete repetitive construction process, a series of physical locations in which work of variable type and quantity must be completed. They also observed that the location based methodology does not exclude Critical Path Method (CPM), in fact dependencies between activities in the various locations and between tasks (that are made up of activities of the same work item) are realized with CPM logic links. Construction projects are location – based projects (Kelley, Seppanen, 2010), where resources perform the same activity in different locations consecutively. Choy, Lee, Park et alii (2014), observe that current construction planning techniques have proven to be insufficient for work-space planning because they do not account for needed spaces of activities. So a framework for work-space planning is proposed categorizing activity spaces and including 4D Building Information Model (BIM) generation for space identification. Zhang, Teizer, Pradhananga and Eastman (2015) highlight safety and productivity poor performances of construction due to congested site conditions, and propose a method for automated visualization of workspace with BIM. Workspace modelling is based on five workspace sets and a conflict taxonomy.

In summary it is felt that there is a lack of structured planning and scheduling method for workspace management, at the design and schedule level of a construction projects. Workspace is an important concept and viewpoint for understanding characteristics of construction projects. The earlier research has covered already several important methodological characteristics of construction planning and scheduling with the site space on focus. Although not covered explicitly here some research has covered also computerized assistance for the generation of alternative plans and schedules – for example (Kahkonen, 1994; Märki et al, 2007). The research presented in the following aims at proposing a method to understand work-space characteristics of a construction project for planning and scheduling purposes, thus creating a process-oriented environment for construction schedule production, and enabling high quality scheduling.

3. Proposed Method

3.1 REPNET: Repetitive Networking technique

In an on-going research an improved scheduling method for construction operations has been developed, based on a CPM - Precedence Network plotted on a Resource–Space chart termed Repetitive Networking Technique (REPNET). Locations or Space Units of the project are identified by a Location Breakdown Structure (LBS) like in the LBM System, and project activities are identified by a two dimensions coordinate system based on Resources (i.e. construction crews) and working Spaces (e.g. floors of a multi-storey building) (Bragadin 2010, Bragadin, Kahkonen 2011). As construction projects activities are often performed in many different locations of the building site by the same crew, a basic component of construction process understanding is the modeling of this time – space related process. A project activity performed in different locations, with similar sub-products, is termed repetitive activity. It is important that repetitive activities are planned in such a way as to enable timely movement of crews from one unit to the next, avoiding crew idle time and space - conflicts with other construction activities. The REPNET heuristics provide optimized activity scheduling maintaining the work continuity constraint and also the As-Soon-As-Possible total project duration calculation.

3.2 Resource-flow tracking with a resource – space chart

A Precedence Diagram Network of the repetitive project is plotted on a resource – space chart, with the x-axis representing resources and the y – axis representing space units of the project. The two coordinates identify each network node representing an activity performed in a specific space unit: the first coordinate is the main resource performing the activity (construction crew) and the second coordinate is the work space in which the activity is to be performed. The procedure of plotting the network on a resource – space coordinates has been used by many researchers in the past. In particular Yi, Lee and Choi (2002) presented an heuristic method for network construction and development for repetitive units project, with the aim of minimizing total project duration by reducing idle time of resources and spaces. The heuristic plotted the activity network on a Resource – Space Chart. Resources in the x-axis of the chart were the work crews or the equipment that was intended to perform activities. Resources were grouped by work item i.e. masonry, plastering, floor concrete slab etc. Multiple resources, i.e. multiple crews, were allowed for the same work item in order to perform parallel repetitive activities in different locations of the same task. In this way in every column of the chart activities are grouped by resources (fig. 1). Space units of the project are plotted on the y-axis. Space units are the locations where only one crew can perform one activity at a time. In the proposed method the Location Breakdown Structure (LBS) can be displayed on the y-axis with a hierarchical decomposition of project locations (fig.3). An activity is defined as the set of construction operation performed by a specialized crew or equipment in a space unit of the construction project. In a repetitive construction project a set of activities, performed by the same crew in more than one space unit, is defined repetitive activity. Resources that perform a repetitive activity are identified by a j code. A task is defined as a set of repetitive activities performed by one or more than one crew for a work item, and is identified by the i code. So a resource path is completely identified as a repetitive activity by the ij code (ie resource path) and a single activity is identified by the ij-k code where k identifies the space unit where the activity is performed (i.e. space path, fig. 1). The k code is a unique alphanumeric character that identifies the operational space of the Location Breakdown Structure.

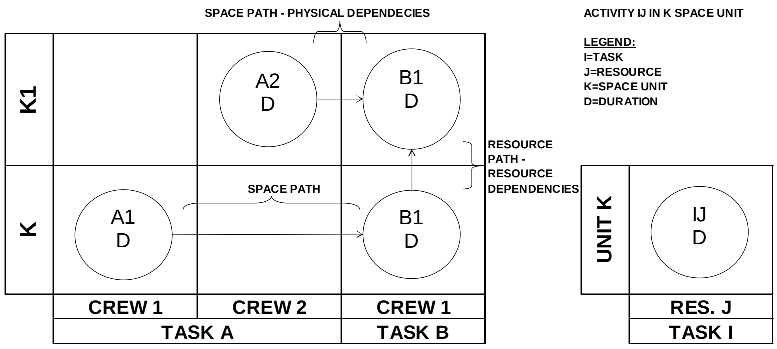

Figure 1: Network Diagram plotted on a Resource-Space Chart (adapted from Yi, Lee and Choi, 2002)

3.3 Space planning with the resource – space chart

The space identification for a construction schedule can be addressed by Location-Based Planning (Kenley and Seppänen, 2010). Location – Based management assumes that there is value in breaking a project down into smaller locations and using these to plan, to analyse and to control work as it flows through these locations. The location provides a container for project data at a scale which is easy to schedule and to control. The emphasis in location – based scheduling is to schedule the construction project achieving high level of productivity, quality and safety. The Location Breakdown Structure (LBS) is the backbone of this design process of on-site operations. Once the project is decomposed into various locations, or space units, understanding the interactions between activities and spaces is needed. In this phase the required spaces for each activity are detected and assigned to space units. Repetitive activities are decomposed into various activities to be performed into specific space units due to their production features, and single activities are allocated to specific spaces of the LBS. The sequence of activities is then generated using Precedence Diagramming Method (PDM). Activities are sequenced with network logic links and consecutive and concurrent work tasks are defined first for each space units and then for the complete building project. The prepared activity network can now be plotted in the Space – Resource chart. The allocation of activity on the resource – space chart can highlight possible time/space conflicts between activities. Conflict resolution can be performed and the optimized space-allocated schedule can be completed. The flow-chart of the proposed scheduling process can be found in figure 2.

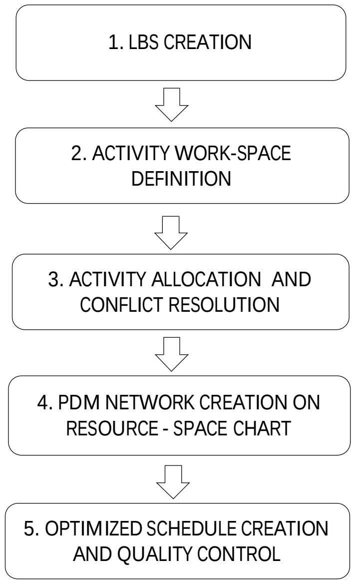

Figure 2: Proposed Scheduling Process

The seminal work of Akinci, Fisher, Levitt and Carlson (2002) investigated the time-space conflicts in construction projects. Six type of spaces required by construction activities were detected: building component space; labor crew space; equipment space; hazard space; protected space; temporary structure space. Each construction activity requires at least one of these spaces. As activities can have time overlaps, i.e. they can be performed at the same time, time – space conflicts may occur (Akinci et alii, 2002; Mallasi, 2006; Zhang et alii, 2015). Time – space conflicts have three characteristics:

- Temporal aspects of time-space conflicts: since activity space requirements change over time, time – space conflicts between activities only occur for certain periods of time.
- Multiple types of time – space conflicts: depending on the types of space conflicting and the quantity of interfering spaces, time – space conflicts can have many types: safety hazard; congestion; design conflict; damage conflict.
- Multiple conflicts can exist between a pair of conflicting activities.

In the proposed method, four types of conflicts are identified for project scheduling purposes:

- Time / space conflicts due to activities' time-space overlapping and consequent contemporary space usage;

- Congestion of space due to labor density. The maximum number of workers per site location should be limited. The increase of labor density can lead to productivity loss and safety hazards.
- Safety hazards due to hazard spaces created by an activity for labor crew spaces of other activities.
- Damage conflicts due to labor crew spaces, equipment space, temporary structure space, hazard space required by an activity conflicts with a protected space of another activity.

The proposed resource – space chart based method can help project planner and production managers to avoid conflicts in many ways. In fact, time-space conflicts can be avoided due to space allocation of activities in the resource-space chart. PDM activities plotted on the resource-space chart give a clear definition of the space used by labor crew for working. At the same time the layout space for each activity execution is identified on the chart, and it is easy to indicate the maximum number of workers per space units. Safety hazard spaces and protected spaces can be represented as unavailable spaces directly on the resource – space chart plotted for a specific time window. Basic limit of the proposed solution is the level of detail of the LBS, and the consequent space requirements for activities and representation of space conflicts between activities. The understanding of space conflicts needs a deep knowledge of the modelled construction process and proper level of detail of work packages.

4. Sample project

A sample project of construction of a small three storey residential building is presented. The created workflow model for the construction phase of the systems and interior finishing works is presented. The residential building of the sample project is composed by two edifices (A and B), joined by a covered corridor. Building A has three storeys while building B has only two storeys. The Location Breakdown Structure (LBS) is depicted in figure 3.

PROJECT	*FLOOR*	*BUILDING*	*SPACE UNIT DESCRIPTION*	*SPACE UNIT LBS CODE*
SAMPLE PROJECT - 1	2^F-SECOND FLOOR: 1.SF	BUILDING A 2^F: 1.SF.A	*FLAT-U6*	*1.SF.A.2*
			FLAT-U5	*1.SF.A.1*
		BUILDING B 2^F: 1.SF.B	*ROOF B*	*1.SF.B.1*
	1^F-FIRST FLOOR: 1.FF	BUILDING A 1^F: 1.FF.A	*FLAT-U2*	*1.FF.A.2*
			FLAT-U1	*1.FF.A.1*
		BUILDING B 1^F: 1.FF.B	*FLAT-U4*	*1.FF.B.2*
			FLAT-U3	*1.FF.B.1*
		ROOF C : 1.FF.C	*ROOF C*	*1.FF.C.1*
	GF-GROUND FLOOR: 1.GF	BUILDING A GF: 1.GF.A	*CELLARS*	*1.GF.A.1*
		BUILDING B GF: 1.GF.B	*GARAGES*	*1.GF.B.1*
		CORRIDOR: 1.GF.C	*CORRIDOR*	*1.GF.C.1*

Figure 3: Location Breakdown Structure of the sample project

After the LBS creation work spaces of each activity have been defined, and the maximum number of workers per space unit has been assigned. Labour density limits are set with the aim of satisfying technology and safety requirements. In figure 4 the maximum number of workers per space unit is shown. In this phase activity allocation on space units is performed with the aim of optimising construction processes in terms of work continuity of crews, safety issues, congestion avoidance due to contemporary space usage and protected spaces usage.

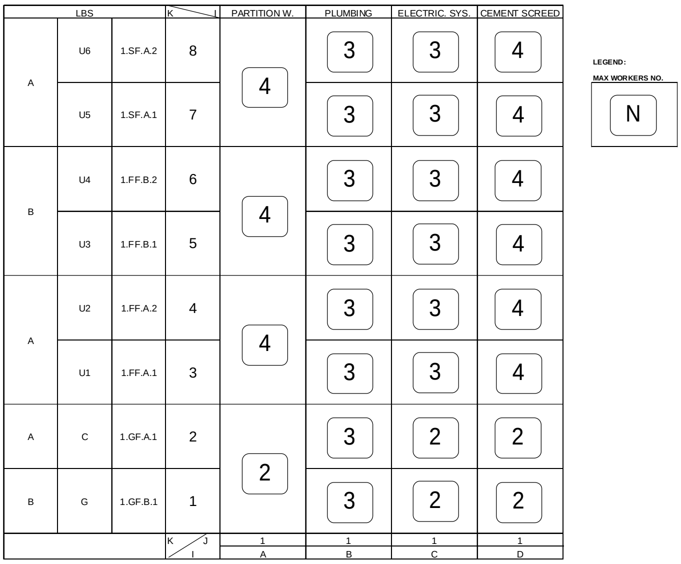

Figure 4: Labour density limits per space unit of the sample project

At the end of this phase activity durations can be computed, as shown in table 1.

Table 1: Sample project activity data

TASK [i]:	*A - PARTITION WALLS*			*B - PLUMBING*			*C - ELECTRICAL SYSTEM*			*D - CEMENT SCREED*		
SPACE UNIT [k]	*SPACE CAPA-CITY*	*No. Laborers*	*DUR. D*	*SPACE CAPA-CITY*	*No. Laborers*	*DUR. D*	*SPACE CAPA-CITY*	*No. Laborers*	*DUR. D*	*SPACE CAPA-CITY*	*No. Laborers*	*DUR. D*
1	*2*	*2*	*10*	*3*	*3*	*3*	*2*	*2*	*5*	*2*	*2*	*2*
2				*3*	*3*	*3*	*2*	*2*	*5*	*2*	*2*	*2*
3	*4*	*4*	*15*	*3*	*3*	*5*	*3*	*3*	*4*	*4*	*4*	*4*
4				*3*	*3*	*5*	*3*	*3*	*4*	*4*	*4*	*4*
5	*4*	*4*	*15*	*3*	*3*	*5*	*3*	*3*	*4*	*4*	*4*	*4*
6				*3*	*3*	*5*	*3*	*3*	*4*	*4*	*4*	*4*
7	*4*	*4*	*15*	*3*	*3*	*5*	*3*	*3*	*4*	*4*	*4*	*4*
8				*3*	*3*	*5*	*3*	*3*	*4*	*4*	*4*	*4*

The creation of PDM network on basis of the Resource – Space chart (fig. 5) is easy to perform as a following step, as it is only needed to add logic links on the previous pattern of activity allocation on the LBS (fig. 4). The REPNET heuristics (Bragadin, Kahkonen, 2011) is then performed and a workflow optimised schedule is developed. In figure 6 the flow-line chart of the sample project is depicted. Then the produced schedule needs to be controlled. Firstly it is easy to observe that for the sample project the work continuity requirements has been satisfied almost completely, with the exception of activity D in units no.1 and 2. Also no time – space conflicts are detected and labour density requirement is satisfied (as activity durations were computed with this constraint in table 1). For each working week the state of the project can be plotted, thus facilitating the controlling process through building site scheduled status representation. Completed and in progress activities are pointed out with successor spaces. Unavailable spaces because of cement screed hardening (after activity D implementation) are highlighted with different colour in the chart, to ease production management of successor construction processes (fig. 7).

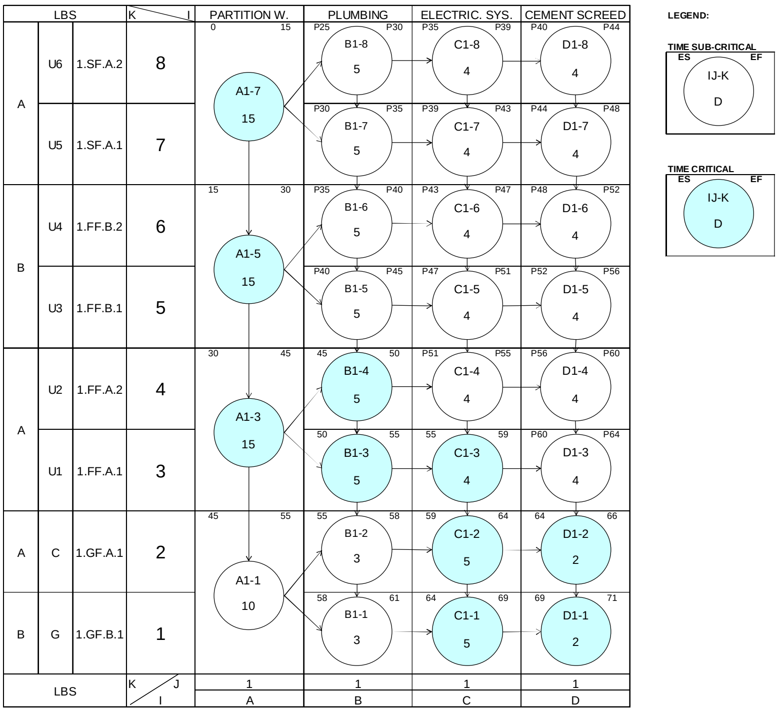

Figure 5: PDM network plotted on a resource – space chart - REPNET

5. Discussion

The proposed method for construction scheduling, is based on workspace management issues. It is considered that the proposed simple method that uses resource – space charts can be useful for preparing schedules of good quality, meaning with this that they are process oriented and easy to update and maintain. On the other hand, the proposed method needs a skilled scheduler especially at the beginning, when LBS is created and activities' work spaces are defined. The need of developing a good LBS is because of the proposed scheduling method structure, i.e. the sharpness of LBS directly affects the sharpness of activities, as project activities are allocated into space units created in the LBS since the beginning. Mistakes and incongruences in this phase can affect schedule development and conflict detection. Also activity allocation and conflict resolution need a good construction expertise for a sharp modelling, but it is believed that the creation of the resource-space chart helps logic thinking and prearranged problem solving. Linking the proposed method with BIM models capturing location details of end product is an interesting way to develop it further. This would mean capturing directly the location data of interest from BIM model to be used for scheduling purpose. With the known spatial needs of different activity types and their operational resources this can provide grounds for highly advanced and detailed scheduling solutions. As previously mentioned, limitations of the method can be found in the workspace modelling performed by the LBS and the two-dimensions resource-space chart. Detailed BIM models can be very effective for workspace conflict detection (Akinci et alii, 2002; Choi et alii, 2014; Ciribini, Galimberti, 2005; Dawood, Mallasi, 2006; Mallasi 2006; Zhang et alii, 2015), but it is also believed that a simple space modelling approach, as the one based on the LBS development, can be a quick and efficient method for workspace scheduling (Kenley, Seppanen, 2009, 2010; Russell, Tran, Staub-French, 2014).

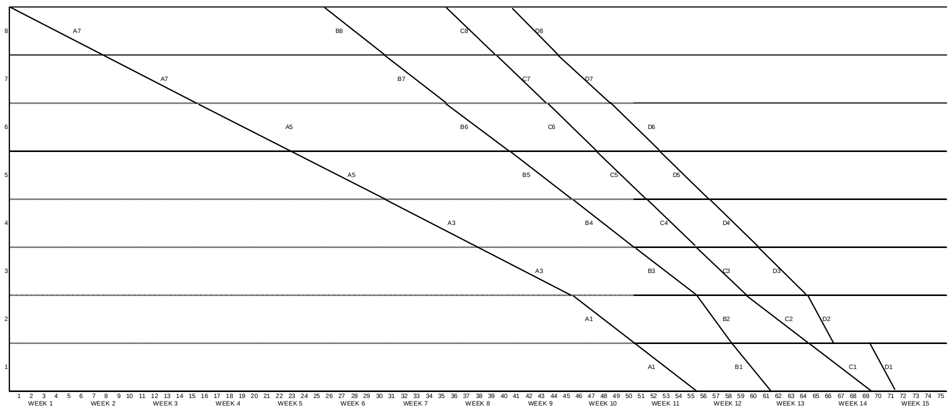

Figure 6: Sample project: flow-line diagram REPNET

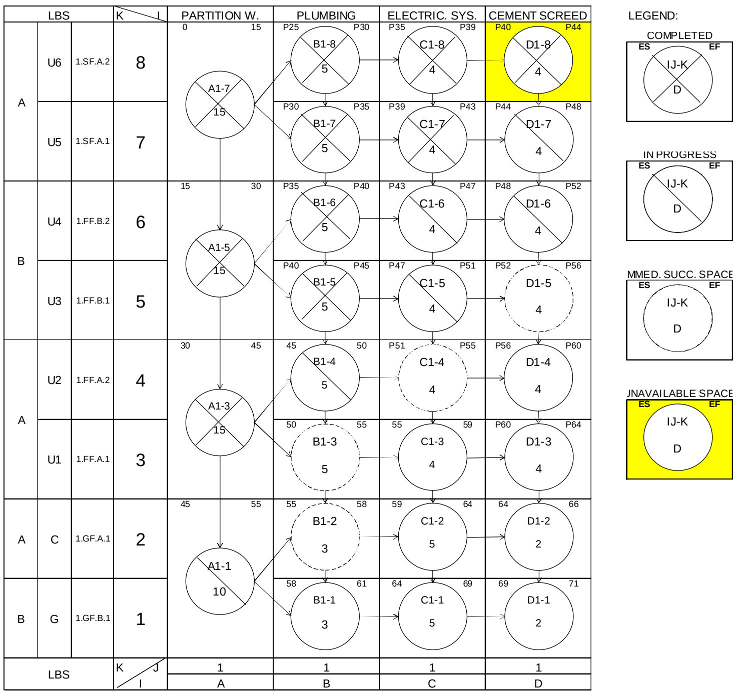

Figure 7. Sample project phase: week 10 plotted on a Resource – Space chart

6. Conclusions

The use of Resource-Space charts for construction workspace scheduling has been presented, since it is considered that explicit inclusion of spatial calculation is essential for preparing construction schedules of good quality. Many researchers and practitioners have highlighted the need of a workspace management system for construction process modelling, planning and scheduling. A Resource-Space chart, based on a Location Breakdown Structure, captures already main part of the logic of construction schedule. Thus, a PDM network can be easily prepared based on this. Accordingly project and production managers are creating process oriented project schedules where time – space conflicts of activities can be prevented, and congestion avoided due to the overall logic of the proposed scheduling method. The proposed method can be linked with BIM models for having direct access to spatial data.

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Analysis of a Time Management Model in Real Estate Projects

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Abstract

Unfortunately, delays are common in the construction industry. They create concerns for project performance and cause losses to project parties. These delays are caused by a number of factors.

The aim of paper is to analyse the main causes of delay in construction projects and to propose a preliminary and structured framework to improve the actual use of time planning tools and control instruments.

The framework is based on assumptions defined to optimise the techniques of tactical-operational planning currently adopted in the academic and professional environment, but reflecting on the Brazilian construction reality. It also assists early risk identification of non-compliance to scheduling and the best ways to compensate for delays.

Initially, a literature review was conducted to identify the main factors influencing the delay of construction projects. One of these surveys was emphasized because it compiled all these factors in a specific list.

Then, an analysis of data from 50 real estate construction projects in Brazilian cities (built in the last eight years) is also described, ordering the results in a frequency rank. This rank showed that the greatest concentration of causes of delay (over 60%) is related to inappropriate use of planning tools, team management and low productivity in the activities.

Using literature review again, this article identifies tools and assumptions to improve the control of project deadlines, thus avoiding the occurrence of various problems raised in the previous rank.

Finally, a time management framework is proposed. It consolidates the tools studied for better managing of time in construction projects. The performance of this preliminary model could be measured by its implementation in new researches, as described in the conclusions of the paper.

Keywords: Delay causes, planning, scheduling tools, construction project, time management

1. Introduction and justification

The execution of real estate projects in Brazil has always been a difficult activity because, historically, the country conditions do not stimulate Brazilian entrepreneurs, such as difficulty in financing, high interest rates, legal risks, defaults, complex regulations and non-qualified labour.

The market scenario started to change in the late 1990s and especially after 2005, with the IPO (Initial Public Offering) of large construction companies, improvement in the country economic conditions and more availability of credit for buyers. This scenario allowed a great market growth, but the sector was not prepared (technically or materially). Thus, despite this positive condition, there was an increase of delays, consumers' complaints and financial losses.

This would be a great opportunity for academic studies in the area. However, Brazilian structured researches about this theme were not found.

In recent years, the situation has been different, due to the global economic crisis and the Brazilian political situation. Even after technical adjustments and market restructuring, delays are still constantly verified. Even with less significant impact, as compared to those of the recent past, the question is what are the reasons why the construction projects are still delaying?

With all these doubts, the importance of academic studies into this subject was identified. This article can provide information and raise the interest of researchers and professionals in the sector.

Outside Brazil, in this period, many studies were observed to identify the most frequent causes of these delays, how they relate to each other and possible mitigation actions. To contribute to future research on the topic in Brazil, De Filippi and Melhado (2015) established a unified list of the most common papers, adapting items based on the Brazilian market scenario.

This article furthered this research, by increasing the number of projects surveyed and established what the main causes would be by studying a sample of companies in Brazil.

Finally, guidelines for a project management model in the construction sector were established, which could minimize the occurrence of the most important causes.

2. Research methodology

The methodology adopted includes some steps, starting from a literature review. The references studied by De Filippi and Melhado (2015) were increased and the new literature review searched not only causes of delay, but also tools to minimize these problems.

Then, using a list of 100 items compiled by De Filippi and Melhado (2015) as a research protocol on a field survey, the authors analysed which of these items influenced the delays of 50 Brazilian construction projects, in the last eight years. The sources of evidence for this analysis were interviews with those responsible for the projects planning and control, besides documents related to the project (plans, schedules, management reports, etc.).

The resulting data were also analysed and classified, resulting in a ranking about the Brazilian scenario.

Based on this ranking, the tools and guidelines by several authors were compared. This study supported guidelines generation to prevent the occurrence of the major causes.

These guidelines were structured as a proposal to improve time management. The application of these guidelines was discussed for developing a time management model (paths supporting the creation of structured methods to overcome the main causes of delay).

3. Literature review on studies into the delay in construction projects

3.1 Delay causes and interference with project time management

Recent researches, such as Fugar and Agyakwah-Baah (2010) in Ghana, Doloi *et al.* (2012) in India, Gunduz *et al.* (2013) in Turkey, Haseeb *et al.* (2011) in Pakistan, Marzouk and El-Rasas (2014) in Egypt and Mydin *et.al.* (2014) in Malaysia, identified the general causes of delay that occur in projects in their respective countries. A number of them allowed verifying different causes of delay and its importance (hierarquy). According to the authors, identifying the most impacting helps professionals and researchers to seek alternative solutions to mitigate delays.

Olawale and Sun (2010) presented an extensive survey on causes of delay with 250 construction companies in the UK, and listed a number of researches on the subject published in a 25-year period, by Ardini *et.al.* (1985 cited by Olawale and Sun, 2010) until the date of its publication.

Other papers discussed the main causes, such as El-Razek *et al.* (2008) in Egypt, which highlighted "financial issues" and "design changes", or Aibinu and Odeyinka (2006), in Nigeria, identifying some main causes, such as "actions and omissions of the project participants" and "external factors".

Assaf and Hejji (2006), in a study in Saudi Arabia, revealed that the most common cause of delay identified in their survey was "change in orders". Yang and Wei (2010) identified similar situations and described that "changes in customer demand" are the main causes of delays and these problems occur in the planning and design stages.

In Brazil, some authors not focused on construction, but who study project management in general, presented very interesting discussions that contributed to this article.

Elder (2006), using TOC (Theory of Constraints) concepts, presented by Goldratt and Fox (2002), established five reasons for projects not to achieve their results, especially the planned deadlines: (i) harmful multi-tasks (constantly changing priorities); (ii) Parkinson's Law (work expands to fill the time available). (iii) Student Syndrome (procrastination of work); (iv) dependency between tasks (probability of dependent events); (v) the termination of an activity does not mean that the other will be started immediately.

Other authors studied how these causes were related to other problems or practices in construction management. In a current survey in the USA, Russell *et al.* (2014) identified not only the causes of time variation in projects, but also the most serious reasons for adding time buffers for the durations of construction tasks.

Several authors, including Rogalska and Hejducki (2007) and La Garza *et al.* (2007) discussed the use of buffers as an improved programming tool and time control over projects.

Nepal *et al.* (2006) stated that accelerating a project can be rewarding but the consequences can be problematics when productivity and quality are sacrificed to keep ahead of schedule. Productivity directly affects the delays, according to Hanna *et al.* (2005), who studied the impacts of overtime with extended duration of the projects.

3.2 Actions to avoid delays and to improve time control

Many of the issues discussed by several authors established guidelines or tools to improve the methods used by managers in their projects.

One of the aspects studied by many authors regards the adequacy of classical planning tools to manage project deadlines. In Malaysia, Abdul-Rahman *et al.* (2006) described the importance of applying appropriate management to deal with the delays in the construction of developing countries.

Although one of the project features is its uniqueness, there is a great repeatability of tasks in construction projects. Different authors identified alternatives to organize the processes when there are repetitive activities or when the projects can be repeated with few changes.

Vanhoucke (2006) affirmed that in repetitive projects, a major goal of the planning is to maintain the continuity of the work and to minimize the downtime of resources.

Under these conditions, traditional tools such as CPM - Critical Path Method would be too complex or they would not add the value expected. In projects with this feature, several authors such as Mattila and Park (2003), Fan and Tserng (2006), Kallantzis *et al.* (2007), Lucko (2008), and Hegazy and Menesi (2010) studied the use of linear programming tools or a repetitive scheduling method, along with their limitations and risks.

Some authors analysed other CPM limitations. Kim and La Garza (2003) stated that a traditional schedule based on CPM is not realistic, because it assumes unlimited resources. Ibbs and Nguyen

(2007) described that the delay analysis without the resource allocation practice substantially affects the results. Some delay may cause the unrealistic allocation of resources in the subsequent service, which could further delay the project.

Yi *et al.* (2002) and Barraza (2011) declared that tools such as CPM constitute a logic established by intuition and human experience; therefore, it could mean that there is a variety of alternative networks and this can bring inconsistencies in planning.

Arditi *et al.* (2002) attempted to establish improvements in the use and representation of the line of balance tool, including the development of an algorithm that improves the project acceleration with efficiency, dealing with resource constraints and deadline milestones, and a new concept of criticality, including the learning curve effect.

Kim and La Garza (2005) advocated the use of the Critical Path Method with multiple calendars to effectively represent the various project conditions, such as site properties, the availability of resources, weather conditions, etc.

In Brazil, a survey conducted by Quelhas and Barcaui (2004), not for the construction market analogously to Elder (2006), described the concept of CCPM (Critical Chain Project Management) as the application of TOC (Theory of Constraints) to the project environment. The authors suggested how best actions: (i) reduction of safety margins per task; (ii) reduction of multitasking; (iii) use of dependencies also based on resources and not only on predecessors; (iv) use "later start dates" to the tasks; and (v) use of buffers at the end of the critical current (project buffer).

4. Classifications of causes of delay

The paper by De Filippi and Melhado (2015) brought a correlation of the main researches classifying the causes of delay. The authors sorted them into groups common to most authors[1], as can be seen in Table 1.

While there are several other studies related to project delays, we chose surveys that effectively brought qualitative descriptions and frequency as they appear in the construction projects in each of the countries where the surveys were conducted.

[1] the authors are references in the paper De Filippi and Melhado (2015)

Table 1: Classifications of causes of delay (De Filippi and Melhado, 2015)

Group	Authors[1] / Delay Causes	Abd El-Azek et al. (2008)	Aibinu & Odeyinka (2006)	Alwi & Hampson (2003)	Assaf & Al-Hejji (2006)	Chan & Kumaraswamy (1997)	Couto (2007)	Faridi & El-Sayegh (2006)	Fugar & Agyakwah (2010)	Gunduz et al. (2013)	Lo et al. (2006)	Marzouk & El-Rasas (2014)	Mydin et al. (2014)	Odeh & Battaineh (2002)	Sambasivan & Soon (2007)	Sweis et al. (2008)
Scope / Feasibility	Conflicts between owners	-	-	-	x	-	-	-	-	x	-	-	-	-	-	-
	Inadequate definition of project scope/construction product	-	-	-	x	-	-	-	-	x	-	-	-	-	x	-
	Legal disputes between project participants	-	x	-	x	-	-	-	x	x	x	-	-	-	x	-
	Type of project bidding and award (negotiation, bidder...)	-	-	-	x	-	x	-	-	-	x	x	-	x	-	-
	Type of construction contract (turnkey, construction only...)	-	-	-	x	-	-	-	-	x	-	-	-	-	-	-
	Unreal duration of original contract (too short)	-	-	-	x	x	-	x	-	x	x	x	-	x	x	-
	Lack of incentives for contractor to finish ahead of schedule	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-
	Ineffective delay penalties	-	-	-	x	-	-	-	-	x	-	x	-	-	-	-
	Errors in the specifications or contract documents	-	x	-	-	-	-	-	-	-	x	-	-	x	x	-
	Improper project feasibility study	-	-	-	-	-	-	-	-	-	x	-	-	-	-	x
Owner	Lack of experience of owner in construction projects	-	-	x	-	-	-	-	-	x	-	-	x	-	-	-
	Slow decision making	x	x	x	x	x	-	x	-	x	-	x	x	x	x	x
	Owner’s interference in the operations / project	-	-	-	-	x	-	-	-	-	-	x	-	x	x	x
	Owner's failure in project information communication	-	-	-	x	-	x	-	-	-	-	-	-	-	-	-
	Delay in revising/approving design documents by owner	-	x	-	x	-	-	x	-	x	x	x	-	-	-	x
	Delay in delivering site to contractor by the owner	-	-	-	-	-	x	-	-	x	x	x	-	-	-	x
	Delay in progress payments	x	x	-	x	x	-	x	x	-	x	x	x	x	x	x
	Design changes by owner or his agent during construction	x	x	-	x	-	x	x	x	x	x	x	x	x	x	x
	Delay in delivery of the material by owner	-	-	-	-	-	x	-	-	-	x	-	-	-	-	-
	Suspension of work by owner	-	-	-	x	-	x	-	-	-	-	x	-	-	-	x
Consultant	Lack of experience of consultant in construction projects	x	-	-	x	x	-	-	-	x	-	x	x	-	-	x
	Inadequate project management assistance	x	-	-	-	-	-	-	x	-	-	-	-	-	-	x
	Delay in budget definitions or work package price	-	x	-	-	-	-	-	x	-	x	-	-	-	-	-
	Late in reviewing andin approving design by consultant	x	x	x	x	x	-	x	-	x	-	x	-	x	x	x
	Delay in approving changes in scope of work by consultant	-	-	-	x	-	-	-	-	x	-	-	x	-	-	x
	Inflexibility (rigidity) of consultant	x	-	-	x	-	-	-	-	-	-	-	-	-	-	-
	Conflicts between consultant and design engineer	x	x	x	x	-	-	x	-	x	x	-	x	-	-	x
	Quality control problems	x	x	-	-	-	-	-	-	-	x	x	-	x	x	x
	Delay in performing inspection and testing	x	-	x	x	-	-	x	-	x	-	-	-	-	x	x
	Project management process	-	x	-	-	-	-	-	x	-	-	-	-	x	x	-
Design	Misunderstanding of owner’s requirements by designer	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-
	Insufficient data collection and survey before design	-	x	-	x	-	-	-	-	x	-	-	-	-	-	-
	Complexity of project design	-	x	-	x	x	-	-	x	x	-	-	-	-	-	-
	Delays in producing design documents	-	-	-	x	x	x	-	-	x	-	-	-	-	-	-
	Unclear and inadequate details in drawings	-	x	x	x	-	x	x	-	-	-	x	x	-	-	-
	Mistakes and discrepancies in design documents	-	x	x	x	x	x	x	x	x	-	x	-	-	-	x
	Insufficient specifications or designs	-	x	x	-	-	-	-	x	-	-	-	-	-	-	-
	Excessive design changes	-	-	x	-	-	-	x	-	-	-	-	-	-	-	-
	Poor use of advanced engineering design software	-	-	-	x	-	-	-	-	x	-	-	-	-	-	-
	Lack of experience of design team in construction projects	-	-	-	x	-	-	-	-	x	-	-	x	-	-	x
Contractor	Inadequate contractor’s experience	x	-	x	x	x	-	x	-	x	x	x	-	x	x	x
	Difficulties in financing project by contractor	x	x	-	x	x	x	x	x	-	x	x	x	-	-	x
	Ineffective financial / cash flow planning	-	x	-	-	x	x	x	-	-	x	-	-	-	-	-
	Conflicts between contractor and other parties	-	x	-	x	-	-	-	-	-	x	-	x	-	-	-
	Poor site management and supervision	x	-	x	x	x	x	x	x	x	x	x	x	x	x	x
	Poor / inefficient sub-contractors’ supervision	-	x	x	-	x	x	x	x	x	-	x	-	-	-	-
	Delays in internal production decisions	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-
	Ineffective project planning and scheduling	-	x	x	x	x	x	x	x	x	-	x	-	x	x	x
	Inappropriate physical reprogramming	-	-	-	-	-	-	x	-	-	x	-	-	-	-	-
	Delay in preparing specifications or material samples	-	x	-	-	-	-	-	-	-	-	x	-	-	-	-

Table 1: Classifications of delay causes (De Filippi and Melhado, 2015) – continuation

Group	Authors / Delay Causes	Abd El-Azek et al. (2008)	Aibinu & Odeyinka (2006)	Alwi & Hampson (2003)	Assaf & Al-Hejji (2006)	Chan & Kumaraswamy (1997)	Couto (2007)	Faridi & El-Sayegh (2006)	Fugar & Agyakwah (2010)	Gunduz et al. (2013)	Lo et al. (2006)	Marzouk & El-Rasas (2014)	Mydin et al. (2014)	Odeh & Battaineh (2002)	Sambasivan & Soon (2007)	Sweis et al. (2008)
Contractor (cont.)	*Slow mobilization of labour*	-	x	-	x	-	x	-	-	x	x	x	-	-	-	x
	Poor layout of site or logistic planning	-	-	x	-	-	-	-	-	-	x	-	-	-	-	-
	Rework due to errors	-	-	-	x	-	-	x	-	x	x	x	x	x	x	-
	Inappropriate construction methods	-	-	x	x	-	x	x	x	x	x	-	-	x	x	x
	Conflicts on sub-contractors scheduling during execution	x	-	-	x	-	-	-	x	-	-	-	-	-	-	-
	Delay in progress payments	-	x	-	-	-	-	x	-	-	-	-	-	-	-	-
	Delay in sub-contractors' activities / tasks	-	-	-	x	x	x	x	x	x	x	x	-	x	x	-
	Sub-contractor's interference in the site operations	x	x	-	-	-	x	-	-	-	-	-	-	-	-	-
	Frequent change of subcontractors	-	-	-	x	-	-	-	-	x	-	-	-	-	-	-
	Work overload	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-
Materials	*Shortage of construction materials*	x	x	x	x	x	x	x	x	x	-	x	x	x	x	x
	Late delivery of materials	x	x	x	x	-	x	-	x	x	-	x	x	-	-	x
	Poor procurement process/ material delivery programming	x	-	x	x	x	-	x	-	x	-	-	-	-	-	-
	Delay in defining the finishing materials(options)	x	x	-	x	x	-	x	-	-	-	-	-	-	-	-
	Delay in manufacturing materials	-	-	-	x	-	-	x	-	-	-	-	x	-	-	-
	Changes in material and specifications during construction	x	-	x	x	x	-	x	-	x	-	-	-	-	-	x
	Poor quality of construction materials	-	-	x	-	-	x	-	-	x	-	-	-	x	x	-
	Damage of sorted materials	-	x	x	x	-	x	-	-	x	-	x	-	-	-	-
Labour	*Labour work shortage*	x	x	-	x	x	x	x	x	x	-	x	x	x	x	x
	Unqualified/inexperienced workers	-	-	-	x	x	x	x	x	x	-	x	x	-	-	x
	Skilled workers' shortage	-	-	-	x	-	x	x	-	-	x	x	-	-	-	x
	Low worker productivity	x	-	-	x	x	x	x	-	x	-	x	x	x	x	-
	Low worker motivation and morale	-	-	-	-	x	-	-	-	x	-	-	-	-	-	-
	Nationality of labours / effect of social and cultural factors	-	-	-	x	-	-	-	-	-	x	-	-	-	-	-
	Personal conflicts among workers	-	-	-	x	-	-	-	-	x	-	-	-	-	-	-
Equipment	*Equipment allocation problem*	x	x	x	x	x	x	x	-	x	-	x	x	-	-	x
	Frequent equipment breakdowns	-	x	x	x	x	x	x	x	x	-	-	-	x	x	x
	Slow mobilization of equipment	-	x	-	-	-	x	-	-	x	-	-	-	-	-	-
	Low level of equipment-operator's skill	x	-	-	x	-	-	-	x	-	-	-	-	-	-	-
	Improper equipment	x	x	x	x	x	x	-	-	x	-	-	-	-	-	x
Project / Construction	*Unexpected surface conditions (soil, water table)*	x	-	-	x	x	x	x	x	x	x	x	-	x	-	-
	Loss of time by traffic control and restriction on job site	-	-	-	x	-	-	x	-	x	-	x	x	-	-	-
	Unavailability of utilities on site (water, electricity...)	-	-	-	x	-	x	-	-	-	-	x	-	-	-	-
	Delay in providing utility services (water, electricity...)	-	-	-	x	-	-	-	-	x	-	x	-	-	-	-
	Accidents during construction	x	-	x	x	-	x	-	x	x	x	x	-	-	-	-
	Poor document controls on the site	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-
	Poor working conditions on the construction site	-	-	x	x	-	-	-	x	-	-	-	x	-	x	-
	Differing site (ground) conditions	-	-	-	x	-	x	-	-	x	-	-	-	-	-	-
	Usual design changes during construction	-	-	-	-	x	-	x	x	-	x	-	-	-	-	-
	Problem with neighbours	-	-	x	-	-	-	-	-	x	-	x	-	x	x	-
	Incompatibility between activities and site infrastructure	-	-	-	-	-	-	-	-	x	x	-	-	-	-	-
External factors	*Unfavourable weather conditions*	x	x	x	x	-	x	x	x	x	x	x	x	x	x	x
	Environmental restrictions	-	-	-	-	x	-	-	-	-	x	x	-	-	-	-
	Changes in government regulations and laws	-	x	-	x	-	x	-	-	x	-	x	x	x	x	x
	Delay in obtaining permits from municipality	x	x	-	x	-	x	x	x	x	x	x	-	-	-	x
	Delay in inspection and in certification by a third party	-	-	-	x	-	-	-	-	x	-	x	x	x	-	-
	Poor communication and coordination with other parties	-	-	x	x	x	x	x	x	x	x	x	x	x	x	-
	Inadequate organizational structure (project parties)	x	-	-	-	x	-	-	-	-	-	-	-	x	x	-
	Price fluctuations / material or equipment prices	-	x	-	-	-	-	-	x	x	-	x	-	-	-	x
	Natural disasters (flood, hurricane, etc.) or Conflicts (war)	-	x	-	-	-	x	x	-	x	-	x	-	-	-	-

5. Field survey

For the field survey, an extended protocol was used, based on Table 1 items. The protocol aimed to ensure that all possible causes of the delays would be verified in all the projects, acting as a research guide.

Based on the monthly reports of each project, which described physical performance and the facts interfering with the schedule, it was possible to analyse when and why problems occurred along these projects and their impact on the deadline.

Complementing the analysis of the facts, interviews with the project professionals were made, mainly with the planning team. Interviews were able to recover some hidden problems in reports.

The sample sought elements from different economic realities. However, so that the results could be compared, it sought projects with some similar features such as:

- Residential or commercial real estate projects, in several different construction companies;
- Vertical buildings (towers) with more than 10 floors (where there is repeatability);
- Projects with at least 5% delay (which had clear problems in the schedule).

Based on these specifications, 50 projects were selected. They presented these characteristics:

- 15 different locations: projects in São Paulo City (33), projects in other cities in the State of São Paulo (12), projects in cities in other States (5);
- 24 constructors: small/local firms (12), medium/regional companies (7); large companies (5);
- Built-up areas: 8,140 to 80,750 sq. meters;
- Number of towers: one tower (25), two (11), three (7), four (5) and six (2);
- Project time foreseen: 13 to 35 months;

Using the history of each project throughout its execution phase, we performed a qualitative assessment of the facts that caused partial delays in scheduled activities and their sum resulted in significant final delays (more than three months, at least).

This survey did not identify which facts more significantly affected the final delay (those most affecting the critical path), but how often they occurred in the projects. Later, in a more comprehensive research, the classification of these impacts was also studied.

We identified in how many projects (of all the 50) each cause was found (in reports or interviews) and this result was characterized as the "frequency" of occurrence. In addition, to facilitate the analysis of the results, the frequency was ordered, creating a ranking as shown in Table 2.

Only the results above 40% of frequency in the rank were analysed, considering that the other items not were impactful or they were outside of the critical zone for future analysis.

Table 2: Rank of delay causes in construction projects

Cod.	*Description*	*Group*	*Frequency*
a	*Poor site management and supervision*	*5*	*68,0%*
b	*Sub-contractor's interference with the site operations*	*5*	*66,0%*
c	*Ineffective project planning and scheduling*	*5*	*60,0%*
d	*Low worker productivity*	*7*	*60,0%*
e	*Slow mobilization of labour*	*5*	*54,0%*
f	*Rework due to errors*	*5*	*54,0%*
g	*Late delivery of materials*	*6*	*48,0%*
h	*Labour work shortage*	*7*	*46,0%*
i	*Delays in internal production decisions*	*5*	*44,0%*
j	*Inappropriate physical reprogramming*	*5*	*42,0%*
k	*Conflicts over sub-contractors scheduling during project execution*	*5*	*42,0%*
l	*Poor procurement process or material delivery programming*	*6*	*42,0%*
m	*Unreal duration of original contract (too short)*	*1*	*42,0%*
…	*Delay in sub-contractors' activities / tasks*	*5*	*38,0%*
	Slowness in decision making by owner	*2*	*36,0%*
	Slow mobilization of equipment	*8*	*36,0%*
	Inadequate definition of project scope or construction product	*1*	*30,0%*
	Poor / inefficient sub-contractor supervision	*5*	*30,0%*
	Frequent change in subcontractors	*5*	*30,0%*
	Unfavourable weather conditions	*10*	*30,0%*
	…	…	…

In Table 2, group 05 (contractor) held the greatest concentration of delay causes. In almost 2/3 of the projects studied, there were problems related to inappropriate use of planning tools and to managing the work teams.

Low productivity problems also appeared with great frequency, the only featured item that was not in group 05.

Then, less highlight, but also important, procurement items were also listed in the survey, which included not only the buying process, but also "delivery delays" and "shortage of labour ".

6. Discussion

Based on the literature and experiences of this paper's authors, we sought to identify, several guidelines related to the focus of this study. It focused on minimizing problems, especially those related to Group 05 (team management in construction, correct planning, rework and reprogramming).

The actions can be grouped into just four groups, which are the most frequent causes in research results and coded as the first column of Table 3, as shown below:

Table 3: Guideline to treat the main causes of delay

Guideline Group	*Cause Code*
I. Planning of bold goals without the inclusion of random floats, but with realistic assumption of estimate;	*c,d,j,m*
II. Establishing the continuity of services, ensuring the end of the activity before starting the next task;	*b,d,f,g,h,k,l*
III. Constantly identifying operational constraints and their elimination with the deployment of simple systematic risk management	*a,d,e,f,j*
IV. Clear definition of hierarchy in decision and elimination of slowness or lateness in decisions affecting the critical path.	*a,e,i,k*

For each guideline, the authors suggest some activities that could be implemented in a structured way in each project. These will be later used as the basis of a management method. See Table 4.

These actions were based on recommendations of several authors, as presented in Section 3.2 or in the analysis of good current practices effectively observed in some of projects belonging to the sampling of the field survey described in Section 5 (but not were in this article).

7. Conclusions

As evidenced, the most significant causes of delay identified were relatively different from those presented by the authors surveyed. The main problems were more concerned with internal issues, organization of construction site or the management of the construction companies hired, than with external issues.

Thus, the authors of this paper identified the importance of investing in qualifying, systems or planning and control methodologies, even if they are simplified. A number of delays are verified to derive from external factors (rain, soil, market, customer, etc.) and the apologies to justify the delays are usually based on these aspects. Yet these factors were identified as less relevant.

Similarly, the results of this research can be useful to promote studies to identify causes of delay in different kinds of projects (such as horizontal constructions or in other regions of Brazil with different characteristics) or to establish more detailed actions or methods that help reduce the problems of delays.

This fact further motivates the studies into the theme showing that it is necessary to apply efforts to understand processes, tools, resources, and their relation to the project success.

Table 4: Actions for improving operational planning

Guide	Suggested practice	Actions suggested for improving operational planning
I. Realistic schedule and bold goals	Establishing "most likely" durations to define the project baseline	- Not accepting the most favorable scenario as a reference; - Establishing details of the inicial schedule (at least in the critical paths); - Validating schedule references identifying risks in task completion; - Separating the contractual dates and the target operational dates (realistic references vs. best scenario to target planning).
I. Realistic schedule and bold goals	No float in each task / controlling with safety buffers	- Avoiding Parkinson's Law (resource demand tends to expand to the total resourse offered) and the Student Syndrome (planned procrastination); - Include controlled buffers only in the critical path.
I. Realistic schedule and bold goals	Calendars differentiated by activity type	- Forecasting of rain days not worked (services affected); - Including regional characteristics, local restrictions; - Analysing seasonality, market realities or partners' restrictions.
II. Establishing continuity of services	Avoiding high productivity periods	- Stabilizing production (cadence of tasks); - Applying line of balance; - Prioritising the work teams maintenance.
II. Establishing continuity of services	Guarantee of task completion	- Not accepting rework of tasks; - Not anticipating activities that do not add value to project; - Incorporating learning curves in production estimative.
II. Establishing continuity of services	Anticipating procurement activities	- Validating previously the task quantitatives; - Placing material orders in advance (critical path items); - Defining compatible delivery schedules; - Transparency in negociating and in managing suppliers (fidelity); - Join into service orders both "easy activities" such as "hard works".
III. Management focusing on restriction identification and its elimination	Identifying and removing tasks restrictions	- Eliminating the programming restrictions previously; - Action plan for recovering unfulfilled items or avoiding reoccurrence; - Developing database with more common items (restrictions check-list).
III. Management focusing on restriction identification and its elimination	Identifying and monitoring the planning assumptions	- Establishing main services variables towards productivity control; - Formalising plan of attack with leaders and team workers - Defining detailed schedules for critical path services; - Develoingp contingency plans / anticipating alternatives to recovery.
III. Management focusing on restriction identification and its elimination	Managing risks of task completion	- Quantifying the risks to identify the critical ones; - Highlighting the critical path activities that will be carefully controled; - Checking the best moment of intervention (triggers); - Defining schedule milestones to control.
IV. No slowness of decisions	Identifying schedule priorities	- Identifying responsibility and decision deadlines with formal methods; - Establishing a priority list based on the impact on the critical path;
IV. No slowness of decisions	Proactive and immediate actions	- Knowing who is responsible for the activities and treating the problems directly with them and as soon as possible (war room concepts). - Applying the GEMBA concept, solving problems in the "real place" (production site, where value is created).

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How Prepared are Small Businesses for Another Earthquake Disaster in New Zealand?

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Abstract

Earthquakes are low probability, high consequence events which are known to cause significant damage. Small to medium-sized enterprises (SBEs) are particularly vulnerable to impacts arising from such disasters, including: business disruption, employee health and safety, financial strain, or even total loss of business. Owners of these SBEs can make a few key decisions to prepare their businesses for an earthquake, in order to ensure business continuity and the wellbeing of their employees. This study sought to examine the level of earthquake preparedness of SBEs located in high seismic risk regions by examining the extent of mitigation measures adopted five years post the Canterbury earthquake disaster. Using a mixed-methods research approach, combining both qualitative and quantitative data, the research findings revealed that a majority of SBEs operating in regions of high vulnerability to disaster are underprepared for a potential earthquake disaster, despite the general increased awareness of earthquake risks in New Zealand. Cost, time, insurance processes, and access to disaster mitigation information, were identified to be the most important and constraining factors in the overall decision-making process. The research findings will provide strategies to local authorities on how to assist SBEs in making better informed preparedness decisions, ultimately improving their resilience to earthquakes, and thus improving the resilience of the New Zealand community as a whole. How Prepared are Small Businesses for Another Earthquake Disaster in New Zealand?

Keywords: Small business enterprises (SBEs), earthquake, preparedness initiatives, New Zealand

1. Introduction

The severity of the recent 2010/2011 Canterbury earthquakes demonstrated the vulnerability of communities which are inadequately prepared for such disasters. These earthquakes created significant economic and social strains on the Christchurch region, as a result of a large drop in economic activities within the central business district (CBD) of the city, and generally on the New Zealand economy. Consequently, this resulted in a staggering 34.6% drop in the number of businesses operating (Statistics New Zealand 2012). Buildings which have insufficient seismic capacity – termed "earthquake-prone buildings" (EPBs) – have been found to contribute to major losses during an earthquake (Egbelakin, 2013). An EPB is considered to be a building that will have its ultimate structural performance capacity exceeded in a moderate earthquake, and would likely collapse causing injury or death to persons in the building or to persons in another property or damage to adjoining structures (Department of Building and Housing 2004). The definition of an EPB contained in the Act is the legislative expression of the New Zealand Government's policy objective to reduce the level of earthquake risks posed by EPBs to the public. These buildings are particularly vulnerable to impacts from an earthquake disaster, due to being built from inadequately strong construction materials, and prior to advancements in seismic design codes, specifically since 1976 (Egbelakin 2013).

The Ministry of Business, Innovation, and Employment define an SBE as one which consists of between 0 to 20 full-time employees (Ministry of Business & Innovation and Employment (MBIE) 2014). These enterprises are a prominent part of New Zealand's economy, collectively make up 99.0% of the nation's business population, and contribute to approximately 30% of the national GDP (Ministry of Business & Innovation and Employment (MBIE) 2014). The majority of SBEs reside in the CBD (Burgess 2008). It is common to find a large proportion of the city's old building stock in the CBD, which are likely to be earthquake-prone due to their age and construction materials. SBEs are the majority leaseholders of these EPBs due to attractive rent prices and greater accessibility to customer foot traffic whilst residing in the CBD (Murphy 2007). Due to inherent risks posed by residing in an EPB, these SBEs are highly vulnerable to damage and losses from a potential earthquake disaster, as evident in the Canterbury earthquakes.

The decision-making process a business owner follows in order to prepare for an earthquake is crucial for maintaining business operations, and post-earthquake continuity, as well as for ensuring employee health and safety. The business owners who are tenanted in these buildings are likely to make a few key decisions regarding earthquake risk mitigation: adopt appropriate risk mitigation measures; accept the risk and do nothing about it; or ignore the risk completely (Egbelakin, 2013). Despite the rising intensity of low probability and high magnitude earthquake disasters, there is a consistently low rate of earthquake preparedness generally in New Zealand. Moreover, earthquake preparedness of local businesses is vital for local communities, whose economic prosperity depends on the types of mitigation decisions made by the owners of SBEs. Mostly, collective losses of these businesses generally devastate the local economy (Yoshida and Deyle 2005). Thus, this has created a need for a study to evaluate the types of decisions and earthquake mitigation initiatives implemented by SBEs, in order to alleviate the damage caused by these disasters. Hence, this study sought to examine the level of earthquake preparedness of SBEs located in high seismic risk regions by examining the extent of mitigation measures adopted five years post the Canterbury earthquake disaster. The research findings will provide strategies to local authorities on how to assist SBEs in making better informed preparedness decisions, ultimately improving their resilience to earthquakes, and thus improving the resilience of the New Zealand community as a whole.

2. SBEs Disaster Preparedness

A plethora of research exists regarding businesses and their preparation for earthquakes. Studies into earthquake preparedness have been conducted predominantly internationally, and also in New Zealand, as a result of several earthquakes since 2007. Disaster preparedness can be regarded as any activity which is implemented in order to reduce damage caused by a natural disaster such as earthquake (Alesch, Holly et al. 2001). There are several of ways an SBE can mitigate risks posed by an earthquake disaster; these are termed earthquake risk mitigation measures or initiatives. Implementing these measures is vital for the resilience of an SBE, as they reduce the seismic risks that they can be exposed to, allowing them to thrive and find opportunities in times of distress (Stevenson, Seville et al. 2011). Several mitigation measures exist which are available for SBEs to implement. These comprise reasonably technical measures such as the purchase of earthquake insurance, and also less complicated low-effort measures such as employee disaster preparation. Despite the abundance of ways which an SBE can prepare for an earthquake, consistently low earthquake preparedness is reported by SBEs in New Zealand (Brown, Seville et al. 2013). Several factors have been identified in the literature to affect SBE owners' decisions to prepare for an earthquake and these are discussed in a subsequent section. The most significant ones will be outlined below.

2.1 Business Characteristics

The ability of an SBE to implement earthquake risk mitigation measures was found to be dependent on certain factors, which are inherent in the nature of the business and its physical operating environment. The size of the business, measured by the number of full-time employees, was consistently found to affect business' earthquake preparedness (Chang and Falit-Baiamonte 2002). According to Brown et al. (2013), small businesses are particularly vulnerable to the damage resulting from an earthquake due to a lack of resources; both in terms of finance and staffing that could be devoted to potential earthquake risk mitigation measures. Large businesses, on the other hand, are more readily able to raise finance due to their ease in accessing business reserves (Chang and Falit-Baiamonte 2002). They are more able to devote greater resources towards possible mitigation measures, and therefore exhibit a greater sense of preparedness compared with SBEs. Drabek (1991) found that businesses in operation longer than six years were involved with greater disaster planning. These older firms are more prominent, have greater financial resources, and more opportunities to consider earthquake planning in their daily business operations. Owning the building in which the business operates, as opposed to leasing, was found to be significant. Dahlhamer and D'Souza (1995) found that owners of the business property were more likely to adopt disaster preparedness measures than lease-holders. Webb, Tierney et al. (2000) explained that the owners of the building have more to lose than lease-holders in the event of an earthquake, which indicated they are more likely to be place greater importance on earthquake planning.

Many older buildings with the potential of being earthquake-prone located in the CBDs of many cities and towns in New Zealand are more likely to be impacted by a potential significant earthquake (Egbelakin 2013). Many SBEs are likely to be tenanted in these EPBs. These businesses are highly vulnerable to the damage dealt from earthquakes and business operations within the community in general, as was evident from the Canterbury earthquake (Brown, Seville et al. 2013). Also, whether a business is independently owned at a sole location, or if it is part of a franchise operating in multiple locations, plays a huge part in the overall decisions they make. Franchise firms have an ability to spread their risk across multiple locations (Dahlhamer and Tierney 1998). These firms have the added benefit of being at ease with regard to financing their capital and starting up costs, as they can be funded by the franchiser. Businesses operating in the insurance, finance and real estate sectors were generally better prepared for disasters (Yoshida and Deyle 2005). This is mainly due to the fact that these businesses have high regulations, and have greater awareness of risk due to the inherent nature of their work.

2.2 Behavioural Factors

Several behavioural factors could affect how owners or managers of SBEs make disaster preparedness decisions. Past experience in a disaster could intuitively enhance readiness for a disaster in the future (Egbelakin, Wilkinson et al. 2011). The decision-making process may require an individual to identify a risk, perceive and assess the risk, and through trade-offs between risks and rewards, come to a final decision on whether or not to mitigate the risk (Egbelakin, 2013). An individual's awareness of the risks they are subjected to, and how they perceive and respond to them, is critical in influencing the final decision carried out (Slovic 2001). Given that perception of risk is regarded to be the one of the most notable barriers to adopting earthquake preparedness measures (Egbelakin & Wilkinson, 2010), this facet is important to consider when studying the decision-making patterns of SBE owners. A study carried out by Egbelakin, Wilkinson et al. (2011) aimed to understand potential behavioural factors which hindered the decision-making process of seismic retrofitting in New Zealand found that many respondents have fatalistic mind-sets and were not concerned about the risks associated with an earthquake disaster, and were unlikely to implement mitigation measures in the future. Fatalistic mind-sets may be attributed to hazard anxiety, and consequently a denial of risk (Paton 2003). Moreover, Webb *et al.* (2000) emphasised that businesses which showed drastic improvements in their preparations were ones which had already prioritised planning, and had the resources to do so. This is further supported by the findings arising from the study conducted by Powell and Harding (2009), which explained that "the careful become more careful" and those who didn't have any mitigation measures in place before the disaster were less likely to employ more measures after.

Legislation plays a key role in earthquake risk mitigation in New Zealand. The Building Act 2004 contains provisions which address EPBs. TAs are required to implement an earthquake-prone building policy, to lessen the seismic risk from EPBs, such that a perceived level of safety is developed (Egbelakin, 2013). In addition, depending on the approach taken, the TAs requires building owners to have an engineer assess their buildings, if necessary, for potential seismic risk. This is vital for business owners, especially ones who are tenanted in an earthquake-prone building. Decisions revolving around seismic strengthening are beyond their grasp, and they must rely on their landlord (the building owner) to act. Knowledge and awareness of these practices is essential in the decision-making process.

2.3 Business Operations and Emergency Planning

The ability for a business to survive a major disaster depends on the organisational structure and operations systems in place (Seville et al., 2008). In New Zealand, prevention of harm to all persons at work and other persons in the vicinity is promoted by the Building Act (2004) and Health and Safety Act (2013). The Health and Safety Management Act was enacted to ensure that employers, and their representatives, adopt practicable steps are taken to ensure the safety of their staff while at work. It is expected that a procedure for dealing with emergencies that may arise during business hours is in place and that this information is readily accessible. Also, safety and emergency policy and practices adopted by the organisation should be known to all employees.

3. Research Methods

A mixed-methods research approach was adopted in this study, combining both qualitative and quantitative data, because of the nature of the research objective, and to overcome deficiencies intrinsic to a single research approach. The basis for this choice was due to the exploratory nature of this study, which was very similar to the study which Egbelakin (2013) conducted on building owners. An online survey was conducted using a questionnaire as the data collection instruments for the quantitative study, which mainly assesses the profile of the SBEs, decision-making processes and the factors that were significant to affect an SBE to implement mitigation measures. Semi-structured face-to-face interviews were undertaken for the qualitative study, in order to gauge a more in-depth understanding of respondents' behaviour. This type of interview allows the researcher to "probe" for in-depth information. In order to ascertain a sample for data collection, a database was formed using data provided by the Napier City Council. The information contained a list of the addresses of approximately 167 SBEs located in the Napier CBD, and mainly in EPBs. Napier was selected as a case study to represent a high seismic hazard region in New Zealand. The selection criteria were predominantly based on: a high seismic hazard factor, Z, of 0.38 (Standards New Zealand, 2004); and the occurrence of a previous significant earthquake disaster in the region in 1931 (Hawke's Bay Earthquake). This earthquake resulted in the emergence of a unique Art Deco architectural style for older buildings within Napier, which has attracted great interest from the local community and the tourism industry. There is a large heritage importance placed on these buildings by the community, and it is therefore necessary to enhance decisions made by SBEs operating in such buildings. Both questionnaire and interviews were administered in one of New Zealand regions susceptible to high earthquake risks; Napier. Care was taken to exclude the interview participants from the survey. Industry experts reviewed the findings for comments and confirmation in order to establish data validity. A total of 42 questionnaires were returned out of 167 sent out. Only 38 were usable surveys due to a large amount of missing responses, generating a response rate of 23%, which is expected for a study of this nature and is similar to that found in previous studies. The extent to which an SBE was prepared for an earthquake was measured by counting the amount of mitigation measures they had implemented as at the present time, out of a possible 21 measures. Potential disaster preparedness measures an SBE could have implemented are summarised in Table 2. A variety of mitigation measures are covered and grouped under four categories, namely knowledge enrichment, insurance and business continuity, business survival, and structural and non-structural mitigation (see Table 2 for details).

4. Results

4.1 Respondents Profile and Business Characteristics

The respondents' profiles and business characteristics are summarised in Table 1. The respondent comprises mainly micro and small businesses (90%).Therefore, the research results and findings results are limited to the research participants. Half of the respondents are business owners, and the rest were personnel acting on behalf of the owner. Sixty-three percent of respondents are above 40 years of age, and 42% of the predominant ownership comprised of female business owners (42%) and combined (male and female) ownership (42%). Seventy-four percent of these SBEs were micro-sized and 58% have been in business for at least 10 years. All SBEs were reported to be operating in the CBD, with 79% operating in the retail sector. Eighty-seven percent of SBEs are located on the building's ground floor level. More than half of the SBEs were operating in a sole location of a locally-owned business, and all were in a separate location for their business (i.e. not operating from home). A majority of the SBEs surveyed in this study leased the building in which they operate. Almost all respondents (95%) had experienced an earthquake in the past. It is interesting to note that only 29% of respondents had been in an earthquake causing physical building damage. Nearly all respondents reported no damage to their personal well-being or their business from the last earthquake they had experienced (86% and 92% respectively).

Table 1: Respondents' profiles and business characteristics

Respondents' Profiles		*Frequency*	*%*	*Business Characteristics*		*Frequency*	*%*
Type of Respondent	*Business Owner*	*19*	*50*	*Size of business / Number of full-time employees*	*1 - 5 (micro)*	*28*	*74*
	Director	*1*	*3*		*6 - 19 (small)*	*6*	*16*
	Manager	*15*	*40*		*50-99 (medium)*	*4*	*10*
	Employee	*1*	*3*	*Age of business*	*< 1 year*	*3*	*8*
	Other	*2*	*5*		*1-5 years*	*9*	*24*
Age	*21 - 30 years*	*7*	*18*		*6-10 years*	*4*	*11*
	31 - 40 years	*7*	*18*		*11-20 years*	*6*	*16*
	41 - 50	*8*	*21*		*21 - 30 years*	*7*	*18*

Respondents’ Profiles		Frequency	%	Business Characteristics		Frequency	%
	years						
	51 - 60 years	10	26		31 - 40 years	3	8
	61 - 70 years	6	16		41 - 50 years	1	3
Gender	Female	30	79		> 50 years	5	13
	Male	8	21	Industry of business	Retail, trade, and hospitality	30	79
Number of years in business	< 5 years	16	42		Finance, insurance, and real estate	2	5
	5-10 years	13	34		Business and personal services	1	3
	11-15 years	3	8		Health services	1	3
	16 - 20 years	1	3		Legal services	1	3
	21 - 25 years	1	3		Art and membership organisations	3	8
	> 25 years	4	11	Location pattern	Separate business location	38	100
Years of industry experience	≤ 5 years	7	18		Home-based business	0	0
	5-10 years	13	34	Operational pattern	Sole location of locally owned business	22	58
	11- 15 years	3	8		One of several locations of locally owned business	5	13
	16 – 20 years	4	11		One of several locations New Zealand wide	8	21
	21 – 25 years	4	11		Part of a Franchise	3	8
	> 25 years	7	18	Predominant ownership by gender	Male	6	16
					Female	16	42
					Combined - Male and Female	16	42
				Age of predominant owner(s)	21 - 30	4	11
					31 - 40	5	13

4.2 Earthquake Mitigation Initiatives of SBEs located in High-Risk Regions

The extent to which an SBE was prepared for an earthquake was measured by counting the amount of mitigation measures they had implemented at the present time, out of a possible 21 measures. Table 2 provides a summary of disaster preparedness measures an SBE have implemented. A variety of mitigation measures are covered and include: knowledge enrichment, insurance and business continuity, business survival, and structural and non-structural mitigation. The respondent's sense of earthquake prepared was categorised based on the number of mitigation measures they had implemented, being: 0-5 (underprepared); 6-10 (somewhat prepared); 11-16 (prepared); and 17-21 (highly prepared). The research findings showed that SBEs were found to have mainly implemented low-effort, less technical mitigation measures, such as insurance, first aid kits, employee preparation, and data backup. These measures are generally easy to acquire and take less time compared to more complex measures such as the seismic retrofitting of buildings and implementation of business disaster continuity plans. Regarding insurance and business continuity plans, a majority of the SBEs had purchased business contents insurance (61%), and 55% had purchased business interruption insurance. In contrast, only three SBEs had developed a business continuity plan, while only one had a business relocation plan. Concerning the knowledge enrichment disaster preparedness activities, a majority of the respondents have discussed with their employees about what to do in the event of an earthquake (42%), while 32% have provided written information on earthquake preparedness to their employees, and 13% of the participants regularly conduct earthquake drills with their organisation. Sixty-three percent did not know whether their building was earthquake-prone or not, and about 50% of the respondents were not aware of the seismic assesSBEnt practice. Overall, the respondent's sense of earthquake prepared was categorised based on the number of mitigation measures they had implemented. The research findings showed that 66% of the SBEs are very underprepared for survival in the occurrence of another major earthquake in the region (see Figure 1).

Table 2: Earthquake risk mitigation measures initiatives adopted by SBEs

Earthquake risk mitigation measures initiated adopted by SBEs	*Frequency*	*%*
1. Knowledge Enrichment Disaster Preparedness Activities		
Talked with employees about what to do in the event of an earthquake	*16*	*42*
Have written information on earthquake preparedness	*12*	*32*
Attended a first aid course	*9*	*24*
Earthquake drills or exercises for your employees	*5*	*13*
Earthquake preparedness or training programs for your employees	*1*	*3*
2. Insurance and Business Continuity Plans		
Purchased business contents insurance	*23*	*61*
Purchased business interruption insurance	*21*	*55*
Purchased earthquake insurance to cover damage to building	*10*	*26*
Developed a business disaster recovery plan	*3*	*8*
Developed a business emergency plan for event of earthquake	*3*	*8*
3. Business Disaster Survival Actions		
Obtained first aid kit, extra medical supplies	*18*	*47*
Stored water and canned food	*6*	*16*
Stored extra fuel or batteries	*5*	*13*
Business relocation plan	*1*	*3*
Obtained an emergency generator for power failure	*0*	*0*

Earthquake risk mitigation measures initiated adopted by SBEs	*Frequency*	*%*
4. Structural and Non-Structural Measures Implemented		
Ensured computer and electronic data backup	*20*	*53*
Engineer conducted a seismic assesSBEnt	*12*	*32*
Secured shelves, cabinets or objects	*11*	*29*
Ensured heavy objects are stored on the floor	*10*	*26*
Secured business records and supplies	*6*	*16*
Retrofitted the building to higher seismic performance	*4*	*11*

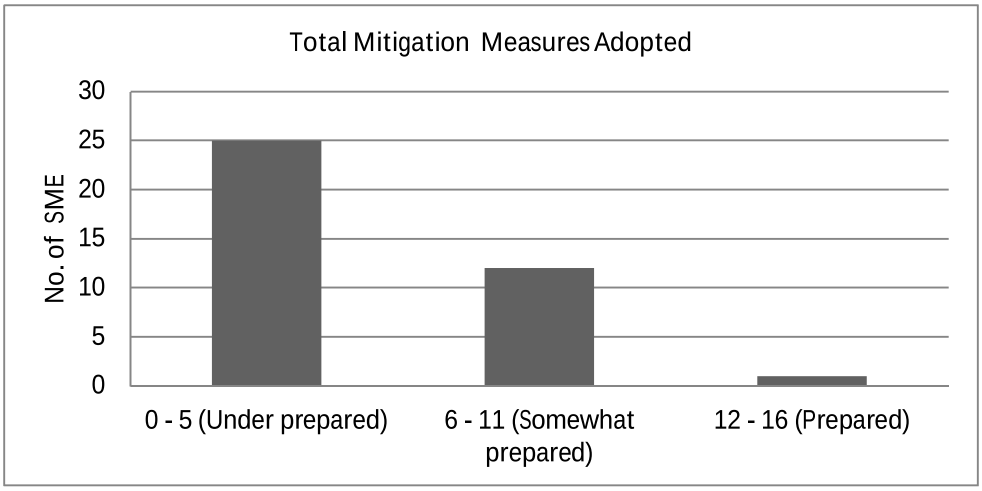

Figure 1: Summary of mitigation measures adopted by SBEs

5. Discussion of Findings

The capability of a business to implement earthquake risk mitigation measures was found to be dependent on certain factors, which are inherent in the nature and characteristics of the business, and its physical operating environment. SBEs in Napier were found to be underprepared for a potential earthquake disaster. Only five earthquake risk mitigation initiatives or measures were implemented, on average, out of a possible 21 options. This finding is similar to previous research conducted in the USA by Han and Nigg (2011). The low rate of preparedness is surprising given the region's high vulnerability to earthquake occurrence. Intuitively, a greater concern towards earthquakes would be expected due to Napier's location in a high seismic hazard zone, and its historical and cultural underpinning due to a past earthquake in 1931. Interestingly, 74% of respondents believed it was important to give consideration to earthquakes in relation to their business operations, yet a vast amount of the participating SBEs were inadequately prepared for a potential earthquake disaster. One of the respondents wrote that "Napier is making its tourist trade a little bit on the fact that it's been through an earthquake, and so I think the knowledge of earthquakes in Napier is pretty good". Due to the region's increased awareness of earthquakes, individuals may have become complacent when giving thought to earthquake preparation. Some business owners were reported to express a sense of optimistic bias and complacency in their approach to disaster preparedness initiatives.

In addition, the majority of respondents who took part in the questionnaire were greater than 40 years of age. The research findings revealed that concern for earthquakes decreased greatly as the age of an individual increased. This may be explained by a complacent or fatalistic attitude which manifests with greater age. When asked if there were specific factors which influenced their preparation for an earthquake, one interviewee mentioned that: "It's quite nice to think that you're a bit secure because you do have the earthquake proofing done up to a standard, but I'm a bit fatalistic to be honest". Many of the respondents demonstrated similar behaviour during the face-face data collection, strongly expressing that earthquakes were an inevitable event, and no amount of preparation would be useful. Due to the large number of older respondents, there may be a prevalence of a fatalistic attitude, resulting in a lesser perception of risks and mitigation measures. This is similar to the findings of Egbelakin, Wilkinson et al. (2011), and this therefore negatively impacts overall earthquake preparedness. This finding is intriguing as one would expect individuals residing in high seismic hazard regions to exhibit more concern about earthquakes.

The size of an SBE measured in terms of the number of full-time employees could be attributed to the number of mitigation initiatives or measures adopted. A majority of SBEs had less than five full-time employees, and hence could be less prepared for an earthquake due to lack of resources to devote to disaster preparedness, and therefore lack the ability to have access to staff, and experts, specialising in disaster mitigation. This may provide a possible explanation as to why such a low sense of earthquake preparedness was observed. In addition, SBEs normally have greater financial constraints than their larger counterparts. A firm's financial capabilities have been proven to be a potential impediment in the preparedness process from past literature. As expected, cost and time were identified in the survey to be the important and constraining factors in an SBE's earthquake preparedness decision. Furthermore, respondents were found to have a low awareness and knowledge of building seismic assesSBEnt procedures. This is interesting given Napier's history with a previous devastating earthquake; one would expect that the respondents would be more proactive in their understanding and knowledge of seismic risks regarding the building in which they operate their businesses. The low level of awareness and knowledge of the building seismic risks may explain the low preparedness in Napier. For those respondents who were aware of seismic assesSBEnt procedures, it was reported that there were issues in consistency. One interviewee stated that: *"What I've noticed is there doesn't appear to be a consistent application of the rules, or understanding of the policies and I think there's been a frustration in that, businesses have found that engineers say one thing, and then another engineer comes around and says 'what were they talking about?'"* These disparities create confusion for SBEs, and complicate the decision to adopt risk mitigation measures (Egbelakin, Wilkinson et al. 2011). A low perception of risk was observed by SBEs in Napier. As discussed above, given the region's history with a prior earthquake, one would expect a greater perception of risk. The low perception may be due to the fact that 71.1% of respondents had not been in an earthquake causing physical building damage. Past experience with an earthquake may affect an individual's perception of hazard exposure.

6. Conclusion

The objective of the study reported in this article is to examine whether SBEs located in regions of high vulnerability to seismic hazard are well prepared by adopting a range of earthquake preparedness initiatives. The research findings revealed that SBEs having less than 20 employees located in Napier were generally underprepared in the event of a potential earthquake disaster, and an average number of five mitigation initiatives or measures were observed out of a total of 21 initiatives. There is a general lack of knowledge and awareness of seismic assessments and risks posed by the building from which they operate, which could be due to the fatalistic attitudes, or a sense of complacency exhibited among the respondents. Cost, time, insurance processes, and access to mitigation information, were the most important and constraining factors for SBEs in preparing for an earthquake. SBEs need to be better informed about seismic assessment procedures. In particular, communication between TAs, building owners, and business owners must be enhanced. In addition, the local authority approach requires some form of increased consistency in building seismic risk assessment results, to allow a greater understanding of the potential risks for SBEs. SBEs need to have greater access and exposure to reliable and effective mitigation measures which have been proven to work. These must be provided by credible individuals or organisations, in order to motivate SBEs to become more active in earthquake planning procedures.

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Achieving Incremental Cost Reduction via Kaizen Costing in the Nigerian Construction Industry

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Abstract

Nigerian small and medium scale construction firms are facing challenges of cost and time overruns which have led to project abandonment and liquidation of some of these firms. This is also as a result of large scale dissatisfaction of clients. This study focuses on how to improve the post-contract cost management in Nigerian construction firms by using Kaizen costing. Kaizen presents a better solution to cost and time overruns, and client satisfactions. This method of managing post-contract cost had been proven to create more profit, quality, value and improved relations with the stakeholders involved in construction activities. Incremental cost reduction is the key element of Kaizen. The most critical activities which can influence kaizen costing implementation in the Nigerian construction industry are addressed in the paper.

This investigation identified eight crucial activities for continuous cost reduction from literature. Based on the existing literature, a Likert scale questionnaire was produced. Data was gathered from one hundred and thirty-five (135) cost and project managers in Lagos, Nigeria. The Kendall's coefficient of concordance was used to test the identified activities based on the agreement of the respondents. Important activities were ranked by respondents. The findings identified "overhead cost related to paying suppliers, sub-contractors and labourers can be reduced continually throughout the construction phase to keep the project cost within budget" as the most critical activity for continuous cost reduction during Kaizen costing. Assessing the essential procedures carried out during construction creates an avenue to implement Kaizen philosophy and Kaizen costing in a developing economy such as Nigeria. Therefore, the benefits of Kaizen are easily transferred for alleviating the challenges of cost and time overrun, effective post-contract cost controlling, profitability of small and medium scale construction firms and client satisfaction.

Keywords: Activities, cost reduction, incremental, Kaizen costing, Nigeria

1. Introduction

Construction cost management in many countries have been using the same conventional cost management systems since the 1920s from inception (Kern & Formoso, 2006; Owens, Burke, Krynovich, & Mance, 2007; Rad, 2002). Johnson and Kaplan, (1993) as cited by Kern and Formoso (2006) stated that the same cost management system which has been used in the 1920s is still in use in many construction firms. Ostrenga et al., (1998) as cited by Kern and Formoso (2006) noted that traditional cost management cannot provide the precise product cost and the system cost estimation does not include managerial decision making approach which eventually brings a positive impact on the project. Traditional cost management system is the conventional cost management system used since the 1920s. This term is used because of modern systems such as value management system and earned value management system which are operation in many construction firms around the world. However, systems such as the value management system, earned value management system, expert systems, benchmarking and building information modelling have emerged over the last sixty years to redefine the art and science of construction cost management. The enormity of negative factors influencing cost estimates at the pre-tender phase as stated by Ashworth (2010); Oyedele (2015) and Samphaongoen (2010), cost estimates always have latent errors which arises during the construction phase. Therefore, the need to focus more on post-contract cost control by project managers and cost managers during a contruction project is imperative.

Cost estimation in construction has set rules by the Royal Institute of Chartered Surveyors and other Quantity Surveyor bodies in the various countries when construction cost estimates are prepared. Nonetheless, the same problems of cost and time overruns, variations during construction, construction disputes have always plagued construction activities. Ashworth (2010) noted the factors which influence the accuracy of cost estimates as being difference in design information, market conditions, experience of the project manager, project complexity and historical data. In a developing economy such as Nigeria, the challenges facing cost estimation is peculiar.

2. Literature review

This section addresses the challenges facing the conventional cost estimating system in Nigeria, the importance of kaizen costing as an effective panacea to the prevailing cost management challenges and the justifications for this investigation.

2.1 Factors affecting traditional cost estimation in the Nigerian construction industry

The unique challenges facing most cost and project managers during estimate preparation are related to a number of factors. Oyedele (2015) highlighted the various influencing factors as:

a) Political situation: Most cost estimates are accurate during stable political times
b) Government policy: Influence of local content investment policies, importation policies, taxes, method of procurement, number of foreign contractors or expatriates are some of the policies which may affect accuracy of cost estimates at a point in time.
c) Economic condition such as inflation, monetary rate, interest rate on lending.

d) The construction season such as rainy season and dry season may affect on-going construction work
e) Geographical location of the project may also affect accuracy of estimates. In places such as the Niger Delta and Northern parts of Nigeria, the accuracy of estimates may be influenced by the topography, swamp or soil conditions
f) Risk emanating from security may also have a drastic effect on the accuracy of construction cost estimates, especially in the Northern parts of Nigeria where there is high level of Islamic insurgency.
g) Years which are close to the general elections in Nigeria have a lot of influence on the cost estimates because prices of building materials are lower and there are a lot of procurement activities and award of contracts.
h) Corruption is a factor which affects cost estimates in Nigeria. Most cases of kickback during procurement have led to inflated cost estimates.

These factors can mar a construction project during the execution phase if they are not addressed. Although, other construction cost management systems, methods and techniques such as earned value analysis, value management, building information modelling may have been applied to curb the excessive cost and time overruns.

2.2 What is Kaizen costing?

Kaizen costing is a continuous improvement technique which emanates from Kaizen, a product of the lean philosophy (Suárez-Barraza & Lingham, 2008; Suárez-Barraza & Miguel-Dávila, 2014; Suárez-Barraza, Ramis-Pujol, & Dahlgaard-Park, 2013). Kaizen costing mean continuous improvement of the cost of production, it was first introduced in the 1960s in Toyota (Arya & Jain, 2014; Brunet & New, 2003; Prošić, 2011; Puvanasvaran, Kerk, & Ismail, 2010). *Therefore, Kaizen costing is the cost management aspect of Kaizen which is usually utilized during the production phase.* The benefits of Kaizen has been transferred to other sectors such as manufacturing , business management, development of small and medium scale industries and construction (Arya & Jain, 2014; Berger, 1997; Puvanasvaran et al., 2010). Several case studies by (Puvanasvaran et al., 2010; Suárez-Barraza & Lingham, 2008; Suárez-Barraza, Ramis-Pujol, & Kerbache, 2011) concluded that Kaizen is very useful for improving manufacturers' profit in this instance contractors, enhancing the quality of products, providing more client satisfaction and encouraging better employee-employer relationship. This aspect of Kaizen is the continuous improvement in the work place. However, the costing aspect involved the process which stems from a Plan-Do-Check-Action (PCDA) process. This process is based on an incremental approach of maintaining and reducing production cost.

This process stands on standardized production. Imai (1997) noted that the three M's in Kaizen are muda (waste), Mura (irregularity) and muri (strain). These three words are the major check points of the Kaizen process. Wastes are identified during the course of construction and eliminated. This lean related concept ensures adequate stakeholders involvement in the overhead cost reduction process. A Kaizen costing team comprising the project manager, architect, cost manager and other relevant stakeholders take on the responsibility of identifying waste and elimination processes. Follow up activities are also carried out during this process for incremental cost reduction.

2.3 Activities for incremental cost reduction during construction

Post-contract cost control activities are based on techniques such as interim valuations, preparation of monthly statement of accounts, cash flow, variation management and monitoring of all activities related to the construction work. There is no technique for continuous cost maintenance and reduction. The traditional cost management technique available in most construction companies do not consider cost maintenance and reduction during construction. Kaizen costing during construction involves specific activities related to transportation, handling of materials on site, overhead cost monitoring and reduction, variations, equipment and plant cost, purchase orders, suppliers' and sub-contractors' cost, planning and preliminary items of work (IFS, 2010; Lin et al., 2001; Ashworth, 2010 $ Sanni and Hashim, 2013). These activities are very delicate and may lead to cost and time overrun if they are not monitored. In kaizen cosing, these activities are monitored for waste, irregularities and strain. The continuous cost redecution process are based on these activities. They are summarized in table 1 below.

Table 1: Cost reduction actitivities required for incremental cost reduction

S/N	COST REDUCTION ACTIVITY	REFERENCES
1	Continual reduction of plant and equipment depreciation overhead cost throughout the construction phase will keep the project cost within budget	Shang and Pheng, 2013; Granja et al., 2005; Suárez-Barrazaa and Lingham, 2008
2	Continual cost reduction of overhead cost of activities related to mobilization and equipment setup will keep the project cost within budget	Granja et al., 2005; Prošić, 2011
3	Continual reduction of activities related to drawing reviews and other variations or alterations will eliminate unnecessary cost thereby keeping the project cost within budget	Suárez-Barrazaa and Lingham, 2008; Granja et al., 2005; Martin, 1993; Kaur and Kaur, 2013
4	Ensuring activities related to construction variations are continually minimized will create more profit for the contractor	Ashworth, 2010; Dada and Jagboro 2007
5	Cost of activities related to purchase orders and material deliveries can be reduced continually throughout the construction phase to control the project cost for optimum profit	Lin et al., 2001; Mansuy, 2002
6	Overhead cost related to paying suppliers, sub-contractors and labourers can be reduced continually throughout the construction phase to keep the project cost within budget	Lin et al., 2001; Mansuy, 2002;
7	Continual reduction of overhead costs related to construction cost planning, general planning, resource planning and project reports will create more profit for the contractor	Sanni and Durodola, 2012, Sanni and Hashim, 2013; Lin et al., 2001; Granja et al, 2005
8	Continual reduction of overhead costs associated with preliminary items of work such as site office, storage, security, electricity, water supply, first aid and so on will	Sanni and Hashim, 2013; Sanni and Durodola, 2012; Lin et

	eventually help the creation of more profit and improve project delivery	*al., 2001; Granja et al, 2005*

The cost activities identified above were gathered from various articles related to important activities which are carried out during construction. They are also a product of the questionnaire designed for the data collection.

2.4 Research objective

The objective of this study is to assess the most critically important construction activities required for incremental cost reduction in the Nigerian construction industry. Having identified the objective of this paper, the following section discusses the research methodology adopted for this study.

3. Research Methodology

Data was obtained from one hundred and thirty-five cost and project managers in Lagos, Nigeria. The questionnaire was designed in a Likert scale format. The range was from 1 to 5, spanning from strongly agree to strongly disagree respectively. The questionnaire is based table 1. This survey questionnaire was aimed at assessing the attitude and beliefs of the respondents towards the costs that might be required to reduce during the construction stage. Therefore, the questionnaire is logically designed to fit the continual cost reduction objective through Kaizen costing.

Two hundred and fifty (250) questionnaires were distributed but only one hundred and thirty-five (135) could be retrieved. The respondents had work experience range of two (2) to forty years (40), this is illustrated in figure 1 below. Seventy-seven (77) cost managers and fifty-eight (58) project managers responded to the questionnaire. Some of these respondents are from the same construction company. However, a total of eighty-seven (87) companies responded to the questionnaire.

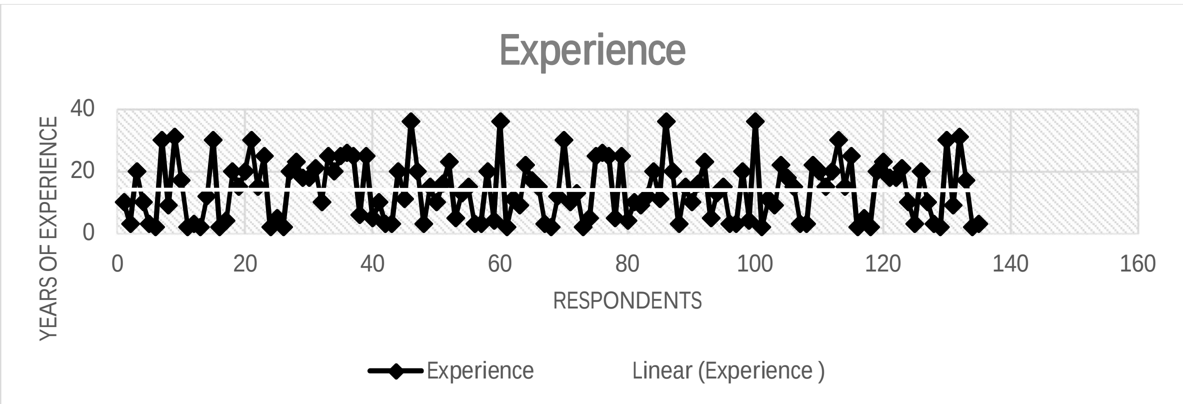

Figure 1: Years of experience of the respondents

In the graph above the linear years of experience for the respondents is fifteen (15). Very few respondents have experience above thirty years.

3.1 Investigating the presence of Kaizen costing

The presence of Kaizen costing in Nigeria was investigated. The questionnaire distributed was aimed at identifying the type of post-contract cost control method in use in Nigeria. It included the conventional cost management system in construction, earned value analysis, value engineering, activity based costing and Kaizen costing. The findings in figure 2 below show that ninety-eight (98) percent of the respondents are still using the traditional post-contract cost control method, while 1.2 percent are using earned value analysis.

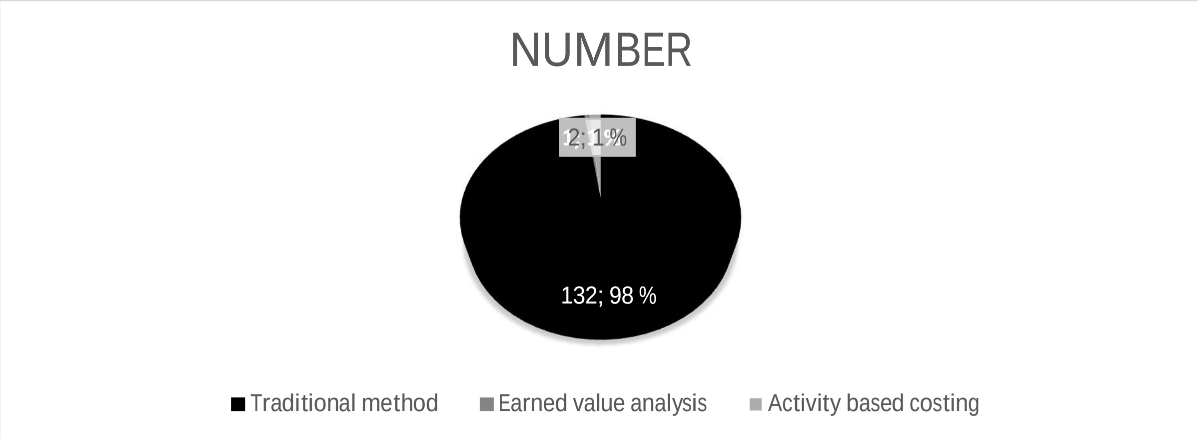

Figure 2: Pie chart showing the type of post contract cost control methods used

1.1 percent of the sample population made use of activity based costing. Kaizen costing is still very new to the construction industry in Nigeria.

3.2 Assessing the most critical post-contract cost control activities

This section addressed the key critical post-contract cost control activities which enables the researcher to evaluate the critical activities which will be required for continual cost reduction on site. This will be meant for small and medium scale construction firms in Lagos, Nigeria. The critical success factors are itemised below.

Table 2: Abbreviations for the activities

Abbreviation	***Meaning***
MESETUP	*Continual cost reduction of overhead cost of activities related to mobilization and equipment setup will keep the project cost within budget*
DRR	*Continual reduction of activities related to drawing reviews will eliminate unnecessary cost thereby keeping the project cost within budget*
PI	*Continual reduction of overhead costs associated with preliminary items of work such as site office, storage, security, electricity, water supply, first aid and so on will eventually help the creation of more profit and improve project delivery*

CGPG	*Continual reduction of overhead costs related to construction cost planning, general planning, resource planning and project reports will create more profit for the contractor*
CVMINI	*Ensuring activities related to construction variations are continually minimized will create more profit for the contractor*
PEOVER	*Continual reduction of plant and equipment depreciation overhead cost throughout the construction phase will keep the project cost within budget*
POM	*Cost of activities related to purchase orders and material deliveries can be reduced continually throughout the construction phase to control the project cost for optimum profit*
PSL	*Overhead cost related to paying suppliers, sub-contractors and labourers can be reduced continually throughout the construction phase to keep the project cost within budget*

The critical post-contract cost control activities were carefully selected from literature review, which highlights the key areas required for continuous cost reduction during construction. It covered monitoring material, plant, labour and overheads, elimination of unnecessary activities, planning and stakeholders.

Table 4: Kendall's W score for the most critical post-contract cost control activities

	PSL	*POM*	*PEOVER*	*CVMINI*	*CPGP*	*PI*	*DRR*	*MESETUP*
Kendall's W score	*5.02*	*4.70*	*4.64*	*4.52*	*4.50*	*4.39*	*4.30*	*3.99*

From table 4 above, PSL representing o*verhead cost related to paying suppliers, sub-contractors and labourers can be reduced continually throughout the construction phase to keep the project cost within budget.* This is ranked highest with a Kendall's W score of 5.02. POM which is *cost of activities related to purchase orders and material deliveries can be reduced continually throughout the construction phase to control the project cost for optimum profit* has a Kendall's W score of 4.70. The least critical activity is MESETUP which stands for *continual cost reduction of overhead cost of activities related to mobilization and equipment setup will keep the project cost within budget,* with a score of 3.93. The Kendall's W score for each of the critical activities for continual cost reduction highlighted the most important activities which cost and project managers have to focus on during construction. The activities were prioritized in order for cost and project managers in small and medium scale construction organizations to address the most important activities which would enable them reduce cost.

Table 5: Kendall’s W test for the most critical activities

Kendall's W^a	*.020*
Chi-Square	*19.077*
df	*7*
Asymp. Sig.	*.008*

In table 5, Kendall’s coefficient of concordance for this analysis is 0.02. This figure is very low and shows that there is almost no agreement between the respondents. Asymp. Sig. is $0.008<0.05$ hence, the respondents have a significant association with the critical success factors.

4. Discussion of results

Based on the findings in figure 2, it can be inferred that kaizen costing is a new concept to the construction industry in Nigeria. This may be the case for other construction industries around the world. Although Kaizen costing is used in the manufacturing industry in Nigeria (Olabisi, Sokenfun, & Oginni, 2012), the construction industry needs to adopt this method as major approach for cost maintenance and reduction. Granja, Picchi, and Robert (2005) noted that cost control is not enough during construction, cost has to be maintained on a daily basis and adequately evaluate for waste factors. An allowable cost in construction is the target price minus the target profit (Granja et al., 2005). Therefore, the cost manager has to ensure the allowable cost is maintained. In reality, the forces of demand and supply and other activities on site influence the cost of construction. This is why the major activities which may denigrate the contractor’s plans for the construction project have to be evaluated.

Activities on the construction sites were evaluated based on their level of criticality. Overhead cost related to paying suppliers, sub-contractors and labourers can be reduced continually throughout the construction phase to keep the project cost within budget has to be taken into consideration more than any other activity. Olawale and Sun (2013) revealed that the performance of nominated sub-contractor and suppliers affects the final cost of construction projects. The incremental reduction of overheads costs resulting from the activity of suppliers, sub-contractors and labourers will definitely create more profit and value for the contractor and project. In most cases, it is very difficult to monitor the activities of the suppliers because of certain forces in the Nigerian construction industry. Such forces include, collusion with a project team member to inflate the prices of the construction materials, kick back and other vices on the construction site. Inflation, foreign exchange rate and market forces also affect the supplier’s and sub-contractors’ cost.

Incremental reduction of activities related to purchase orders and material deliveries ranked second in the test. The Kaizen team can focus on this aspect to ensure that the wastage arising transportation of material to site and purchase orders are kept within an allowable cost limit. The cost limits allowed may have a profit and overhead of twenty-five percent plus (25 %+). Most cost managers who are mainly Quantity Surveyors in Nigeria also include this profit and overhead. In some construction companies it is a management function. However, focusing on actions relating to purchase orders and material deliveries will definitely assist the contractor in getting more value for money and client satisfaction.

For most complex projects, equipment and plants are required. "*Continual reduction of plant and equipment depreciation overhead cost throughout the construction phase will keep the project cost within budget*" was ranked third on the scale. The plants and equipment hiring cost, depreciation and maintenance cost is highly important. This aspect is very difficult to maintain and incrementally reduce cost. This aspect is very critical to the success of the project. The final account for the project depends on these factors. Therefore, the cost manager needs to address precise steps which pertain to plant and equipment hiring.

5. Conclusion and further research

The presence of kaizen philosophy is necessary for kaizen costing to be in place during construction. Although this study did not address the presence of kaizen in the management level, the findings revealed that Kaizen is non-existent in the Nigerian construction industry. Cost control during construction has to go beyond monitoring. Maintenance procedures is viewed as monitoring. However, identifying waste and gaps in cost during construction will invariably reduce the cost of construction. The critical activities identified in this paper has to do with external influences such as suppliers, sub-contractors, purchase orders, material handling, equipment and plant hire. These factors are very difficult to control and are critical to a project's success. Achieving a successful incremental reduction of cost during construction depends on these factors.

The involvement of other stakeholders such as the suppliers, sub-contractors and labourer may also facilitate continual cost maintenance and reduction. A research framework may be designed to provide guidelines for a successful Kaizen costing procedure in the Nigerian construction industry.

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Developing Risk-Based Cost Contingency Estimation Model Based on the Influence of Cost Overrun Causes

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Abstract

Cost overrun on infrastructure projects is widespread and represents significant financial risks to stakeholders. The large number of possible causes makes the planning and management of projects challenging. A survey of 160 project managers of infrastructure projects in Saudi Arabia was conducted to elicit the cost overrun causes. After cluster analysis, the causes were reduced to four dimensions: scope changes, market and regulatory, inadequate planning and control, and unforeseen circumstances. These four dimensions were then used to develop a risk-based cost contingency estimation model (RBCCEM) to improve the accuracy of cost forecasting and then validated using a bootstrapping approach. The accuracy of cost estimation measures was used to compare RBCCEM with fixed cost contingency (10%), reference class forecasting (RCF P50 & P90), and hybrid (it is a combination of RBCCEM & RCF P50). The comparison suggested that the RBCCEM could be more accurate as the error decreased by 10%. Therefore, by considering the actual impact of cost risk of similar projects, the results show that cost contingency was improved and the model delivered a better result compared to RCF.

Keywords: Cost overrun, cost overrun causes, infrastructure projects, classification and cost contingency estimation

1. Introduction

A significant proportion of large infrastructure projects have experienced substantial cost overrun which has led to financial or fiscal distress to project stakeholders and resulted in the deferral or cancellation of other projects (Flyvbjerg, 2014). Cost overruns in infrastructure projects are common around the world, as identified by Flyvbjerg et al (2003). Controlling project cost within budget is important for most if not all projects. The focus on cost performance is even stronger for infrastructure projects because of their high costs. Therefore, it is critical that causes of cost overrun are identified and effectively managed to minimize cost overrun.

Studies have identified a wide range of factors that lead to cost overruns, with two main schools of thought on the causes of cost overrun: technical and strategic causes. Technical causes include mistakes in design, overall price fluctuations, inaccurate estimations, government regulations, project size, quality of the contractor management team, plan changes, priority on construction deadlines, completeness and the project information timelines, the lack of experience of the estimators, certain bidding conditions, project characteristics, and lack of past data on similar types of projects (Koehn et l., 1978; Shash and Al-Khaldi, 1992; Lowe and Skitmore, 1994; Al-Harbi et al., 1994; Flyvbjerg et al., 2002; Memon, et al., 2011). The strategic causes considered optimism bias, which encapsulates the systematic propensity of decision makers to be over-optimistic about the outcomes of planned actions, as the main culprit of cost overruns for infrastructure projects (Flyvbjerg et al., 2002). However, the rhetoric seems to have shifted towards strategic misrepresentation as the main cause of cost overrun, which refers the use of deceptive means in order to win the project or obtain project funding (Liu and Zhu, 2007).

One of the techniques of reducing the impact of project cost overruns is the use of project cost contingencies—usually as a fixed proportion of the project total estimated cost and most recently estimated produced using sophisticated approaches such as reference class forecasting (RCF) or risk-based estimating (RBE) (Liu et al., 2010), but each method has its limitations. By taking into consideration the actual impact of cost risk of similar projects this paper develops and validates a cost contingency estimation model. A cross-sectional survey was conducted in Saudi Arabia to identify the causes of cost overrun of infrastructure projects in Saudi Arabia and the causes identified form the basis of the new cost contingency estimation model.

The structure of the paper is as follows: literature on causes of cost overrun was reviewed and the research design was explained. Cluster analysis is used to classify the causes of cost overrun into clusters. Subsequently, a cost contingency estimation model was developed by regressing project cost overruns on the clusters of causes. The model was then validated using the split sample. Further validation was conducted by comparing the accuracy of RBCCEM with those produced by the fixed cost contingency (10%), RCF (P50 & P90) and hybrid method, respectively. Finally, implications were discussed, future research directions were outlined and conclusions were drawn.

2. Literature review

This section examines the concept of the classification of cost overrun causes. Then, cost contingency estimation in infrastructure projects was also reviewed, followed by a discussion on using a classification approach in a cost contingency estimation model to improve cost contingency estimation accuracy.

2.1. Classification of causes of cost overrun

Cost overrun occurs in infrastructure projects (Memon, et al., 2011), and the causes are various. Classifying or grouping the large number of causes of overrun that may share similar patterns of impact can help manage causes during planning and construction.

Based on a survey of project managers on high-rise construction projects in two Indonesian cities, (Kaming et al., 1997) grouped seven causes of cost overruns into three groups using factor analysis: inflationary increases in material cost, inaccurate material estimating and project complexity. In Vietnam, Le-Hoai et al. (2008) categorized 21 causes of cost and time overrun for the construction industry using factor analysis and identified seven groups of causes: slowness and lack of constraint, incompetence, design, market and estimates, financial capability, government and worker factors. In Malaysia, Abdul Rahman et al. (2013) modelled 35 causes of cost overrun in large construction projects with a partial least squares-structural equation modelling approach and categorized the cost overrun conceptually in seven groups: contractor's site management related factors, design and documentation related factors, financial management, information and communication, human resource, non-human resources, project management and contract administration. These classification attempts have shown that homogenous groups of causes of cost overrun exist which aggregate the effect of causes within the same dimension.

Flyvbjerg has published various widely cited papers on causes of cost overrun for infrastructure projects. Flyvbjerg (2006) proposed a conceptual categorisation of cost overrun based on four main types of explanations that are claimed to account for cost overrun: technical, economical, psychological and political. Flyvbjerg et al. (2003) and Flyvbjerg (2008) acknowledged the technical explanations for cost overrun such as project size and location, but they concluded that the political-economic explanation of strategic misrepresentation and the psychological explanation of optimism bias are the main causes of cost overrun.

In brief, many causes significantly overlap, with relationships between multiple causes contributing to the final cause of cost overruns. There is a need to understand how the diversity of causes share similar patterns and how these causes impact on cost overrun, how causes can be mitigated, and the techniques or tools to ameliorate or eliminate cost overrun.

2.2. Estimation of infrastructure project cost

Accurate cost estimation tools can help reduce or eliminate the uncertainties of cost overrun. Accurate cost forecasting of large project costs is based on the availability and the level of professional knowledge and the historical cost data quality (Liu and Zhu, 2007). Available information, however, might be limited in the early stage of a large project. This may mean the quantity surveyor must make assumptions about the design; a detail of a project that may not eventuate as the life cycle of the project evolves (Liu et al., 2010).

The most critical feature of effective cost estimation is its potential for accuracy. Classic cost estimates consist of a base estimate, accounting for all physical quantities of materials and labour, and an additional risk contingency quantifying the underlying levels of uncertainty associated with the base estimate (Liu et al., 2010). Accuracy in forecasting costs and risks is valuable for decision makers to make rational decisions. Research has shown that cost forecasting errors are not unique to any specific industry or to project type with estimate inaccuracy in transport (Flyvbjerg et al., 2002), roads (Odeck, 2004), general construction (Liu and Zhu, 2007) and industrial projects (Merrow and Yarossi, 1990). Many studies have found, however, that there has not been noticeable improvement in estimation accuracy despite continued research (Flyvbjerg et al., 2002; Liu and Zhu, 2007).

The dominant methods of cost contingency estimation used in infrastructure projects can be classified into three categories: conventional contingency approach, risk-based estimation (RBE) and reference class forecasting (RCF) (Liu et al., 2010). The conventional contingency approach is to add a percentage, such as 10%, to the most likely estimate of the known works (Burger, 2003) based on the estimator's experience, which may be prone to optimism biases and could lead to cost overrun (Yeo, 1990; Newton, 1992; Mok et al., 1997). The cost contingency technique is acceptable under stable conditions and simple projects, however, it is inappropriate for large and complex projects (Newton, 1992). As a result, it is a less evidence-based approach and a reason for many projects having cost overrun (Hartman, 2000).

The other two methods, RCF and RBE, have been shown to increase the accuracy of cost contingency estimation (Liu et al., 2010). The RBE model is the cost of individual components with base estimates and stochastic or random risk contingencies. Summing the stochastic cost components determines the distribution or probability of the overall project cost (Shaheen et al, 2007). The RBE method identifies inherent risks that directly relate to the internal behaviour of a project; as well as contingent risks derived from external events that may or may not occur (Aspinall and Trueman, 2006). It requires large amounts of expert time and expense (Liu et al., 2010) especially for large and complex projects.

RCF developed by Flyvbjerg, which only takes into account a project's class (the outcome of cost overrun), even when other project factors might impact upon estimate accuracy. RCF utilises a database of previous project performance, from which a subsample of similar projects is selected, and adds a contingency to the total project cost (Liu et al., 2010). As RCF's aim is to mitigate either optimism bias or strategic misrepresentation, it does not specifically address other causes of cost overrun such as technical causes and does not forecast events which may influence the project.

Since cost contingency accounts for the unforeseen cost risks, it is likely the estimating model based on the actual impact of cost risk of similar projects could produce more accurate cost contingency estimates. As a result, in the paper a risk based estimation method was adopted, by including 'cost overrun causes classification scheme', the accuracy of cost estimation could be improved. Supporting this proposal, (Liu et al., 2010) showed how RBE had excellent predictive validity as 90% projects having an actual cost within the range of the risk-based estimate in which they estimated the risk contingency of every single components of the project but they did include the cost overrun causes of similar projects. Therefore, this study designs and validates RBCCEM for infrastructure projects.

3. Research design

To develop the RBCCEM model, the survey data and the risk factors identified by the authors in a separate paper (Allahaim and Liu, 2015) is used to demonstrate development and validation process. First, the data collection and the identified causes of cost overrun for infrastructure projects in Saudi Arabia were summed up. Then, the use of cluster analysis to reduce the dimensionality of the risk factors was explained in preparation for the subsequent multiple regression analysis. The regression analysis derives the RBCCEM which was validated using bootstrapping analysis. Finally, the estimates produced by RBCCEM was compared those by alternative approaches such as the fixed cost contingency (10%), RCF (P50 & P90) and hybrid (RBCCEM & RCF P50) approaches.

4. Data collection

A survey of infrastructure project managers in Saudi Arabia was conducted to collect data from key infrastructure project professionals in three groups: owners exposed to project cost overrun, consultants supervising the projects, and contractors delivering the projects. The survey asked about the frequency of the 41 causes of cost overrun most frequently identified from 25 selected studies, as shown in Table 1. Respondents used five Likert-scale response anchors to assess the frequency of each cause in Saudi Arabia, based on their own professional experience. For more information about the data collection please refer to the survey data that conducted by the authors in a separate paper (Allahaim and Liu, 2015).

5. Data analysis and results

Based on the clusters identified, the scores for each cluster in each case was derived by aggregating the scores of each cause within each cluster. Subsequently, the cost overruns of projects were regressed on the four clusters identified to develop a risk-based cost contingency estimation model. R project software (version 3.0.2) and IBM SPSS 19 were used for statistical computing and graphics in the cluster analysis, model building and validation of the model.

5.1. Cluster analysis

Cluster analysis was used for dimension reduction (Everitt et al, 2011). The steps in cluster analysis of the data include preparing the data, determining the number of clusters, testing the cluster solution and finally validating clusters.

In Figure 1, there is an extreme “elbow” in the plot suggesting that solutions over four clusters do not have a substantial impact on the total SSE, which indicates that four clusters are appropriate. The next step tested hierarchical cluster analysis with the selected number of four clusters (Everitt et al, 2011). The Euclidean distance method was used to measure the dissimilarity distance based on the information values and the nature of the variables describing the objects to be clustered. Figure 2 shows the hierarchical cluster (tree) generated from R software, where the cause numbers (C1, C2... C41) refer to the causes listed in Table 1.

In the analysis, 10,000 bootstrap resamplings were used to reduce the error (Suzki and Shimodaira, 20016). In Figure 2, four rectangles have an AU *p*-value of 99 (0.99), therefore, for a cluster with AU p-value ≥95 (0.95), the hypothesis is rejected with significance level 0.01 for one cluster and 0.00 for three clusters, which indicates how strongly four clusters are appropriate as each cluster group contains objects which have a relationship with each other (Figure. 2).

5.1.1. Results – four cluster classification

The four cluster groups were defined based on causes of cost overrun and the literature as scope changes, market and regulatory uncertainty, inadequate planning and control and unforeseen circumstances. Table 1 shows how each of the 41 causes in Table 1 is allocated to one of the four clusters.

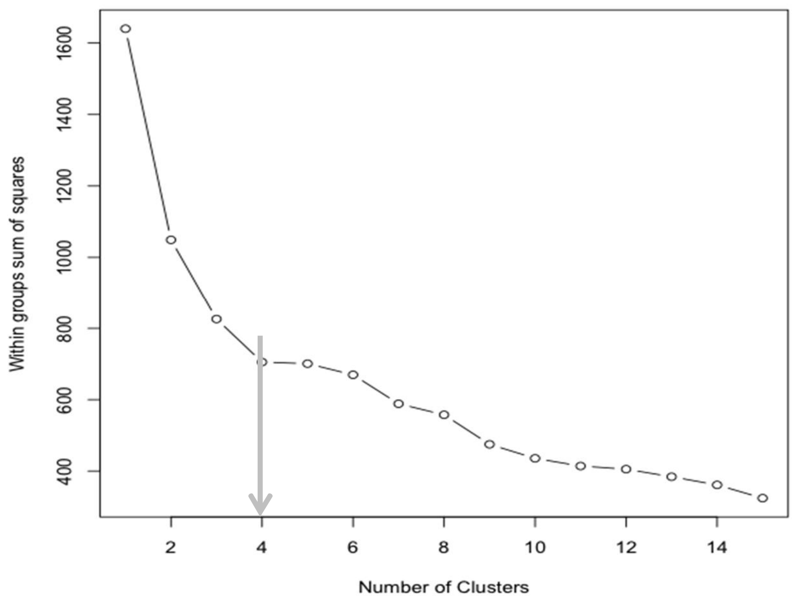
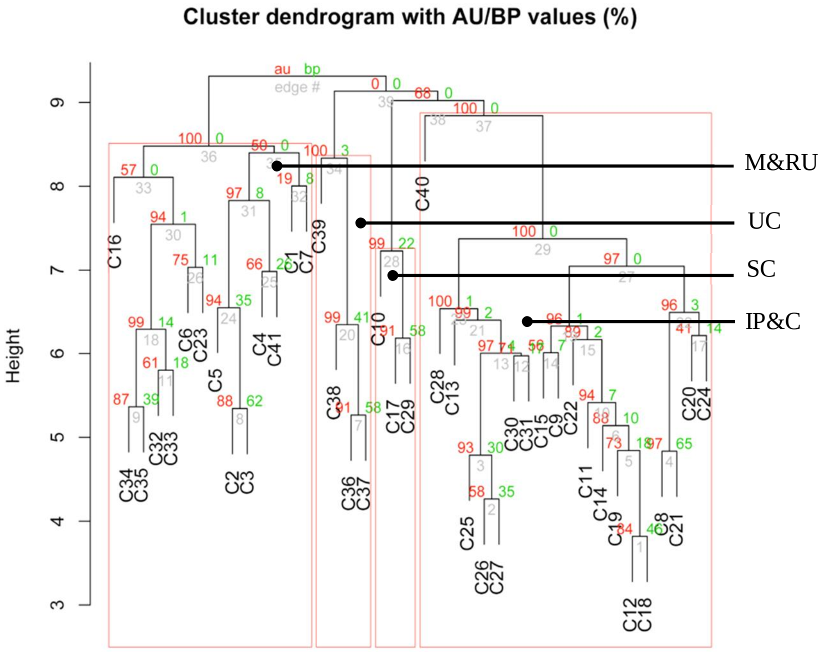


Figure 1: Elbow plot for the cluster determination



Note 1: Values at branches are AU p-values (left-red), BP values (right-green), and cluster labels (bottom). Clusters with AU ≥ 95 are indicated by the four red rectangles.
Note 2: Inadequate planning and control (IP&C), Market and regulatory uncertainty (M&RU), Scope changes (SC) and Unforeseen circumstance (UC).

Figure 2: Hierarchical clustering with four cluster solution

As shown in Table 1, the first cluster group is scope changes (SC), which represents the causes of cost overrun due to design changes, additional work and rework, and change in the scope of the project. The causes in this cluster are related to time, that is the urgency of the project, namely how much time there is to complete the job. Forcing the project team to take short-cuts or to work on tasks which clash with other tasks and working on concurrent tasks and projects are known to cause delays and cost overrun. The second cluster group is market and regulatory uncertainty (M&RU), which includes causes of cost overrun that relate to the chance or speculation changing costs, whether directly or indirectly. The third cluster group is inadequate planning and control (IP&C), it represents the causes of cost overrun which relate to project planning and control, which comprise the most critical causes of cost overrun in large projects in Saudi Arabia. Inadequate planning and control dimension is referring to the factors that could increase the complexity and thus difficulty of controlling the project cost. The last cluster group unforeseen circumstance (UC). The causes of this cluster relate to environment issues, as well as social and cultural impacts. These issues increase the pressure to find a solution to these problems associated with the project site. For example, the increase of environmental requirements has a significant impact on construction operations, which leads to technical uncertainty that relates to the physical difficulty of completing a project.

Table 1: Four-cluster classification scheme for causes of cost overrun

Classification clusters	Key	Causes of cost overrun	Relationship to cost overrun
Scope changes	C17	Design changes*	Unclear project scope forces project team to take short-cuts, crashing tasks, concurrent tasks/projects, which are known to cause delays and cost overrun (Shenhar and Dvir, 2007).
	C10	Additional work and rework*	
	C29	Change in the scope of the project*	
Market and regulatory uncertainty	C5	Market conditions (materials and labour)*	Increases the volatility of input costs and thus chances of overrun (Pindyck, 1993).
	C41	Practice of assigning the contract to the lowest bidder*	
	C4	Slow payment of completed works*	
	C3	Cash flow during construction	
	C33	Obstacles from government	
	C1	Inflation	
	C35	Laws and regulatory frameworks	
	C16	Failure to price in some risks	
	C2	Monthly payment difficulties from agencies (e.g. contractor, owner)	
	C34	Political complexities	
	C7	Deficiencies in cost estimates prepared by public agencies	
	C32	Fraudulent practices	
	C23	High interest rate charged by bankers on loans	
	C6	Fluctuation in money exchange rate	
Inadequate planning and control	C40	Delays (decision making, in approval of drawings, material delivery)*	Increases the complexity of coordination of parties and tasks, thus making it harder to meet present targets (Baccarini, 1996).
	C21	Design error*	
	C8	Deficiencies in the infrastructure*	
	C20	Changes in material specification and type*	
	C13	Shortage of site workers	
	C18	Incorrect planning and scheduling by contractors	
	C24	Inadequate specifications	
	C14	Unrealistic contract duration and requirements imposed	
	C11	Lack of experience of project manager (e.g. location, type)	
	C28	Lack of constructability	
	C15	Strategic misrepresentation	
	C22	Project size	
	C12	Contractor’s poor site management and supervision skills	
	C19	Late delivery of materials and equipment	
	C25	Waste on site	
	C9	Labour, insurance, work security or workers’ health problems	
	C27	Poor financial control on site	
	C26	Equipment availability and failure	
	C31	Optimism bias	
	C30	Inadequate modern equipment (technology)	
unforeseen circumstances	C37	Site constraints	Increases the uncertainty of tasks and
	C36	Weather conditions	

	C38	Social and culture impact (e.g. problems with neighbours)	outcome, thus making planning and estimating difficult (Ofori, 1992).
	C39	Heritage material discovery	

Note: (*) ranked in the top ten causes

5.2. Development of the risk-based cost contingency estimation model

To build the model using multiple linear regressions (MLR), as there are 160 cases and 41 causes, the data was randomly split into two data sets with two-thirds of the data as the training set (100 cases=62.5%) for model building and the remaining one-third (100 cases=37.5%) as the test set to ensure more reliable results and also to reduce bias in the validation (Kothari, 1985). For model validation, bootstrap resampling of multiple linear regressions was employed. Then, the estimates by RBCCEM were compared with those produced by alternative models such as fixed contingency and RCF. Error indices such as mean absolute error (MAE), mean absolute percentage error (MAPE), mean square error (MSE) and root mean square error (RMSE) were used to compare the accuracy of estimates produced (Han and Kamber 2006). Then, RBCCEM, fixed cost contingency (10%), RCF (P50 & P90) and hybrid (is a combination of two models which used to increase the accuracy of cost contingency estimation as Liu et al., (2010) identified) were compared based on the distribution of the means of adjusted cost overrun as the smallest dispersion with the shortest distance between the mode and median indicates the most accurate model (Rothwell, 2005; Lawrence, 2007).

5.2.1. Risk-based cost contingency estimation model building

The regression results using the training subsample are reported in Table 2. The results in Table 2 show all four clusters have significant impact on cost overrun. It is worth noting that Table 2 shows that the R-squared is 32% and adjusted R is 30%, which indicates that the four clusters explains about 30% of variance in cost overruns (Chambers, 1992). The interpretation here is that the observed variation in cost overrun is also explained by other factors beyond those captured in the equation. It is not the intention of this paper to delve into which other factors explain overrun, as it focused on the four clusters (p-value < 0.05) as all variations that were categorised based on 41 causes that are frequently identified in the literature are significant. Therefore, the RBCCEM is represented by the equation 1.

$$\boldsymbol{BCCEM} = \%\boldsymbol{Cost\ overrun} = \mathbf{0.652} + \mathbf{0.157}(\boldsymbol{scope\ changes}) + \mathbf{0.089}(\boldsymbol{market}\ \&\ \boldsymbol{regulatory\ uncertainty}) + \mathbf{0.047}(\boldsymbol{inadequate\ planning}\ \&\ \boldsymbol{control}) + \mathbf{0.024}(\boldsymbol{unforseen\ circumstnaces})$$

Equation 1

Note: the value of inadequate planning and control, market and regulatory uncertainty, scope changes and unforeseen circumstances ranges from 1-5 as 1 has low risk and 5 has major risk.

Table 2: Residuals, coefficients and p-values of regression analysis

Residuals	**Min**	**1Q**	**Median**	**3Q**	**Max**
	-2.109362147	-0.515626813	0.00002042	0.47228	1.52539

Coefficients		**Estimate**	**Std. Error**	**t value**	**Pr(>|t|)**
	(Intercept)	0.65196	0.08967	2.35254	0.00027***
	Scope changes	0.15733	0.10251	0.46178	0.00452**
	Market and regulatory uncertainty	0.08865	0.11366	0.77998	0.03734*
	Inadequate planning and control	0.04728	0.06818	0.54674	0.05218
	Unforeseen circumstances	0.02431	0.11406	2.13199	0.03558*
Residual standard error: 0.0159 on 95 degrees of freedom Multiple R-squared: 0.3249 Adjusted R-squared: 0.3048 F-statistic: 9.463 on 4 and 95 DF					

Note: $p < 0$ '***', $p < 0.001$ '**', $p < 0.01$ '*', $p < 0.05$ '.'

5.2.2. Models validation

The bootstrapping method was used for validating the RBCCEM. 5,000 bootstrap samples were created to validate the predictive ability of the proposed RBCCEM (multi-linear regression (MLR) model). According to all three measures (Table 3), the coefficient was statistically significant (the default for boot.ci is a 95% confidence interval) as they are centred to the normal, which indicated the model was valid. As reported in Table 3, the mean values of the four regression coefficients estimates from the RBCCEM bootstrapping were close to the proposed RBCCEM (Tables 2 and 3). Also, the standard error values of the four-parameter estimates from the RBCCEM bootstrapping were close to the proposed RBCCEM (Tables 2 and 3). The similarity of estimates of the RBCCEM model from both split samples suggests that RBCCEM is valid and robust.

Table 3: RBCCEM bootstrapping

Ordinary nonparametric bootstrap		**Estimate**	**bias**	**std. error**
	(Intercept)	0.57073	- 0.01413	0.092570
	Scope changes	0.14501	0.00348	0.128087
	Market and regulatory uncertainty	0.07840	- 0.00275	0.101091
	Inadequate planning and control	0.03820	- 0.00481	0.083566
	Unforeseen circumstances	0.03298	0.00148	0.100938

Bootstrap Confidence interval calculations	**Level**	**Normal**	**Percentile**	**BCa**
	95%	(0.2662, 0.9035)	(0.2243, 0.8637)	(0.2453, 0.8803)

Note: Calculations and Intervals on Original Scale

5.2.3. Models evaluation using estimation accuracy measures

In the models evaluation we used two methods. The first method was by using estimation error (error indices). The second method was comparing the adjusted cost overrun percentage means by using independent samples t-test. The following section will discuss these two methods and the results are delivered.

5.2.3.1. Model evaluation using measures of forecast accuracy (error indices)

To further validate the model, the estimates produced by RBCCEM were compared with alternative methods such as RCF. RCF uses a database of actual performance of comparable past projects within a given reference class to provide an objective reference point for the cost forecast of a current project (Flyvbjerg, 2006). For a particular project, reference class forecasting requires the following three steps (Flyvbjerg, 2006, p. 8): (a) identifying a relevant reference class of past projects as the base, (b) establishing a probability distribution for the selected reference class and (c) comparing the specific project with the reference class distribution.

To compare the models, the accuracy of each model was measured. Forecast accuracy measurements were based on the distributions of absolute errors (|E|) or squared errors (E^2), taken over the number of observations (n), which are the most commonly used measures to compare the performance of predictive models (Hyndman and Koehler, 2006). These include mean absolute error (MAE), mean absolute percentage error (MAPE), mean square error (MSE) and root mean square error (RMSE) (Swanson et al., 2011). Table 4 presents MAPE MAE, MSE and RMSE where values of 0 indicate a perfect fit (Singh et al., 2013). Table 4 shows that the RBCCEM has comparable error indices to that of RBCCEM bootstrapping. In contrast, the error indices for RCF are much higher, suggesting RBCCEM is more accurate.

Table 4: The MAE, MAPE, MSE, and MAPE of MLR and error estimates of the four-clusters model: Proposed RBCCEM, RBCCEM bootstrapping and RCF model

	MAE	MAPE	MSE	RMSE	RMSE -MAE
Proposed RBCCEM	0.473786	15.78 %	0.426456	0.653036	0.18
RBCCEM bootstrapping (5,000 bootstrap of test data)	0.428924	14.68 %	0.358026	0.598353	0.17
RCF model	0.872376	25.19 %	1.190669	1.091178	0.22

5.2.3.2. Models evaluation by comparing the means of adjusted cost overrun percentage of the models

As discussed, β1 to β4 were estimated based on a sample of 100 and the model was validated using bootstrapping based on the 60 samples, which shows the model was valid and accuracy was improved compared with RCF. In this section, the mean of the adjusted cost overrun percentage of the RBCCEM was compared with those estimated using alternative approaches, such as RCF and fixed contingency (10%), using the split sample. The result in Tables 5 and 6 shows the adjusted cost over. The comparison results reported in Tables 5 and 6 showed that the adjusted cost overrun of RBCCEM results are significantly lower than adjusted cost overrun of fixed (10%) cost contingency, RCF and hybrid approach.

Table 6 shows that the means of adjusted cost overrun percentage using the fixed cost contingency, RBCCEM, RCF P50, RCF P90 and hybrid (RBCCEM + RCF P50), respectively, are all significantly different from each other (*p*-value <0.00). Considering the negative mean (under budget) in the adjusted cost overrun percentage mean of RBCCEM (-0.11451), the results suggested that the mean of adjusted cost overrun percentage using the RBCCEM approach is preferable to that using the RCF P50, RCF P90 and hybrid.

Moreover, Table 6 reports that the adjusted cost overrun using RCF reduce the overrun significantly (*p*-value <0.05) as the mean differences for P50 is (0.1049) and for P90 is (0.0140) (Table 5 and 6). Despite the fact that RCF P50 and RCF P90 have lower mean differences, it should be noted that the RCF estimates are subject to the acceptable risk of cost overrun which RBCCEM does not. In addition, the RBCCEM model tends to underrun budget while the RCF model tends to overrun budget. The dispersions of the RCFs are higher than RBCCEM (Figure 3) suggesting RBCCEM produces more consistent results. In sum, using estimates of contingencies by RBCCEM results in slight average cost underruns with more consistent and accurate estimates than that from RCF.

In addition, the variance of adjusted cost overrun percentage using the fixed cost contingency, RBCCEM, RCF P50, RCF P90 and hybrid, respectively, are significantly different (*p*-value <0.035) (Table 6). Considering that the variance of adjusted cost overrun percentage using the RBCCEM is lower than those using fixed cost contingency, RCF P50, RCF P90 and hybrid (Table 6), respectively, the results indicates RBCCEM produces the most consistent estimates for cost contingency Therefore, RBCCEM is the preferable method for estimating cost contingency for infrastructure projects.

Table 5: Descriptive statistics for mean of adjusted cost overrun of two models

	N	**Mean**	**Std. Deviation**	**Std. Error Mean**
Fixed cost contingency 10%	60	**0.3319**	0.22739	0.02935
RBCCEM	60	**– 0.1145^**	0.15616	0.02016
RCF uplift P50	60	**0.1049**	0.17155	0.02214
RCF uplift P90	60	**0.0140**	0.15604	0.02014
Hybrid of RBCCEM and RCF uplift P50	60	**–0.0096^**	0.32646	0.04215

Note: ^ A negative value denotes under and a positive figure indicates over budget.

Table 6: Test results for the equality of means and variances

	Leven's Test for Equality Variance		t-test for Equality of Means				
	f	**sig**	**t**	**df**	**Sig. (2-tailed)**	**Mean Difference**	**Std. Error Difference**
Fixed cost contingency 10% *vs.* RBCCEM	3.289	0.035	6.54	104.52	0.000***	0.44650	0.13561
Fixed cost contingency 10% *vs.* RCF uplift P50	7. 659	0.005	9.174	109.73	0.000***	0.23677	0.03117
Fixed cost contingency 10% *vs.* RCF uplift P90	7.394	0.006	8.931	104.48	0.000***	0.31795	0.04360
Fixed cost contingency 10% *vs.* Hybrid of RBCCEM and RCF uplift P95	6.616	0.010	6.650	105.342	0.000***	0.34157	0.05136

Note: Significance codes: p < 0 '***', p < 0.001 '**', p < 0.01 '*', p < 0.05 '.'

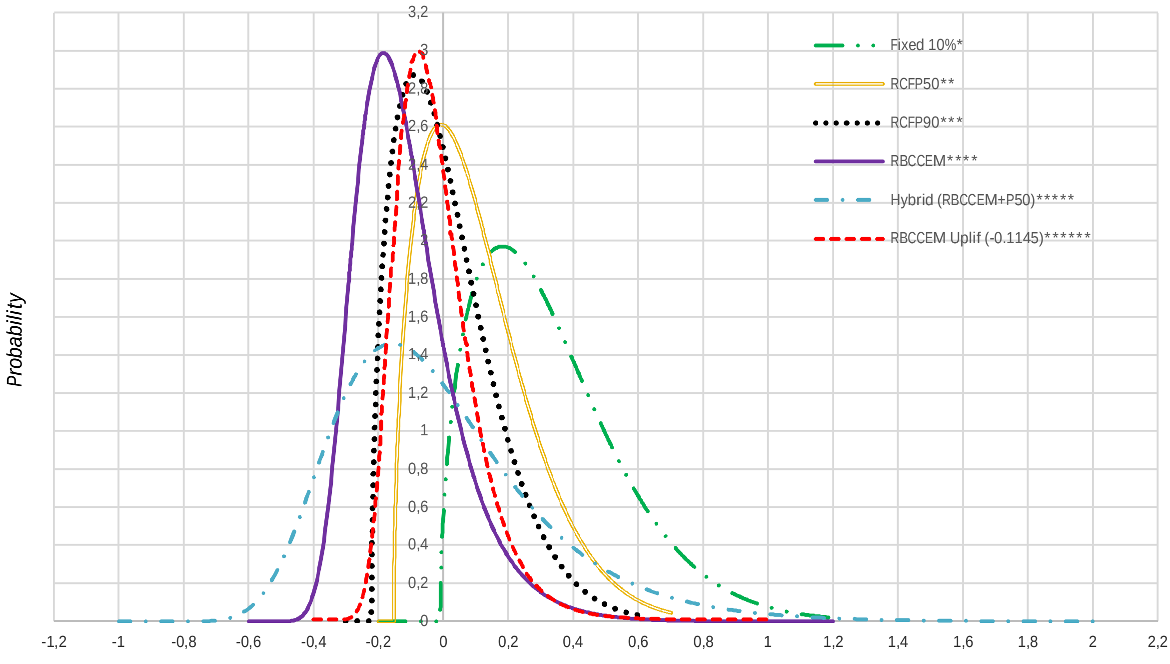
Figure 3 shows the mean distributions fitting to the data. As can be observed that all distributions are skewed to the left and the tails of the distributions are longer in the right. Therefore, the mode is the peak of each distribution, and the median and mean come after it in the right. Furthermore, the distribution of adjusted cost overrun percentage for RCF P50 and P90 are fitted to Weibull distribution as can be observed in the Figure 3 by the orange doubled line and black dotted line, respectively.

In addition, the fixed 10% cost overrun (green long dashed dot dot line) is fitted to Weibull distribution and hybrid (RBCCEM + RCF P50) (blue long dashed dot line) is fitted to exact value distribution. The adjusted cost overrun of RBCCEM distribution (purple solid line) is fitted to exact value distribution which is biased toward under-budget (mean adjusted cost overrun=-0.1145). Comparing the dispersions of the distribution curves presented in Figure 3, RBCCEM has the narrowest dispersion, supporting the above conclusion that RBCCEM produces the most consistent estimates for cost contingency of infrastructure projects.

Further, the small negative mean of adjusted cost overrun of using RBCCEM can be offset by adding an amount equal to 0.1145As a result, the distribution of RBCCEM +0.1145 (red dashed line) shifted around zero and has the narrowest dispersion compared to the other distributions.

6. Conclusions

Based on a cross-section survey of managers involved in infrastructure projects in Saudi Arabia, cluster analysis was used to reduce 41 causes of cost overruns to four clusters; scope changes, market and regulatory uncertainty, inadequate planning and control, and unforeseen circumstances. Using multiple - regression analysis, the risk-based cost contingency estimation model (RBCCEM) was developed by regressing project cost overrun on the four clusters. Then, validity of the RBCCEM was validated by multiple regression bootstrapping using the remaining split sample (sample size of 60) and by comparing the cost overrun outcomes of using cost contingency estimates from RBCCEM to those of using alternative estimating approaches such as RCF and fixed contingency. The validation analysis



*Note: * distribution fitting of fixed % cost contingency of cost overrun (Weibull distribution)*
*** distribution fitting of adjusted % cost overrun based RCF on 50% percentile (Weibull distribution)*
**** adjusted % cost overrun based RCF on 90% percentile (Weibull distribution)*
***** distribution fitting of adjusted % cost overrun based on RBCCEM (proposed model) (Exact value distribution)*
****** distribution fitting of Hybrid model (RBCCEM + RCF P50) (Exact value distribution)*
******* distribution fitting of adjusted % cost overrun based on RBCCEM (RBCCEM + uplift (-0.1145) (Exact value distribution)*

Figure 3: The fitting distribution curves of fixed cost contingency, RBCCEM, RCF (P50 & P90), hybrid and RBCCEM uplifted (RBCCEM-0.1145)

showed that the degree of dispersion of the cost overrun and the mean of the cost overrun after including the cost contigency is the lowest for RBCCEM, in which it is prefered method of estimation for cost contingency. However, the accuracy of cost contingency could be improved further by offsetting the negative mean of cost overrun using hybrid approach, i.e. by deducting the mean from the cost contingency produced by RBCCEM. Such an adjustment uplifts the means of cost overrun to zero while the degree of dispersion remains unchanged.

To apply RBCCEM, an organization needs to ascertain a comprehensive list of the risks to the cost overrun of similar projects through using questionnaire survey. The questionnaire should be based on the questionnaire used in this study and tailored to the project at hand. Assuming the survey responses of at least 30-40, then the organization can proceed to categorizing the risks by conducting clustering analysis. Subsequently, construct scores can be derived by aggregating the scores of individual risks within each category. Finally, regression analysis of cost performance on risk categories is conduced to drive the cost contingency model which will be used to predict cost contingency for the project. Bootstrapping using a holdout sample is a useful validation of the cost contingency estimation model.

The findings are based on a cross-sectional survey of managers involved in infrastructure projects in Saudi Arabia. Therefore, caution should be exercised when generalizing to other contexts. Future research needed to develop RBCCEMs in different contexts following the process for developing RBCCEM as in this study. This study is treating RBCCEM as static concepts that have a constant value, rather than dynamic concepts that evolve over time. Past research has suggested that project management practice changes over time due to a growing knowledge-based society which accelerates change in technological, social and economic knowledge (Jaafari, 2003). Therefore, the survey needs to be undertaken periodically and the subsequent processes need to be conducted to update the RBCCEN regularly. Finally, this study has not compared RBCCEM with the risk-based cost estimation approach future research should consider collect data on RBE estimates and compare the two approaches.

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Volume IV

Understanding impacts and functioning of different solutions

Edited by
Suvi Nenonen
Juha-Matti Junnonen

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Preface

Volume four includes 58 paper contributions linked to the congress sub-theme “Understanding impacts and functioning of different solutions”. The proceedings provides insights to six sub themes. First of all the sustainable impacts are discussed from the perspectives of energy use and energy management. The diverse solution over the globe like sustainable housing in Colombia and a Net Zero Energy Building in Finland provide insights to culture specific issues.

The second theme is dedicated for the papers about building information modeling. Different phases of construction process are approached in diverse articles. Also this theme has an international flavors: research from Ethiopia and Singapore is presented among many other interesting papers. The third theme is about diverse working environments: in the office, at the schools and in connection with healthcare. Also housing and mobility are discussed.

The fourth theme includes economical case studies as well as issues connected to calculations with interesting insights to cost estimations to assessments and issues about infrastructure management. The fifth theme is focusing on construction projects especially in terms of productivity, networks and partnerships as well as regulations and norms. Also ever-green topic of lean production is touched in various papers. Finally the sixth theme is about diverse solutions: roofs, thermal conditions and ventilation have inspired the researchers. This book has hilarious amount of interesting papers from different countries and research organizations. In order to provide some key figures the amount of papers is among the themes following.

I Sustainability	8 papers
II Building information modelling	15 papers
III Work environments	6 papers
IV Economics and construction	9 papers
V Construction projects	12 papers
VI Solutions	8 papers

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May 2016

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May 2016

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Building Codes and Demand Response of Energy Use

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Abstract

Buildings are an essential part of the wider energy system. A significant share of electricity consumption occurs in buildings. Traditionally buildings have been places where electricity is consumed. Now they have a growing role also as a location where renewable energy production, such as solar power, occurs.

Demand response means the voluntary actions that are taken on the customer side as a response to something on the demand side. In practice, demand response can involve, for example, reducing the energy consumption during the peak times of the larger energy system or shifting the timing of the building's energy consumption by synchronizing it with local renewable energy production's profile inside the building. The building codes of Finland direct the designers' energy-related solutions both in new construction and licenced renovations.

In this conceptual paper the literature related to demand response and regulation is reviewed, and it is discussed what kind of a role the building codes could have in advancing the buildings' preconditions for demand response. Demand response is currently brought out in EU directives in the regulation with relation to network operators. However, preparedness for demand response could also be advanced by giving more attention to the timing of power use in the building codes.

Keywords: Building Codes, Demand Response, Energy Law, Energy Use, Power

1. Introduction

The balance between supply and demand in electricity networks has traditionally been achieved mainly by controlling the output power of generators. However, the role of the demand side may be growing. According to the newer paradigm, the system can be more efficient and environmentally friendly if also the fluctuations of demands are controlled (Albadi and El-Saadany, 2008).

Historically, night-rate electricity (and seasonal time of use) tariffs have been time-based incentives that encourage the timing of electricity consumption to those periods of the day or year when consumption without such pricing incentives would be lower. Hot water dispensers and both fully and partially storage heating systems in buildings have been tuned to work at night especially in many of the buildings built in Finland after the 1970s. A more recent step is electricity exchange (Nord Pool)-based consumer energy pricing, which has become increasingly popular. Electricity prices vary seasonally, daily, and hourly in the electricity markets; this variation is based on many factors, including the estimated balance situation (demand and supply). Building's energy consumption varies during different hours (Dirks et al., 2015; Vihola et al., 2015). Market price signal-based demand response can aid in the balance between supply and demand on the wider energy system.

In the future, a growing share of the electricity production will be based on intermittent generation with variable power output (Brouwer et al., 2014). The possibilities of managing the energy system by controlling the production side of electricity are more limited when the share of weather-dependent renewable energy resources (i.e., wind and solar) increases in the energy system. This is especially the case when the power is expected to be flexible upwards. Thus, there is a growing need for managing the demand-side resources of the built environment, including controllable loads, energy storages, and small-scale power generation. As a result, buildings that have been passive consumers in the energy system are expected to be more active and flexible parts of future smart energy systems (Bulut et al., 2015). At the same time, it is possible that profile of peak electricity demands in the building stock will change in the future (Dirks et al., 2015).

It is estimated that buildings account for approximately 20-40 % of energy consumption in different countries (Pérez-Lombard et al., 2008;), representing approximately 32 % of the worldwide energy demand and approximately 39 % of the total energy consumption in Europe (Allouhi et al., 2015). The need to increase the energy efficiency of buildings is nowadays recognized, and presently, energy regulations of buildings are under change. New houses should be "near zero energy buildings" (nZEB) in the European Union (EU) countries in the near future, following directive 2010/31/EU. Exceptions of this requirement include the smallest buildings and buildings that are intended to be used annually for a limited time; otherwise, most of the heated new buildings will be at least nZEB level in the future. "Near zero energy" regulations are a step towards meeting more energy-efficient requirements. The aim of the nZEB level building codes is to increase the energy efficiency of buildings and the share of energy that is produced from renewable sources. In practice, those requirements will likely increase the share of weather-dependent and small-scale energy production, e.g. solar energy and heating pumps and, in the built environment, which can influence the entire energy system.

2. Basics, advantages and problems of demand response

According to Darby et al. (2013), there are three approaches by which smart grids can reduce greenhouse emissions: (1) reduction of demand alias energy efficiency, (2) reduction of demand at peak times, and (3) increased penetration of renewable energy generation. In smart grids, it is possible to manage and reduce the demand peaks by changing the demand loads in such situations that previously were and currently are handled with energy generation from fossil energy sources. After the Paris Agreement in 2015 regarding global average temperature development, there will probably be growing pressure to develop energy systems towards such solutions that reduce greenhouse gas emissions.

Demand response (DR) denotes several types of voluntary actions that are taken on the customer side as a response to something in the energy system (Torriti et al., 2010). In practice, demand response can mean, for example, shifting energy consumption to a different time or reducing the energy consumption during the peak times in the larger energy system. The execution of demand response can be based on the energy price signal or, for example, on reliability (i.e., system security, capacity, or power balance based needs)-based actions (Aghaei and Alizadeh, 2013). Humans can have either an active role in controlling the loads in demand response or more passive roles, if DR is based, for example, on automated load shifting (Torriti, 2014). End users can have an active role, if households are, for example, scheduling their cooking times based on energy prices. Possible loads for automated load shifting, i.e., shifting that the end user does not necessarily even notice, when DR occurs can include the heating loads of buildings or boilers.

There are several papers on demand response from the perspectives of electricity retailers, distributors, producers, users, and DR technology (Kim and Shcherbakova 2011; Ruester et al., 2015; Shariatzadeh et al., 2015); however, the role of building codes has thus far nearly always been missing from studies related to DR and its opportunity to become more popular. In this paper, we consider how the demand response might be advanced by building codes and the instructions related to them. The regulation examples are written especially from the Finnish perspective, but many of them are also applicable in many other countries. The focus in this paper is on the forms of demand response actions where the end user can have a rather passive role: in this case, the holder of a building's electrical interface might need to commit to take DR in use but not personally or actively follow the demand situation.

By DR it is possible to affect environmental impacts of energy production. DR can aid in reducing CO_2 and other emissions if it is utilized to change the timing of energy use from the peaks, when fossil energy is utilized more frequently in the energy system, to those times when fossil energy sources are not needed as much (Cardell and Anderson, 2015; Gilbraith and Powers, 2013).

Smarter demand response actions were previously possible for only large energy users, e.g., industrial actors; however, with technological development, the situation may be changing (Ruester et al., 2014). One development is that there are currently some technological preconditions in the buildings, such as smart meters and other solutions, that can enable the use of real-time price information concerning individual consumers' consumption; the lack of such preconditions was earlier seen as a potential barrier to the realization of DR (Torriti et al., 2010). In addition, the amount and role of distributed energy generation is growing (Ruester et al., 2014), which can increase the need for DR. It can be most profitable for the building's owner if, for example, the solar energy produced in a nearby building is at least for the most part also used in that building. Such a situation requires synchronizing at least part of building's energy consumption with the local fluctuating energy production.

There are several technological possibilities for implementing load control in practice. In addition to smart meters, larger buildings normally have some type of building automation system. Technically, DR can be carried out by smart meters or separate appliances, e.g., a home energy management system (HEMS). Also for example electric alternations can be utilized in managing or controlling demand need variations inside the building.

DR can provide different advantages for different market players in the energy system. These advantages include system level power balance and frequency control for the transmission system operator; portfolio optimization and novel pricing structures for the electricity retailer; peak cutting for the distribution system operator; and new possibilities for minimizing the purchase costs of electricity for the end user (Aghaei and Alizadeh, 2013; Shariatzadeh et al., 2015). If DR cuts the peak demands and improves the reliability of the energy system, then it can also reduce the need for additional power plants and committing capital costs to those investments (Siano, 2014). Feuerriegel and Neuman (Feuerriegel and Neumann, 2014) argue that the financial benefit of DR could increase in the future due to rising energy prices, increasing price volatility at different times, and regulatory reasons (Feuerriegel and Neumann, 2014). The possible advantages of DR include the following:

- **End user:** Decreasing electricity purchase costs, optimizing the utilization of energy produced in users' local power plants, and optimizing the size of the main fuse.
- **Retailer:** Optimization of the procurement of the electricity (portfolio optimisation), management of the balance between procurement and sales, novel products and pricing structures, and new business opportunities (e.g., operating as aggregator).
- **Distribution System Operator (DSO):** Peak cutting in normal and disturbance situations, using demand response as a substitute for back-up lines, and optimizing the dimensioning of the network.
- **Transmission System Operator (TSO)**: System-level power balance and frequency control (balancing and reserve power) in normal and disturbance situations.

Both the amount and the reaction time of demand-side resources are important from the perspective of energy system management. The speed at which the load can be changed based on demand affects that capacity's market value (Valtonen, 2015). In addition, the length of the possible elasticity is meaningful for its value.

Significant potential DR resources in Finnish buildings include the electric heating loads of detached houses and ventilation, cooling, and lighting in larger buildings. When utilizing demand response, several types of restrictions must be considered, e.g., indoor air quality (Alimohammadisagvand et al., Forthcoming). In addition, pre-heating of cars, supplementary electric heaters, greenhouses, and freezing plants provide load control resources.

Currently, in Finland, almost every electric customer has a smart meter (~97%), which is remotely readable, registers hourly consumption, and has some load control enabling functionalities. Furthermore, the balance settlement is based on the measured hourly energy consumption of the end-users. It is estimated that Finland could currently have approximately 1800 MW of such controllable loads via smart meters, which are, in principle, technically ready for the utilization of DR, but in practice, there are obstacles for utilizing it (Honkapuro et al., 2015).

Several market places for DR and other flexible resources already exist in Finland. There are the day-ahead (Elspot) and intra-day (Elbas) energy markets offered by electricity exchange (Nord Pool) and the balancing and frequency-controlled reserve power markets offered by TSO (Fingrid Oyj). However, the holders of buildings or apartments are normally not wholesale electricity market parties. Thus, they cannot sell their own loads directly to these electricity markets; instead, they require a third party to join that market and connecting potential loads together. The business ecosystem for DR should be further developed, though some possibilities for smaller electricity users to participate in DR have recently emerged.

Though time-based pricing (night-rate tariff) was popular even before the electricity markets opened and although DR has been part of industrial and academic discussion for some time, a more developed, energy-market-based DR has not been rapidly adopted. Electricity market parties do not appear to have high incentive for developing DR markets. According to Kim and Shcherbakova, the main challenges that DR programs have met can be classified as consumer, producer, and structural barriers. Consumer barriers include the consumer's knowledge, the availability of required technology, fatigue related to continuously responding, technological costs, and the low level of real savings, whereas structural barriers include rate structures, technology, regulatory process, and policy support (Kim and Shcherbakova, 2011).

Greening argued that the reason for slow popularization of DR is not technical by nature and recommended that state regulators regulate DR by developing incentive mechanisms to promote the utilization rate of DR (Greening, 2010). Van Dievel et al. (2014) noted that the consumer privacy issue can also be one potential barrier to the use of demand response for both investors and consumers. The execution of demand response goes hand in hand with accurate consumption data, and these data can include private information. Further, the potential rebound effects after demand reductions must be managed (Fuller et al., 2011)

There can also be conflicting interests between the retailer and DSO that can make the realization of DR more difficult. These conflicting interests have been analysed, for example, in network simulations (Rautiainen, 2015) that examined how peak loads in real-life network would change if the electric heating of the households were controlled according to the market prices of different market places. According to the results, the peak loads of the distribution network would increase if the loads were controlled based only on the market prices.

Cottwald et al. (2011) reported that DR also has potential for producing new challenges, e.g., new types of peaks in energy system. Energy-price-based demand response can change both the load profile in the distribution network and the conflict of interest situations between stakeholders. If a distribution tariff is structured based on the power maximums instead of energy use, then customers are also provided incentives to decrease their peak powers (Rautiainen, 2015). Hence, this kind of tariff would prevent the market-based load control from negatively impacting the peak power of the network. If customers are incentivized to optimize their loads according to both the system price and the distribution network load in such a way that tariffs support the total energy efficiency of an energy system, then more environmentally positive outcomes can result.

3. Demand Response and EU Directives

Demand response is a new approach from the perspective of legal regulation. Present market rules for flexibility in the electricity markets were created in a context when demand response was not real alternative for generation-side resources (Koliou et al., 2014).

In the EU's most recent energy efficiency directives, some changes seems to be occurring compared to earlier energy policy. According to Butenko and Sceres, there is currently "*significant discrepancy between the dominant concept of the consumer as adopted in the hard and in the soft EU energy law*" (Butenko and Cseres, 2015). In particular, in some of the soft-law-type documents produced in the EU, the position of consumers appears to be more active than before: there, consumers are described as active providers of demand response services to the markers. In addition, in the Energy Efficiency Directive (2012), the consumer's role is presented as somehow active providers, whereas in many other directives, consumers are seen as more passive (Butenko and Cseres, 2015). In directive 2012/27/EU, the significance of demand response in developing energy efficiency is explained as follows:

> *"Demand response is an important instrument for improving energy efficiency, since it significantly increases the* ***opportunities for consumers or third parties nominated by them to take action on consumption and billing information*** *and thus provides a mechanism to reduce or shift consumption, resulting in energy savings in both final consumption and, through the more optimal use of networks and generation assets, in energy generation, transmission and distribution."*

In the same directive (2012/27/EU), in article 15, it is required that European Union's member states should ensure "*the removal those incentives in transmission and distribution tariffs… that might hamper participation of demand response, in balancing markets and ancillary services procurement*", "*that network operators are incentivised to improve efficiency in infrastructure design and operation, and, within the framework of Directive 2009/72/EC, that tariffs allow suppliers to improve consumer participation in system efficiency, including demand response, depending on national circumstances*", "*national energy regulatory authorities encourage demand side resources, such as demand response, to participate alongside supply in wholesale and retail markets*" and "*promote access to and participation of demand response in balancing, reserve and other system services markets, inter alia by requiring national energy regulatory authorities or, where their national regulatory systems so require, transmission system operators and distribution system operators in close cooperation with demand service providers and consumers, to define technical modalities for participation in these markets on the basis of the technical requirements of these markets and the capabilities of demand response*".

Thus, the Energy Efficiency directive sets requirements for network and retail operators to promote demand response by their pricing tariffs. In annex XI of the same directive, time-of-use tariffs, critical peak pricing, real time pricing, and peak time rebates are mentioned as examples of network or retail tariffs that could support dynamic pricing for demand response measures. However, this directive does not set requirements for building designers or for the consumer side related to demand response.

Network regulation (Agrell et al., 2013) and energy market regulation solutions are important tools when promoting demand response. However, in the literature, little attention has been paid to how demand response could be promoted in buildings by building codes and by buildings' original designers. In this paper, it is argued that preconditions of demand response could be promoted by building codes among other regulation instruments. Next, we examine this subject using Finland's building codes as a case example.

4. Building Codes and Energy Efficiency

Lee & Yik classified instruments encouraging energy efficiency in buildings into three categories: (1) building energy codes, (2) incentive-based schemes, and (3) eco-labelling schemes (Lee and Yik, 2004). Building codes affect buildings' design and construction processes and, thus, its features aside from land use planning regulations. Incentives include energy taxation and energy renovation aids; in addition, energy certificates can be seen as examples of eco-labelling.

Buildings codes have a meaningful role in reducing the energy consumption of buildings (Scott et al., 2015). The use of mandatory building codes in encouraging energy savings in the buildings became widespread in the 1970s after the energy crisis. (Allouhi et al., 2015; Lee and Yik, 2004). These building codes are currently widely used instruments, especially in many developed countries, and are used among other things to control the energy consumption levels of new or renovated buildings (Iwaro and Mwasha, 2010; Salvalai et al., 2015). The content of building codes varies in different countries and areas, where climate conditions and local needs can differ. Building codes are applied in the design and construction phases of new and renovated buildings; however, such codes are not necessarily able to give orders regarding the use of the buildings or buildings products, for which different legal instruments should be used. The legal status of building codes also varies in different places: their status is mandatory in some countries or areas, voluntary in others, and mixed in still others (Iwaro and Mwasha, 2010).

In Finland, building codes (see Building Codes of Finland) have traditionally included both mandatory rules and voluntary instructions in the same documents; however, the situation is changing, and there is ongoing a process for separating mandatory parts from instruction parts by 2017. All mandatory parts of the building codes will be in the future given by decrees of the Ministry of the Environment in Finland. In this paper, both the mandatory and instruction parts given by the responsible ministry or government are called building codes.

Finland's valid Land use and construction act (117 g §) mandates the Ministry of the Environment giving building decrees about the minimum requirements for energy efficiency in buildings; building products and technical systems and their calculation methods; heating systems in buildings; improving energy efficiency; measuring energy consumption; and the minimum energy efficiency requirements based on a building's intended utilization. Mandatory regulation regarding the electricity use of buildings is focused on safety issues and is given in documents that are not classified as building codes. HPAC issues are addressed in the building codes.

Building codes of Finland are applied when building licence is sought. Building codes guide the designers' solutions, and consequently the features of the buildings. When it comes to the many details of the energy systems, building professionals make several decisions for the end users. related to the details of buildings' energy systems. Thus the designers and electricians may play a key role in how DR-ready the new or renovated buildings will be or whether DR features are utilized. However, the building codes and the design solutions can impact the user behaviour only partly and indirectly in the utilization phase.

Even though building codes are currently instruments that can be used also in encouraging towards energy efficiency, their role in predefining the probable load profile of buildings' energy use has not often been dealt with. Plans of new buildings have to be in accordance with regulations. Current building codes in Finland set limits for computational annual energy use in new buildings, which is calculated based on plan documents. However, timing profile of energy use inside the year or energy load profile of building has no weight in current regulations.

5. Discussion

Through building codes it is possible to set requirements for technical solutions or technical readiness issues in buildings, to guide the selection of building products utilized in buildings, and also for example determine the targets, objects and methods of energy calculations. Table 1 provides some examples how demand response capabilities in new or renovated buildings could possibly be advanced by building codes. The cost efficiency and effectiveness of the means presented in the table are not analysed in this paper. It could be a theme for further research.

The ways how demand response capabilities in the buildings could possibly be advanced by building codes could include for example changes in minimal technical requirements; changes in the other details of energy efficiency incentives; and changes in things that influence designers', buyers' and public officers' awareness of the power behaviour of buildings and how it can be affected by design solutions. In principle, it is possible to respond by demand on many levels, including the energy market level, the distribution network, and the building's own electric network. Also the regulating means listed in Table 1 can have targets on different levels.

Table 1: Examples of how readiness for demand response could possibly be advanced by building codes (or voluntary actions related to them)

Means of regulation	Object of impact	Example
Defining the technical requirements so that readiness for DR grows in the buildings	Technical solutions and possibilities to exploit DR	Massive structures and boilers are often able to store heat energy in building, which can be utilized in DR. However, if HVAC systems are not easily ready for DR, those capacities are not so likely utilized.
Requiring that power use efficiency is noted when performing the energy calculations required for building licence	Power use behaviour of buildings	Target values for the electric power use could be set both for peak and empty use times of buildings for daily hours and different seasons. Those values could be calculated when the energy calculations of buildings are performed anyway.
Taking into account DR when determining the primary energy factors per energy carrier	Energy certification class & profitability of DR investments	Lower primary energy factors per energy carrier could be utilized for electricity in the primary energy calculations if DR are considered in the design
Instructions for synchronizing distributed local renewable energy production and energy use inside the building	Timing of energy use in comparison to timing of local energy production	The DR features of appliances could be encouraged to put into operation, when they have such
Instructions or recommendations for power management inside buildings	Power fluctuation management inside the building	It could be encouraged that especially larger loads, e.g., sauna stoves and heating pumps, are alternated to limit the probabilities of sharp power peaks in the energy demand of the building

Currently, the building codes of Finland concentrate on annual energy consumption, and the timing of the consumption or the power peaks do not play a significant role. However, as noted in the literature review, the timing of consumption can be an environmentally significant issue, and influence, for example, the greenhouse gas emissions of energy production and wider energy systems. Technical solutions affect some DR capabilities. For example thermally massive structures can slow temperature changes in a building and add the possibility of changing the timing of heating. To guide the designers' and building owners' attention towards the power use instead of annual energy use alone, some target power values could be set and calculated for both peak and empty use times that could be taken into account in the design phase.

One idea that we have proposed as an incentive for DR is that lower primary energy factors per energy carrier (see 2010/31/EU, Annex 1) could be utilized for electricity in the primary energy calculations if DR was utilized. The basic idea behind those primary energy factors is to encourage reduction of the total primary energy consumption and to promote the share of renewable energy sources. If DR could help to reduce the consumption of non-renewable energy sources, then this fact might be an argument for applicability of lower computational factors. The values for those factors are nationally appointed in the member states of EU. In Finland, those factors are given as a Government Decree and published also among the building codes.

The aim of the instructions for synchronizing distributed local renewable energy production and energy use inside a building is to direct the demand inside the building towards the production time and power profile of local energy production. The same technical structure for demand response system might be applicable in other levels and types of DR. In the present smart electricity meters, there are some readiness features for demand controlling that could, in principle, be utilized in some type of DR. However, those features are often not installed for use or are not utilized if they are installed.

In Finland, the electric sauna stove and heating systems of several residential houses have been alternated via the electric installations for decades without legal commands. Those alternations have reduced the power peaks inside the building and needs for larger fuse size. However, omission of such alternations has nowadays become more common in new buildings. Building codes have not traditionally regulated electric installations in Finland, but the power behaviour of buildings could be at least indirectly guided also by building codes.

When developing regulation related to DR, also the risk aspects must be considered so that the regulation wouldn't, for example, lead to such new losses that do not exceed the benefits obtained from the perspective of total energy efficiency. For example it is possible that if DR readiness is required by mandatory regulation, the features may not in all cases be utilized in practice, at least if DR features are not sufficiently economically profitable or easy enough to use. When developing regulation, also technological development and new types of future solutions for power management should be somehow taken into account. The focus in this paper has been in such types of demand management that do not require the end user to play an active in the using phase of the building's life cycle. However, the building's owner or user may need to make decisions whether the DR features are utilized in the building or not.

6. Conclusions

From the perspective of total energy efficiency of energy systems, it could be useful if the power aspects were considered more in the design phase of buildings in addition to annual energy use examination. Regulation by building codes is not the only possible approach for affecting preconditions of DR, but it can be one piece of the larger puzzle, which includes also for example information issues, taxation solutions, tariff structures in distribution network and energy market regulation.

Although the load profiles of different building types vary in different countries, the need for load management and demand response ability may grow worldwide as the structure of energy production is changing towards a more renewable nature. Further research is needed about the connections of DR and effectiveness of regulation in the built environment.

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Regulations

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Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings

Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency

Government decree on the primary energy factors per energy carrier utilized in the buildings. Valtioneuvoston asetus rakennuksissa käytettävien energiamuotojen kertoimien lukuarvoista 9/2013.

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Modelling for efficiency in energy management of the building life

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Abstract

Energy efficiency is a requirement included in building for the future constructions; modelling tools to manage the design, construction and maintenance of the building are available to assure quality in the process by controlling the interaction between disciplines connected with the built environment (i.e. architectural design, structural design, MEP design). The building construction management and the durability screening of the building can be improved and optimized by the BIM techniques that can also became an efficient tool to check the economic aspects during the building lifespan. The energy consumption during the running phase is the focus of possible future contract of building quality and the possibility of providing accurate and robust performance analysis, including prediction of uncertainties and variations related to change of use and occupants' profiles will become dramatically important. Define procedures and tools to provide a connection between models used in the design and management phases of the building with the objective of minimize the energy discrepancy between energy prediction in the project phase and actual energy consumption in the operating phase are accordingly the aim of the paper towards future energy assurance contracts. The paper describes the tested procedures to outline interoperability paths between BIM and BEM models with different software providing workflows that can be suitable in different design processes and work phases. The easiest process cannot be the more accurate and a results comparison with test reliability procedures can improve the reproducibility of the process and modelling strategies to facilitate the interaction between analysis tools at different levels.

Keywords: BIM to BEM workflow, energy efficiency, Building Information Modelling, Building Energy Modelling, Energy contract

1. Introduction

The housing crisis shifted the focus of the building sector from new construction to existing assets. International studies about energy retrofitting show the benefit of benchmarking in improving the energy efficiency during time. Benchmarking is the collection, comparison and sharing of building energy use data and ratings and can lead to an improvement of energy saving about 7% in few years (Vancouver Council, 2014; IEA-ECBCS, 2011). The use of digital methods to manage the design process allows the integration of multi-objective analyses (Asadi et al., 2012) (i.e. architectural, structural, MEP, energy modelling) into a main chain of information enhancing the effectiveness and the accuracy of the design, construction and management processes. Compared evaluation of multi-options scenarios and crosschecks between disciplines on a same BIM model (Building Information Model) can reduce time and cost due to variants and adjustments in the construction site.

The aim to prevent inconsistencies occurring in the standard design process led the BIM into the limelight in the public procurement as is explicit in the European Directive 2014/24/UE, art. 22/4 that states: *"4. For public works contracts and design contests, Member States may require the use of specific electronic tools, such as of building information electronic modelling tools or similar…"*. Consequently, the BIM model adopted to manage the whole building process in a wide-sense life cycle approach includes additionally the energy management of the building. The energy item should be included in the BIM model since it is could be a key factor in the building contracting. The building energy compliance to evolving regulation towards more and more restrictive thresholds of consumption during the lifespan of the building needs powerful tools that redraw the building status when maintenance changings occur. If there is an envelope improvement and/or a HVAC system replacement as well as the requirement to provide energy retrofit measures, the possibility to run a BEM model connected to BIM information is crucial both in existing and new constructions.

The residential and tertiary buildings have the considerably weight of 40% in the final energy consumption of the European Union (Directive 2010/31/EU). Energy reduction of about 30% of energy consumption of the building sector is mandatory in European directives to reach the 20-20-20 Climate-Energy Package (Directive 2009/87/EC) objectives. Furthermore, energy and environmental policies require greenhouse gas emissions reduction by at least 40%, a growing renewable energy production and energy efficiency by 27% (European Commission, 2030 Framework, 2013). The main field of implementation for energy efficiency is related to the new constructions as the renovation rate of the complete building stock is 1.1% and the existing buildings interested by retrofit represent about 1.8% (Ascione *et al.*, 2012) of the total amount. Additionally, renovation strategies should be based on cost-optimality criteria (BPIE, 2010).

Northern European countries commonly use the BIM model to manage public contracts and it is widely adopted at national level; nevertheless, a dissemination phase is still required. BIM tools enhance and optimize the interconnections between actors and stakeholders of a project allowing the rationalization of the different phases: design and programming, project management, construction, operation, maintenance and budget (East et al., 2013). In term of energy efficiency BIM is an influential tool to include the control and reduction of the energy consumption of the building during the design phase and running phase decreasing the related costs and environmental impacts. Therefore, the connection and interoperability of BIM (Building Energy Modelling) to BEM (Building Energy Modelling) is a key point to share information and results for development purposes between the experts in the involved fields. Furthermore, the reliability of the energy simulation and result is an additional issue when energy requirements are part of a sale or rent contract; currently the energy certificate of a building or an apartment is mandatory in these kind of trades.

2. BIM to BEM

The BIM federated model can be the information base or the main store of the data allowing designers to perform structural, MEP, energy analyses. According to BIM uses, the development of the input requirements permits to cover the more fields of knowledge. For an effective BIM to BEM workflow, reducing data loss, the correct information for energy modelling has to define the building information model according to the different stages of the project (COBIM 2012, Series 10). The possibility to use the same information included in the BIM model directly into the BEM model provides a guarantee in minimizing the discrepancy and loss of information between the two models. The need to implement the information, usually not included, in the architectural model, requires as first the cooperation in the team work of the energy analyst with the architectural team in a starting phase of the design (with positive consequences) and the enrichment of the model with energy information such as:

a) thermo-physical characteristics of the envelope materials;
b) specification of window energy performance;
c) space uses to identify homogeneous thermal zones;
d) thermal loads due to the specific use of the different thermal zones;
e) ventilation rates of the thermal zones (per occupant or space size criteria);
f) set point temperatures of the thermal zones;
g) HVAC systems for the building and for each thermal zone.

An additional information related to energy issues is the value of the embodied energy for each material, the data sheet for specific products (e.g. phase change materials, membranes, etc.) that can be useful to qualify the energy model; however, this information has to be post-processed in the BEM modelling phase. The relevance of a unique repository of structured information is the basis for the organized and shared set of data belonging to all the concerned parts. BIM allows the comparison of system configurations, to compute components (e.g. pipes, plants, etc.) by metric automatic calculation and to connect data sheets to the plant components or other elements of the project. The BEM simulation can provide a strong criterion in the decision process, when energy saving strategies to pursue economic targets are included.

The paper provides a list of BIM to BEM workflows with commercial available software to deliver enlightenment about this data interchange process. The research work aims in identify the most promising interoperability paths. The methodology adopted is explained in the following section 3 in which the interoperability workflows are discussed.

3. Methodology

3.1 BIM software

The BIM software used as starting point is Autodesk Revit, a BIM platform widely used in the professional and research field of construction and digitalization of the design, construction and operating phase of a building life cycle. Different BEM tools imported the output from Autodesk Revit to test the workflows. In section 6 the discussion of strengths and weakness for each software is reported considering the following indicators:

- Usability;
- Accessibility;
- Accuracy;
- Geometry import;
- Envelope thermal features;
- HVAC setup;
- Model export;
- Parametrization;
- Compatibility.

3.2 BEM software

The review of the BIM to BEM workflow does not claim to be exhaustive; however, the provided review covers much of the most significant options today available in the digital land for energy modelling in the professional field and advanced research. The tested energy simulation software are listed below:

- Autodesk Green Building Studio;
- SketchUp / Energy Plus;
- Design Builder;
- Grasshopper / Honeybee.

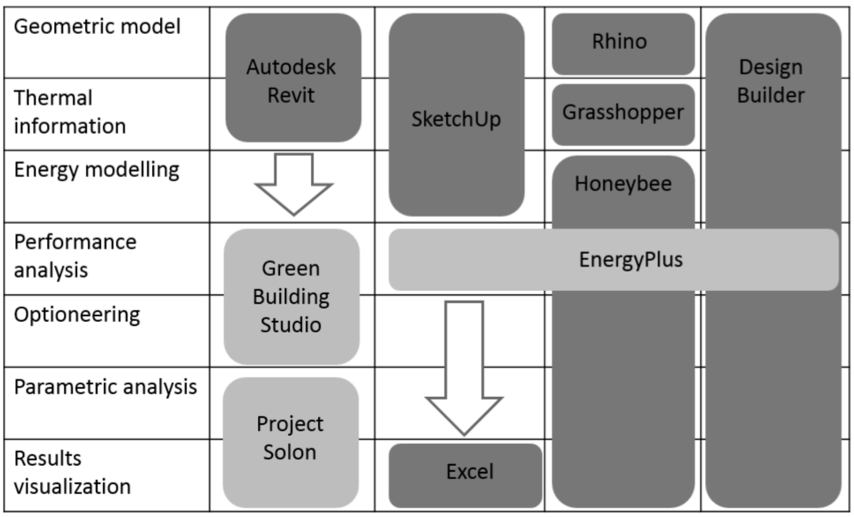


Figure 1: Digital tools used to manage different phases of the analysis process.

3.3 Research process

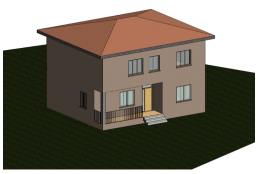
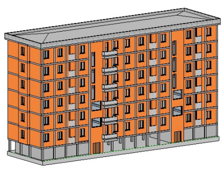
The work process has been structured by applying to three residential case studies, described in section 4, the different workflows following standard steps:

- Preliminary analysis of the project in order to evaluate the suitable thermal zoning (heated and unheated zones, shading surfaces, etc.) and thermal data collection (materials data);
- Realization of the BIM model of the buildings with thermal homogeneous spaces (spaces, rooms) to apply thermal zoning;
- Definition in the BIM model of the thermal characteristics of the envelope materials and components (both opaque and transparent);
- Setting of the heated and unheated zones in the BIM model (temperature set-point, internal loads due to people, appliances, ventilation rates, HVAC type applied to the thermal zone);
- Energy analysis within the software Autodesk Revit using the Energy Analysis form exporting to Autodesk Green Building Studio; then Green Building Studio can export Energy Plus software standard files (*.idf file);
- Import of the exported information to Energy Plus software, procedure of information transfer, tracking/checking/detection of critical issues;
- Realization of energy models into the listed software and reliability comparison of the results to assess the user friendliness, accessibility and robustness of the process.

4. Case studies

The three residential case studies are representative of the main problems extensively diffused in the existing building stock at national level considering the age of construction and technology. The buildings are located in northern Italy, in the city of Brescia (latitude 45.54°N, longitude 10.22°E). The sizes range from a detached house (Castenedolo) to apartment building (social housing in Casazza) to double family detached houses (social housing Case Marcolini), as shown in Table 1.

Table 1: Case studies located in Brescia province, Italy.

	Single family house, Castenedolo	*Social Housing, Casazza*	*Double family "Case Marcolini" settlement*
Actual building			
BIM model			

5. Workflows

The tested workflows are described in the following sub-sections. The simpler workflow is the basic one from Autodesk Revit to Autodesk Green Building Studio through the Energy Analysis toolbar. This workflow allows a first analysis and an output file to perform detailed simulations in EnergyPlus software. Moreover, other accredited energy software widespread adopted have been tested considering the criteria listed above in sub-section 3.1 and the goal was to achieve the detailed dynamic simulation with EnergyPlus software (LBNL, California).

5.1 Autodesk Revit to Green Building Studio

The energy simulation of the building takes place in the cloud using a special form in the main Autodesk Revit toolbar. As first, a detailed BIM parametric model of the buildings have been created. An accurate BIM library of materials, with defined thermal properties, has been used as basis to design the envelope. Internal loads, ventilation rates, detailed schedules of use and thermal plant features have been selected for each thermal zone. The “Spaces” tool permits to identify and describe the rooms as thermal zones. Autodesk Green Building Studio (GBS) has been used to analyze the buildings. The simulation in GBS runs 40 parallel parametric options of the project introducing variation in different parameters to evaluate the variability of the energy performance based on ASHRAE standard requirements. This tool is very powerful and the application of the Project Solon panel allows an effective results vitalization and communication. Project Solon is an experimental customizable interface to create dashboards and set up specific graphs and comparison chart used to manage and report the data about the energy performance. However, the user must carefully control the settings to export the model in Autodesk Revit to the GBS platform because the application is organized such as to give default settings to the model for the analysis and often the inexpert user cannot be so aware to avoid uncontrolled change/overwriting in the model features. The information are equipped of additional considerations that can be misleading for unprofessional user. The GBS tool allows a simple interoperability path giving access to the project team to the energy analysis in a smart way, it must be underlined the need of a supervision and verification process by energy experts.

5.2 Autodesk Revit to EnergyPlus (through GBS)

From the first workflow the EnergyPlus compatible file (file *.idf) has been exported. The file imported in EnergyPlus software has been verified to verify the data transfer. Three BIM to BEM models have been tested using different level of detail in the BIM model as listed below:

- Detailed architectural model;
- Simplified architectural model;
- Conceptual mass model.

The data transfer process from BIM model to EnergyPlus allowed successfully importing of the energy characteristics of the layers of the vertical walls, while errors occurred in the importation of floors and windows characteristics. Furthermore, the visualization of the model into the graphical interface SketchUp allowed pointing out serious problems in the intersections between the interior partitions and exterior walls and floors due to model specification in the "Spaces" configuration. The high level of detail of the BIM model is not always an advantage in the BEM model and sometimes a simplification, without significantly outcome on the energy results, is required to enhance compatibility. For this reason, a simplified parametric model has been realized and compared to the detailed one. In this way, it was possible to achieve an improvement in geometry transfer. Finally, a conceptual mass model has been analyzed. In this model, it is possible to simplify the assignment of energy characteristics even though with default constructions. These constrains leads to a time-expensive post process of the file in the EnergyPlus interface (EP-Lunch) due to the change in the naming transfer process that modify all the elements' name given in the BIM model, beyond the fact that the actual envelope characteristics have to be manually implemented.

5.3 SketchUp to Energy Plus

Upon the data transfer problems between Autodesk Revit and EnergyPlus, an alternative model in SketchUp has been developed and tested. SketchUp is a graphical interface used for the geometrical Modelling for Open Studio (NREL). On the same concept, the plug-in BESTenergy (Politecnico di Milano) allows to run EnergyPlus simulations through a simplified modelling in SketchUp. The geometrical model has been constructed as sum of adjacent thermal zones supplied by thermal characteristics of the envelope, internal gains and ventilation rates, schedule and temperature set points. The model allows to extract demands of sensible heating and cooling. The *.idf file exported from GBS has been tested in Open Studio and BESTenergy; however, problems in identification of materials, geometry, schedule for varying parameters and simulation setting have been reported and time-expensive procedure of adjusting have been compared to the "starting from zero" modelling process. The process is simplified (in comparison with direct use of EnergyPlus software) and transparent (compared to GBS process) easing the hourly dynamic energy simulation effort. When modelling errors or lacks are detected, the software generates a detailed list of errors that have to be corrected in order to successfully run the simulation. As opposite, in the GBS model the lacks are automatically corrected with default construction and settings allowing the energy simulation. This process enables the simulation on the other hand could contemporary lead to modelling errors out of user's control. Results can be organized in graphs and communicated through *.xls file data post-processing.

5.4 Rhinoceros to Honeybee (through Grasshopper)

An alternative workflow has been to model the geometry of the buildings into the software Rhinoceros, using the component Grasshopper and simulate the energy behavior through the plug-in Honeybee running EnergyPlus simulations. The file can be exported directly as *.idf file and as *.gbXML file through GrizzlyBear (Core Studio, 2015). This workflow was lunched with the aim of creating an energy model defined by algorithmic components of Grasshopper in order to subsequently develop retrofit solutions through the parametric solver Galapagos. The creation of the model is a time-expensive process requiring hardworking effort due to the software's complexity. In particular, the schedules' management has been reported as particularly complicated. It is possible to visualize and customize the output into Honeybee plug-in in order to underline the relationship between energy parameters (e.g. wall insulation/energy performance). The values of the results are comparable with results coming from other tools and actual energy bills (section 6), even so further verification on the accuracy of the data to calibrate the models and test of robustness of the interoperability process have to be applied.

5.5 Autodesk Revit to Design Builder

The parametric BIM model realized in Autodesk Revit can be directly exported by an add-in button to Design Builder software or through *.gbXML file. Design Builder is a complete commercial product including EnergyPlus thermal simulation, daylighting simulation, CFD and optimization tool (using JEPlus, a Java shell for EnergyPlus parametric analyses). The software can export *.idf file for direct use in EnergyPlus software. The Autodesk Revit to Design Builder add-in button allows transferring the correct geometry of the building; however, some problems in thermal characteristics of the envelope data transfer occur in multi-zone models. In single-zone models, a complete transfer of thermal properties of the stratigraphy of the wall through “Rooms” tool (instead of “Spaces” tool) could be verified however, other specifications cannot be included in this setting. The schedules’ settings (internal gains, ventilation rates and set point temperatures) and thermal plant have been setup in Design Builder software. Expertise in energy modelling specifically for thermal HVAC systems and operating is required to manage correctly the software and results analysis. A set of standard results visualization is available into the software. The exported *idf file is compatible in EnergyPlus (through an updating process in the EnergyPlus utility form).

6. Discussion

The tests carried out showed that information requirements in terms of energy analysis need a careful management, especially considering the quality of data implemented in BIM platforms used by designers (COBIM 2012, Series 10). Revit model has not to present a high LOD (level of detail), in order to reduce errors in the information workflow. At minimum, the architectural model has to define spaces and rooms. Some of the tested BIM-to-BEM workflows required the creation of a separate geometry model containing all the necessary energy requirements. The export file must essentially include features related to energy analysis by reducing them to essential data for the specific analysis in order to not burden the *.idf file transfer with information that may be distorted and compromise the successfully processing of the analysis within EnergyPlus software. The SketchUp plug-in can be extremely useful for displaying the geometry problem of data transfer that could not be pointed out directly in EnergyPlus interface (EP-Lunch). The interchange *.idf files created by GBS are not directly useable and a hard work of adjustment of the exported files turns into more convenient to restart to model into compatible graphical interfaces with EnergyPlus (SketchUp plug-in) or including it (Honeybee, Design Builder). In this way, the compatibility of the file is complete.

Design Builder is the most directly connected BIM to BEM model tool in the present review, however manually implementation of some data setting is required. A full interoperability occurs between Autodesk tools (Revit to GBS), although the reliability of energy calculations is not easily verified and comparison of results with actual data shows significant discrepancies (*Figure 2*).

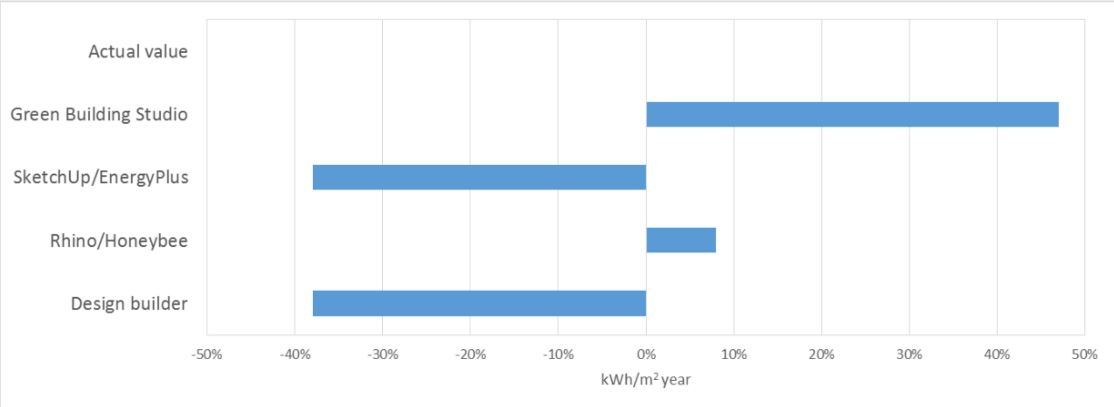


Figure 2: Energy results comparison between BEM software and actual results (energy bill).

Directly use of energy simulation software allows a parallel workflow starting from traditional data. The challenge is to find out an uninterrupted information flow even in both direction assuring reliable results. Interoperability workflow based on the *.gbXML format, such as the Autodesk Revit to Design Builder, can guarantee consistent results even though a detailed set up process of the thermal zone has to be performed. This workflow connects Autodesk Revit model to EnergyPlus (version 8.2) through a working *.idf file without additional adjustments, as is instead required for the *.idf file exported by GBS.

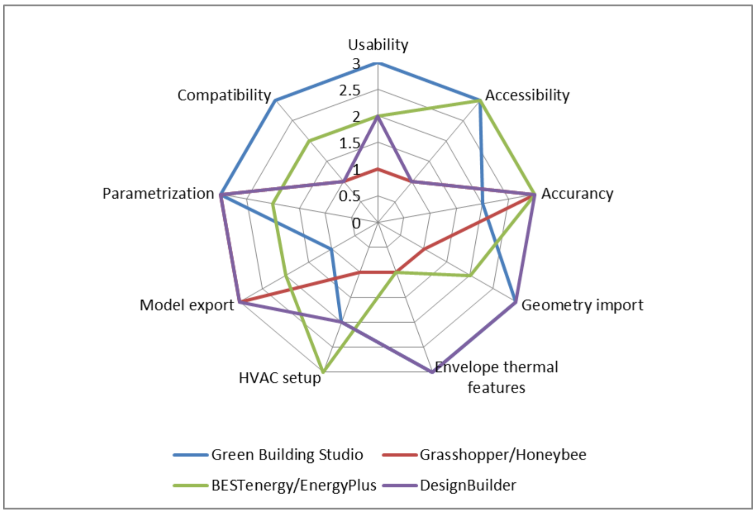


Figure 3: Spider diagram: evaluation of the BIM to BEM workflows.

Thermal zone properties defined in the BIM model can be also exported by using the interoperability workflows proposed in this research. For example, thermal properties can be added to spaces for energy analysis in Autodesk Revit. Geometrical attributes can be added in

Revit rooms. Both geometrical and thermal properties can be imported in Design Builder by the *.gbXML format, but more tests have to be completed on this data flow. The Industry Foundation Classes (ISO 16739:2013) IFC-based BIM to BEM workflow has been initially tested to be used with software Energy Plus (EnergyPlusTM, 2013) through SkecthUp interface, e.g. BESTEnergy (Aste et al., 2012) and Open Studio (Parker et al., 2014). However, it has not been resulted as a user-friendly option so far if compared to the results of other workflows. Further tests will be conducted as future works, especially for the IFC-based data flow Open Studio/SketchUp.

7. Conclusions

The research aims to evaluate the reliability and usability of workflows to ensure energy analyses for buildings in a market scenario in which the BIM model will be the reference database for the whole management of the asset. Issues as maintenance, LCC (Life Cycle Cost), LCA (Life Cycle Analysis), energy management and standard compliance can be controlled through the same exhaustive repository of a central federated model. In this scenario, the data sharing between all the actors of design and built management processes promotes the integration of skills and information without lack of knowledge. This can be achieved through interoperability processes and including platforms, especially if they are based on neutral data formats.

Nowadays, energy simulation are required to be dynamic in order to detail on hourly basis the energy behavior of the building. The Net Zero Energy Building task needs a tailored design, an accurate construction and a structured management to reduce the variability of the energy consumption due to factors introducing a fluctuation of the energy needs (i.e. user behavior, control of the running parameters vs. designed parameters, built quality, etc.). Finally, the possibility to carry out a monitoring phase of the energy consumptions through sensors installation connecting them to the BIM model could be the further step to manage the whole life of the building in a holistic vision and to calibrate the predictive models (Miller et al., 2014).

The performance gap commonly occurring in comparing energy simulation results and actual energy bills needs a crossing by providing a reliable model on which energy contracts could be based. Moreover, the information-based technologies allow visualizing, sharing and comparing data that become strong decision drivers for energy strategies and policies. Subsequently with the evolving energy regulations the energy performance of the building turned into a discriminating factor for the building sector market and the evaluation of the whole quality of the asset together with economical (that is strictly related) and location and space flexibility criteria. Standard test procedures ANSI/ASHRAE 140 and Regression test for Energy Results validation are decisive to evaluate and to define the consistency of prediction results; however, tests on real buildings to calibrate the model are not avoidable.

An informed use of energy simulation tools, based on the knowledge of physical and thermal exchange phenomena, is fundamental for the user to be able to crosscheck results using simplified models. Anyway the validation of input data is the first check to correctly predict, with a uncertainty rate, the energy result, in order to guarantee consistency between input and output (to avoid the “garbage in – garbage out” effect). For this reason, a solid knowledge of limits of the interoperability workflows can be seen as a core interest in the applied research. In this direction, the laser scanner technology integrated with BIM model is a step to survey existing building providing transparent and validated geometrical data.

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Environmental Assessments in the Built Environment: How Reliable Are They?

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Abstract

Assessing the environmental consequences of using and developing the built environment is becoming more and more important. A huge problem is that in many cases the assessment methods are not well-enough developed to lead to credible results. Life cycle assessment (LCA) is one of the most widely used assessment approaches and it is believed to deliver reliable data. Still, two assessments can lead to very different outcomes even when following high academic rigor. In this study, a streamlined LCA to greenhouse gases (GHGs) was utilized to demonstrate certain problematic perspectives in the state-of-the-art of environmental assessments in the built environment. The focus of the study was on buildings and especially on the assessments of embodied GHGs in buildings, which provide an abundance of great examples of problematic issues. In the study, three examples are presented of situations where the reliability of the results of a certain study is questionable: (1) a wooden frame window, (2) a steel body passenger elevator, and (3) a multi-story concrete frame residential building. The particular uncertainty/error perspectives discussed are truncation error in conventional process LCAs in different assessment cases and the assessment scope differences between different studies. Through discussion the case results are positioned to depict the problems on a wider scale. The particular perspective with novelty value for the truncation error discussion is the so-called "first tier truncation error", which has received very little attention so far. The error arises if, for example, a certain building item, is assessed according to the different materials needed. The assessment de facto does not take into account the actual window manufacturing stage, resulting as an additional downwards bias.

Keywords: Built environment, environmental assessment, life cycle assessment, LCA, uncertainty

1. Introduction

Assessing the environmental consequences of using and developing the built environment is becoming more and more important. Developing our settlements sustainable is one of the grand challenges of our time (Rees and Wackernagel 1996; Seto et al. 2014). Climate change mitigation has already grown into an aspect to consider at virtually all levels of decision-making (Säynäjoki et al. 2014), and new global problem areas like biodiversity loss are gaining attention (Steffen et al. 2015). The environmental issues have penetrated into the processes of the users and developers of the built environment, and various assessments are run on regular basis to understand the environmental impacts of certain actions or activities and to compare different options (Säynäjoki et al. 2015). The huge problem is that these assessments are believed to produce reliable information, and the results are utilized to justify decisions and draw policy-guidelines, when actually both the quality of a high share of these assessments and often even our state-of-the-art in assessing certain impacts are not high enough to lead to credible results.

Life cycle assessment (LCA) has established a strong position among the environmental assessments and it is believed to deliver reliable data. Still two assessments can lead to very different outcomes even when following high academic rigor (Suh et al. 2004), and many assessments are lacking this quality. With other assessment approaches, similar and even more worrisome examples can easily be found. It is not even rare that a new study suggests entirely different impact factors to be utilized than the current tradition to assess the impacts of a certain action or activity.

In this study, a streamlined LCA to greenhouse gases (GHGs) is utilized to demonstrate certain problematic perspectives in the state-of-the-art of environmental assessments in the built environment. The focus of the study is on buildings and especially on the assessments of embodied GHGs in buildings, which provide an abundance of great examples. In the study, three examples are presented of situations where the reliability of LCA method in the built environment context is questionable: (1) a wooden frame window, (2) a steel body passenger elevator, and (3) a multi-story concrete frame residential building. The particular uncertainty/error perspectives discussed are truncation error in conventional process LCAs in different assessment cases and the assessment scope differences between different studies. Through discussion the case results are positioned to depict the problems on a wider scale. The particular perspective with novelty value for the truncation error discussion is the so-called "first tier truncation error", which is present in the majority of building and civil structure LCAs but has received very little attention so far. The first tier truncation error arises, if e.g. a certain building item, like window, is assessed according to the contributions of the different materials needed. The assessment does not take into account the actual window manufacturing stage, resulting as an additional downwards bias (in addition to the "traditional" truncation error inherent to all process LCAs).

The remainder of the paper is arranged as follows. In Section 2 the main LCA approaches are presented with the emphasis on the qualities potentially leading to biases and errors in the assessments. Section 3 presents the demonstration cases and the data. Section 4 shows the results and Section 5 provides discussion about the key issues. Section 6 presents some key conclusions.

2. Method

According to its name, LCA estimates the environmental burdens of goods, services or processes over their life cycle from cradle (e.g. raw materials extraction) to grave (e.g. disposal or recycling) (Klöpffer 1997). The method has been developed since the '60s (e.g. Hunt and Franklin 1996), but the use in the building sector has increased rapidly since the '90s at least in terms of number of academic publications (Fava 2006; Sartori and Hestnes 2007; Buyle et al. 2013; Sharma et al. 2011). There are two main approaches to LCA: process and input-output (IO) LCA. Both have their strengths and weaknesses, but are inherently different, potentially leading to very different assessment outcomes (e.g. Lenzen 2000). Here the methods are only briefly summarized, and the focus in the next sections is on the particular weaknesses which may add significant uncertainty to the results.

2.1 Process LCA

Process LCA is the traditional, most widely utilized, method for an LCA (e.g. Suh et al. 2004). Process LCA utilizes material quantities to estimate the impacts related to their production. The environmental data are typically taken from existing databases such as ecoinvent or GaBi. The method is held as accurate due to its quantity basis and the high-resolution material distinguishing ability. At the same time, however, the method suffers from an inherent truncation error from certain higher-order phases of the production and delivery chains being virtually always left outside the assessment boundary (e.g. Suh et al. 2004; Matthews et al. 2008). Lenzen (2000) has suggested these cut-offs to be quite significant overall, and in one of the very few building LCA comparisons Lenzen and Treloar (2002) suggest the error as potentially being 50% or even more in that context. Junnila (2006) has demonstrated the cut-offs to be significant in the service industries.

Another, much less discussed, issue is that there actually is a "first tier truncation error" quite typically present as well in process LCAs (Heinonen et al. 2016), particularly in the context of the built environment. When items are assessed through the material quantities, the final production and assembly phase might be omitted, especially in the case of pre-manufactured items utilized in the production of the assessment object, such as electricity and piping systems or elevators in a building. The material quantities omit potentially an important share of high-degree processing leading to a significant "first tier truncation error". This issue will be discussed through the selected assessment examples of this study.

2.2 Input-Output LCA

IO LCA assesses the environmental impacts based on monetary transactions and the spreading of the value-added through the economy. IO LCAs utilize environmentally-extended economic transaction matrixes (i.e. IO tables), which allow for summarizing the overall impact caused by a transaction on one sector based on how the value-added spreads through the economy. IO LCA is typically based on the IO tables of national accounts, although multi-region models exist nowadays. The method was first introduced by Leontief (1970) in the '70s. IO LCA achieves a theoretical full system completeness since an infinite number of upstream processes are inherently included (e.g. Suh et al. 2004). However, as Lenzen (2000) presents, IO LCAs don't inherently include the use and disposal phases (the life cycle ends at the factory gate) and thus they also suffer from a kind of a truncation error without amendatory actions.

The method suffers from several inherent problems. The most important are aggregation error and homogeneity and linearity assumptions. Aggregation error arises from the fact that each IO sector actually is just a weighted average of the emissions intensities of multiple sectors of an actual economy (e.g. Suh et al. 2004, Crawford 2009). Thus the intensity might randomly over- or underestimate the actual emissions from the assessment object. Homogeneity assumption means that all the products within an IO sector have the same emissions intensity. Linearity assumption refers to the inherent assumption of IO models that the exchange price would have linear correlation with the emissions, which in many cases doesn't hold true (Girod and de Haan 2009). IO LCA is thus a tool for assessments of average products and systems.

3. Research Design

In the study, three examples are presented of situations where the reliability of the LCA method in the built environment context is questionable: (1) a wooden frame window, (2) a steel body passenger elevator, and (3) a multi-story concrete frame residential building. Next each example is presented.

3.1 Wooden Frame Window

As depicted in the method section, one feature of process LCAs is the so-called "first tier truncation error". In this study the potential impact of this error is depicted with a case of a wooden frame window 1.2x1.9 m. The case window is a business-as-usual northern latitude triple-glazed window with insulation gas (argon) and wooden frames with the outer frame covered with aluminum. The insulation gas is omitted from the assessment as having a negligible climate change impact. The glass is assumed to be 4 mm uncoated flat glass and the frame 80x210 mm. In between the glass layers are aluminum board frames. The estimated material volumes are:

Glass	54.3 kg
Wood	29.3 kg
Aluminum	6.7 kg

The process LCA approach and SimaPro with ecoinvent 2.0 database (PRé Consultants 2010) are utilized in the assessment to compare two different assessment approaches. The first option is an assessment utilizing a traditional process LCA approach in calculating the quantities of wood, glass and aluminium and summarizing the contribution of each to the overall result. This approach is by far the most utilized when the window is assessed as one item of a building but leads to the so-called "first tier truncation error" presented in Section 2.1. As the second option, the same window is assessed utilizing the ecoinvent 2.2 sector "Window frame, wood U = 1.5 W/m2K, at plant". This sector includes the final production sector (first tier), and should suffer only from the traditional truncation error of process LCAs, thus enabling conclusions on the significance of the so-called "first tier truncation error". It is of course obvious that there might be other differences in the two approaches hindering this particular error from showing. For example, the binding materials in the window frame or the paint are not taken into account in the first type of approach, but this is a very typical cut-off in an LCA study in the building sector and just aggravates the problem of underestimation of the first approach.

3.2 Steel Body Passenger Elevator

The second case depicts the often significant difference between the two main LCA approaches, process LCA and IO LCA. An elevator is a great example of a case where the inventory of the main materials for a process LCA captures only a limited share of the actual overall GHGs related to the manufacture and assembly of the elevator. The production requires a significant amount of high quality processing in between the materials and the ready product, which is not fully captured with such typical building LCA approaches where the main material quantities are assessed in the LCI phase and given emissions intensities according to an LCA database. Overall it is thus a good representative for both types of truncation error that process LCAs can lead to. IO LCA for its part then again includes also the capital goods and overall does not suffer from the truncation error.

In this study a comparison was run between (1) a traditional process LCA with a bill of material quantities for a modern steel body elevator for a five-story residential building, and (2) the same elevator assessed with the IO LCA method utilizing the U.S. economy based EIO-LCA (Carnegie-Mellon University 2008) adjusted for inflation and the currency exchange rate. The estimated bill of quantities and the cost estimate for the elevator were:

Cables, doors, rails	1,000 kg
Motor	300 kg
Elevator body	700 kg
Cost	25,000 €

3.3 Concrete Frame Multi-Story Residential Building

The third case studied was a concrete frame multi-story residential building. The comparison builds on a literature review of the published case results from the academic literature. A total of 16 cases were found for comparison, presenting a huge variation in the results, not explained by the case characteristics but rather by the differences and uncertainties in the LCA methods. The cases are not presented one by one but rather the range of results together with a discussion of the utilized assessment approach.

For comparability, one m2 of gross space was utilized as the functional unit. If only net areas of the case buildings were reported, these were converted into gross areas using a conversion multiplier of 1.43 m2 based on Lylykangas et al. (2013). This was also in accordance with the respective ratio taken from Passer et al. (2012). In the cases when the original paper presents the results in embodied energy rather than in GHGs, a conversion factor of 0.266 kg CO2e per kWh was utilized taken from the EIO-LCA tool of Carnegie Mellon University (2008). For reliability, the factor was also compared to Junnila et al. (2006) and Fuller and Crawford (2011), who give estimates of 0.24 kg/kWh of and 0.25 kg/kWh.

4. Results

4.1 Wooden Frame Window

The two assessments returned significantly different results. For the three main materials the GHG LCA estimate is approximately 130 kg CO2e, whereas the wooden-frame window sector of ecoinvent 2.0 gives an estimate of 300 kg CO2e for the case window. It is obvious that the two assessments are not identical in their scopes since the material-approach excludes, for example, paint, glue, handles and hinges and is thus downwards biased in comparison to the window sector. The difference is still striking, however, and gives indications for two important issues: (1) the “first tier truncation error” (see Section 2.1) can potentially be of high importance in building LCAs, which tend to omit the final production phase of many items; (2) the main materials might in many cases not lead to a sufficient scope. The first issue is present with important systems and items of a building, e.g. with the electrical system in general, piping and fixed furniture. Heinonen et al. (2016) depict how these categories might have an important impact for the LCA results and should not be cut off as is often done, but it is alarming if the truncation errors are of this magnitude if only the main materials without the final production phase are included.

4.2 Steel Body Passenger Elevator

The steel body passenger elevator case demonstrates how different results the two LCA approaches, process LCA and IO LCA, can return. The process LCA result is approximately 5,500 kg CO2e, whereas the IO LCA result is almost 14,000 kg CO2e. Again a couple of important conclusions can be made. (1) While process LCA inherently leads to an underestimation of the actual emissions due to the truncation error, an elevator is a perfect example of an item in a building with which the main materials can only capture a considerably limited share of the actual overall emissions. In addition to the inherent traditional truncation error, the “first tier truncation” can be high. (2) A significant amount of materials is left out from such traditional assessments which only include the main materials, as in this study, and altogether these cut-offs can create a significant additional truncation error. (3) The IO LCA can randomly over- or underestimate the actual emissions due to the aggregation error, but this cannot easily be checked, and due to its quality of including a substantially wider scope than process LCA (e.g. the capital goods), an important share of the difference in these two results is likely to be due to the underestimation of the process LCA.

4.3 Concrete Frame Multi-Story Residential Building

The result range runs from less than 100 kg/m2 to over 1 ton, as shown in Figure 1. There are partial scope differences, for example just the frame taken into account vs. close to all materials, but also important assessment differences. Only one IO LCA was found for this comparison, but it has resulted in by far the highest estimate. With hybrid LCAs the varying amount of IO and process data make the comparisons difficult from this perspective. In the lowest end the low estimates are at least partially the product of adopted assumptions regarding recycling and carbon uptake, which often are not considered. The cut-off criteria varies significantly as well between the studies. According to the LCA tradition, it is typically claimed that only materials with minor impact are excluded, but as discussed by Suh et al. (2004) and depicted by Heinonen et al. (2016), these excluded shares can easily be heavily underestimated. Thus scope-wise a more complete assessment can lead to substantially higher estimates even when the assessments would otherwise be similar. Further differences, outside of those caused by the actual building

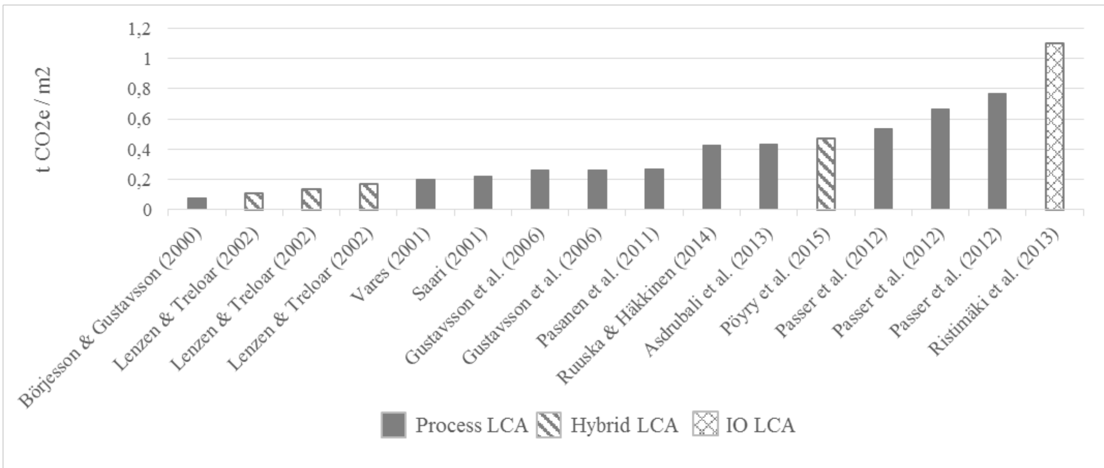

Figure 1. Results per m2 of the selected 16 cases.

qualities, can result simply from the assessment database choice, as depicted recently by Herrmann and Moltesen (2015).

5. Discussion

The aim of this paper was to study the reliability of environmental assessments in the built environment. The scope was further limited to GHGs and the LCA method, but it is very likely that a similar situation exists with regard to other impact categories and assessment techniques as well, as discussed previously by Heinonen et al. (2015). Three cases were presented to depict and discuss some problematic issues: (1) a 1.2x1.9 m wooden frame window, (2) a steel-body passenger elevator, and (3) a multi-story concrete frame residential building. Through each example different uncertainties were discussed.

The errors and uncertainties of LCAs have been studied for a long time (e.g. Lenzen 2000; Huijbregts 1998 a, b), but not many studies exist which have concentrated on the built environment. Lenzen and Treloar (2002) suggest that the truncation error can potentially be of the magnitude of 50% in building LCAs, but not many other such direct method comparisons or uncertainty analyses exist. Actually many studies report the results as if they were precise and not subject to uncertainty. While this study is very limited in scope and its ability to give evidence, it brings up issues which should be better taken into account and studied more in the future.

Overall it seems that there is room and need for development to make LCAs more robust in the context of the built environment. This is not to say that current assessments are worthless, but anybody reporting an LCA study or utilizing the results for decision-making should understand the method well enough not to draw wrong conclusions. For example, the cut-off impacts from the assessment boundary selection may well be underestimated, the different inherent errors make it difficult to compare the results of process LCAs and IO LCAs, and "first tier truncation" can be a severe problem, though currently not well recognized at all. It is striking how much an assessment with just the main materials included seems to underestimate the actual emissions, or how different is the outcome for an assessment of the same object but using a different LCA method. Furthermore, several other assessment assumptions can vary between two studies and cause the results to be very different, even for similar assessment objects, as was discussed with regard to the residential building cases in Section 4.3.

6. Conclusions

Based on this study, it seems obvious that there is plenty of room for development of LCA methods in the context of the built environment. Currently the assessments vary so much that the results are often not comparable between different studies without a deep understanding of the methods and the details of the studies. The study did not reveal particularly new issues, but surprisingly little attention has been devoted to the uncertainties presented, especially given the order of magnitude this study (and previous studies) indicates. The "first tier truncation error", meaning the last production phase being excluded when such objects are assessed which utilize prefabricated products, such as windows or pipes in building construction, has received very little attention in general. However, this error exists particularly in such sectors as the built environment, especially with buildings but to some extent with other civil structures as well. At least this study suggests that it can be a significant source of bias. Finally, this study only shows areas where more work should take place, though the message is still important and the development of needs is significant and urgent.

Acknowledgment

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Establishment Of Weights In A Rating System Of Sustainable Housing In Colombia Through The Analytic Hierarchy Process (AHP)

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Abstract

Currently there are several rating systems or certifications systems for sustainable construction in the world such as LEED and BREEAM. These responds to a need for generating solutions to the big problems that construction involved: emission of greenhouse gases, energy consumption, waste generation, water and materials consumption.

In this order, these certifications systems are typically formed as checklists required to obtain a minimum number of points according to established evaluation guidelines and generally associated with certain categories of impact.

In the other hand, we have that Decision Theory provides a methodology called Analytic Hierarchy Process, which consist of a process of ranking criteria from the implementation of a matrix of pairwise comparison.

In this way, this study proposed to use the AHP methodology for the establishment of weights in an eventual rating system of sustainable housing in Colombia, according to its context and the kind of current information and tools at legal level that the country has. The above, considering that Colombia does not have a clear regulatory scheme for sustainable buildings yet. Therefore, this study seeks to provide a strategic tool for the regulatory framework for sustainable housing in Colombia from the integration of the Decision Theory with existing certification systems adapted to the country. All that, with a panel of experts with people from academia and industry.

As a result, the study shows how this proposed strategy can be helpful in countries which do not have sufficient technical tools to generate robust impact assessment schemes, as LEED in the United States. Thus, it can be obtained very good results from a consensus between academia and industry in Colombia, which are comparable with recognized certification systems in the world.

Keywords: Sustainable Housing, Analytic Hierarchy Process (AHP), Weights, Certification System, LEED.

1. Introduction

According to the definition of Sustainable Development from the Brundtland Report in 1987, it is important to consider the great contribution that construction industry can give to this concept because of its impact to the environment: consumption about 40% of the world's electricity, 17% water, 25% of felled timber, and production over 40% of overall waste and 33% of carbon emissions (Thakore, Jack, & Benuzh, 2013). Moreover, in the specific case of this research it will be important considering that cities in the world are composed around 70-80% by the residential sector.

In this way, nowadays it exists in the world classification and certification systems for sustainable buildings seeking to assess the presence of factors related to environmental quality in the different stages of the life cycle of a building. Although each of the certification systems is an approach or own philosophy, depending on where it has been conceived, all options provide design/construction that are environmentally responsible, and in turn deliver awards and public recognition to the additional effort required to conduct more sustainable projects (Secretarías Distritales de Ambiente, Habitát y Planeación de Bogotá, 2014).

In Colombia, recent governments have shown in one way or another some interest in the topic, however, it has not yet been given a broad and comprehensive policy for the country that offers some kind of official certification system that promotes sustainable construction.

Therefore, and in order to provide tools to facilitate and coordinate with the items that the country already have in terms of public policy aimed at promoting sustainable construction, the following study presents the research done for the generation of a first Referential of Sustainable Housing in Colombia (or certification system for the housing sector) and the establishment of the weights of their criteria, after the implementation of the Analytic Hierarchy Process methodology as a tool for decision making level.

2. Background

In this section we will understand briefly the determination of weights in the two main certification systems in the world (LEED and BREEAM) and the Analytic Hierarchy Process implemented in this study.

2.1 Leadership in Energy and Environmental Design (LEED)

Taking into account that LEED scheme is organized in categories and credits, it is important to understand that the process to be followed for this certification is basically to achieve a certain score from obtaining some criteria, known as credits within the system, which seek to meet the needs of sustainable development. These credits, according to the impacts they want to avoid, minimize or mitigate are classified into the following categories: Integrative process, Location & Transportation, Sustainable sites, Water efficiency, Energy & atmosphere, Material & resources, Indoor environmental quality, Innovation, and Regional priority.

In the previous version v3 credits' weights were determined by impact categories by TRACI software. For the current version v4 new impact categories were used.

For the current version v4 they coupled to the premise of making "greatest positive impact" and not "do less harm", for which the TRACI categories did not fit totally into their new goals. This was based on the fundament that categories did not capture totally sustainability goals anymore and they were not the best way to make a life cycle assessment for all components that a building has.

The above idea led to the United States Green Building Council (USGBC) to favor the creation of their own impact categories to broaden their approach to social, environmental and economic material. This made the certification stop focusing on how "environmental problems can be reduced", but in what LEED certified projects should contribute and achieve.

In this way the USGBC devised the form to work with impact categories and subcategories with which every credit was scoring. They basically did an exercise of association between credits and subcategories. This exercise had three aspects (duration, control and relative effectiveness) which were multiplied in a formula and in that way it was obtain the score of the credit. The score resulting from the association of each credit with all subcategories was computed and dictated the final score for each credit (Knaw, 2013).

2.2 Building Research Establishment Environmental Assessment Methodology (BREEAM)

Although this system does not name as "credits" the criteria they use within their categories, they have some similarity with LEED in their overall scheme. In that way, we can see they have the following categories for the assessment: Management, Energy, Health & wellbeing, Transport, Water, Materials, Waste, Land use and ecology, Innovation, and Pollution.

BREEAM uses a scoring system explicitly derived from a combination of weights and classifications product of a consensus by a panel of experts. The results of this exercise are used to determine the relative value of the environmental sections used in BREEAM and its contribution to the overall score of this Certification Scheme.

This scoring system is defined in detail in the BRE Global Core Process Standard (BES 5301) and in the documents that support its proceedings, which are part of the Standard BREEAM and Code for a Sustainable Built Environment. The classification of impacts used in BREEAM follows the same mechanisms score of BRE Green Guide to Specification and BRE Environmental Profiling Method for building materials. BREEAM FCO provides ways to adapt this system in specific credit score by region or country in which a project is certified (BREEAM, 2011).

2.3 Analytic Hierarchy Process (AHP)

It is a method that allows represents a problem using a hierarchical structure where the last link are alternative decisions. This method was developed in the 70s by Thomas L. Saaty and since there it has been studied extensively, currently it is being used in decision-making in complex scenarios, where people work together to make decisions when human perceptions, judgments and consequences have a long-term impact (Bhushan, 2004).

The application of AHP begins with a problem to be decomposed into a hierarchy of criteria in order to be easier to analyze and compare independently (See Figure 1). After this logical hierarchy is built, the decision makers can systematically evaluate alternatives when making comparisons between pairs for each of the criteria. This comparison can use the specifics of alternatives or human trials as a form of input information underlying (Saaty, 2008).

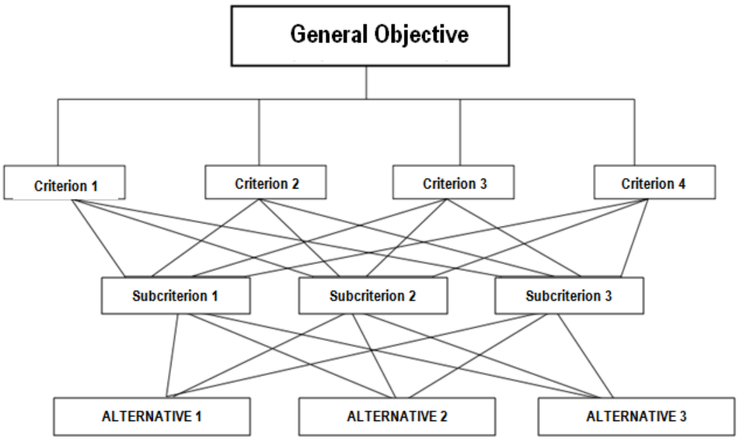

Figure 1: Example Hierarchical Structure

After the definition of the hierarchical structure, it is necessary to construct matrices. In this manner, using an appropriate scale, it should be performed pairwise comparison for each of the elements of each level in relation to the elements of the next higher level (Saaty T. L., 1994).

Then, using an estimation method, the relative weights for each element are calculated with respect to the other elements and at the next higher level. After obtaining the weights of each element, the weight of each of the alternatives is estimated and sorted. It is important in this point to understand the estimation method proposed by Saaty, which mainly part of the matrix principle of $A * W = \lambda_{máx} * W$ where A is a matrix with a dimension n, $\lambda_{máx}$ is the maximum eigenvalue of matrix A , and W is the final weight vector estimated appropriately normalized so that its components sum to 1 (Castillo, 2006). Theory behind the above can be revised in the literature.

Finally, a proper interpretation of the results projected by the model is done. Once interpreted the consistency of the results is analyzed and determines whether changes are needed to the model. Once it reaches a satisfactory answer, the right choice is determined.

3. Methodology

For the development to this study it is important to understand that first we had to limit the scope of this. In that way, although the present study was focused on generating a first Referential for

Sustainable Housing in cities of cold zone (see Table 1), this research despite assist in the establishment of categories and credits to be considered in this first version of the certification system, with the support of the Colombian Sustainable Building Council (CCCS), it was concentrated mainly in the establishment of the ID, Name, Objective and Weight of each of the credits to be considered in the Referential, but we did not work in their requirements, form of implementation, calculations, Regional Variation and References.

Table 1: Climatic zoning for the application of environmental criteria proposed by the Ministry of Environment, Housing and Territorial Development in Colombia

Warm zone – Wet	**Warm zone – Dry**
Altitude in the range of 0 to 800 meters above sea level, temperatures above 24 ° C and relative humidity above 75%	Altitude between 0 and 800 meters above sea level, with greater than 24 ° C temperatures and relative humidity below 75%
Temperate zone	**Cold zone**
Altitude in the range of 800 to 1,800 meters above sea level, mean annual temperature between 18 ° and 24 ° C and relative humidity between 70 and 85%	Altitude above 1,800 meters above sea level, temperature between 12 and 17 ° C and relative humidity between 60 and 80%

Additionally, it was considered appropriate to restrict climatically (cold zone) and typologically (new multifamily housing projects) the exercise given the geographical and urban conditions that are assumed can get to induce significant differences in generating a specific system of certification for housing, according to some discussions on the subject (Buendía López, 2013). Thus, this study, in addition to taking the initiative to generate a first version of a certification system that provides the theme of sustainability in the country, it leaves the door open for future research in different areas and different types of housing buildings to validate if the course assumed is correct or it could eventually generates a single Referential of Sustainable Housing for all Colombia.

Thus, after understanding the problem that we wanted to address - definition of credits that should be considered for a first version of a certification system for multifamily housing in cold areas of the country and the determination of its possible weights - It began with the selection of candidates, either for their expertise in environmental issues and/or their sustainability or outstanding professional preparation, for being considered as experts on these issues to participate in the development of this exercise. This group was mainly composed of professors from the University of the Andes and professionals from member companies of the CCCS.

From this, several meetings was agreed with experts who voluntarily wanted to participate in this study. The first meetings focused on establishing what the AHP methodology termed as criterions and subcriterions, which for purposes of this research are the same categories and credits respectively. For this phase, it was decided to begin the exercise taking into account the schemes of LEED Homes v4 from United States and the Reference House from Brazil, thus experts gave feedback on what they saw relevant or not to the Colombia case, as well as some criteria were not being taken into account and that experts considered they should be included. At this point, it is important to understand the modification done to the AHP methodology, because in this case we did not have alternatives, just criterion (or categories) and subcriterion (credits), this, using the same LEED terminology (see Figure 2).

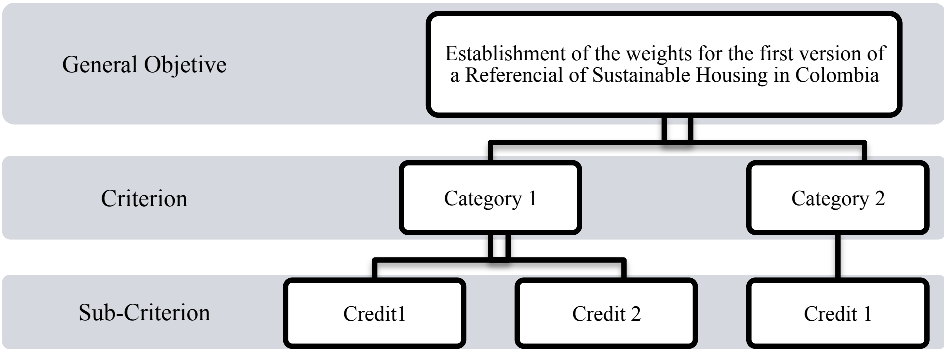

Figure 2: Structuring of the problem

Later, when all the information was gathered and some preliminary credits were established, we proceeded to the elaboration of the matrices according to the scale of Saaty[1], which was done using the software *ExpertChoice*, program that allowed evaluating immediately the index inconsistency of matrices, thereby reducing the error which would be evaluated later.

Although ideally suited for this type of methodology is the generation of a panel of experts, which all interact to finally define a single matrix, given the difficulty appeared to gather all participants in one place, due to the agenda that most of them handled, we decided to averaging matrices with a geometric mean, according to the suggestions of Professor Mario Castillo, an expert in AHP issues in the Industrial Engineering Department of the University of the Andes, to finally get results in terms of the score for each of the categories and credits considered.

4. Results

According to the methodology explained above, we finally had six matrices in agreement with the Table 2.

Table 2: Participants in each of the considered matrices

Assessed Level		Number of participants
Criterion	1.General Scheme – All the categories	6
Subcriterion	2.Implantation	5
	3.Efficient use of water	7
	4.Energy & Atmosphere	8
	5.Material & Resources	7
	6. Indoor Environmental Quality	7

[1] Saaty scale has a range between 1/9 and 9 where 1/9 means that the criterion compared with another one is extremely not important and 9 when the criterion is extremely important compared with the other one

The following Table shows the specific results in every final matrix obtained after the geometric mean applied to the several matrices for each level handled.

Table 3: Results of the weights obtained from the every considered case

Assessed Level	Matrix A	Vector W (Weights)
General Scheme – All the categories	see below	see below

Matrix A:

	CAT1	CAT2	CAT3	CAT4	CAT5
CAT1		2.61	1.59	2.96	1.41
CAT2			0.60	2.10	0.90
CAT3				2.93	0.75
CAT4					0.57
CAT5	Inconsistency	0.02			

Vector W (Weights):

CAT1	0.32
CAT2	0.16
CAT3	0.22
CAT4	0.09
CAT5	0.21

Assessed Level	Matrix A	Vector W (Weights)
Implantation	see below	see below

Matrix A:

	IMP CR1	IMP CR2	IMP CR3	IMP CR4	IMP CR5	IMP CR6	IMP CR7	IMP CR8	IMP CR9	IMP CR10
IMP CR1		1.03	2.14	1.93	1.64	1.73	1.84	0.76	2.29	0.96
IMP CR2			3.84	2.14	1.38	1.64	5.19	2.05	4.29	1.25
IMP CR3				0.66	0.72	0.84	1.38	0.46	1.93	0.34
IMP CR4					1.04	1.11	2.14	0.58	1.82	1.06
IMP CR5						1.55	1.48	0.61	2.22	1.15
IMP CR6							1.18	0.47	2.41	0.87
IMP CR7								0.61	2.29	0.62
IMP CR8									3.50	1.38
IMP CR9										0.27
IMP CR10	Inconsistency	0.02								

Vector W (Weights):

IMP CR1	0.13
IMP CR2	0.19
IMP CR3	0.06
IMP CR4	0.09
IMP CR5	0.10
IMP CR6	0.08
IMP CR7	0.06
IMP CR8	0.14
IMP CR9	0.04
IMP CR10	0.12

Assessed Level	Matrix A	Vector W (Weights)
Efficient use of the water	see below	see below

Matrix A:

	UEA CR1	UEA CR2	UEA CR3
UEA CR1		3.67	3.08
UEA CR2			1.15
UEA CR3	Inconsistency	0.01	

Vector W (Weights):

UEA CR1	0.63
UEA CR2	0.19
UEA CR3	0.18

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<tr><th>Assessed Level</th><th>Matrix A</th><th>Vector W (Weights)</th></tr>
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<tr><td>CAI CR1</td><td></td><td>1.66</td><td>3.00</td><td>3.11</td><td>2.02</td><td>1.49</td><td>2.57</td><td>1.05</td></tr>
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Thus, starting from a base of 100 points for the entire Referential it can be understood that with the first matrix showed in the table above we made a distribution of these percentages to each category considered. So then, for example the category of "Efficient Use of Water", or CAT 3, with a weight of 0.16 will have 16 points, at the same way we make this exercise with the weights of the credits in every category. For example, on this category CAT3 we distribute 16 points for the credits (or CRs) considered in the category.

The following is the final Referential obtained, as previously it was explained:

Table 4: Final Referential of Sustainable Housing in Colombia

REFERENTIAL OF SUSTAINABLE HOUSING IN COLOMBIA

FIRST VERSION — **100 Possible Points**

IMPLANTATION	Possible Points	32
IMP CR1	Control of negative impacts by altering the field	4
IMP CR2	Project orientation based on the solar chart	6
IMP CR3	No use of invasive plants	2
IMP CR4	Site Selection	3
IMP CR5	Location near existing urban developments	3
IMP CR6	Access to open space	3
IMP CR7	Reducing the heat island effect	2
IMP CR8	Stormwater management	4
IMP CR9	Toxic products and plague control	1
IMP CR10	Compact developments	4

EFFICIENT USE OF WATER	Possible Points	16
UEA CR1	Efficient water use indoors	10
UEA CR2	Efficient water use outdoors	3
UEA CR3	Measurement and control of water consumption	3

ENERGY&ATMÓSPHER	Possible Points	22
EYA CR1	Quality of electrical installations of low voltage	3
EYA CR2	Energy efficiency of hot water system	2
EYA CR3	Artificial lighting	4
EYA CR4	Energy efficiency of the residence	5
EYA CR5	Efficient home appliances	2
EYA CR6	Generation of electricity through renewable energy	2
EYA CR7	Energy audit of installed systems	2
EYA CR8	Sectioned measurement and verification	2

MATERIAL&RESORUCES	Possible Points	9
MYR CR1	Management plan for construction waste	2
MYR CR2	Waste management plan for the operation of the project	2
MYR CR3	Environmentally sustainable products	3
MYR CR4	Products and materials with improved components	2

INDOOR ENVIRONMENTAL QUALITY	Possible Points	21
CAI CR1	Control of flue gas emissions	4
CAI CR2	Ventilation	4
CAI CR3	Outdoor air filtration	2
CAI CR4	Comfort of the indoor environment	2
CAI CR5	Control of particulate pollutants	2
CAI CR6	Protection from garajes pollutants	3
CAI CR7	Noise protection	1
CAI CR8	Cigarette smoke control	3

CERTIFIED	40-49
SILVER	50-59
GOLD	60-79
PLATINUM	80+ Points

5. Discussion

We did a whole analyses from the results in every matrix considered with the different experts' opinions, however, below only we will present the analysis made for the matrix of the general scheme case.

For the general case, which determines the weight or importance of each of the categories previously exposed, it looks like at the end of the procedure performed, on average the categories were organized from highest to lowest score as follows: Implementation, Energy & atmosphere, Indoor environmental quality, Efficient water use and Materials & Resources

Now, in Figure 3 we make a comparison of the results obtained for the Colombian case with the scheme in USA (LEED) and Brazil (Referential House) in terms of possible points within the certification systems. Thus, it is important to note, and although it was mentioned that while the whole exercise was done with relative weights with a base of 1, then the corresponding extrapolation was made to a system that considers 100 possible points.

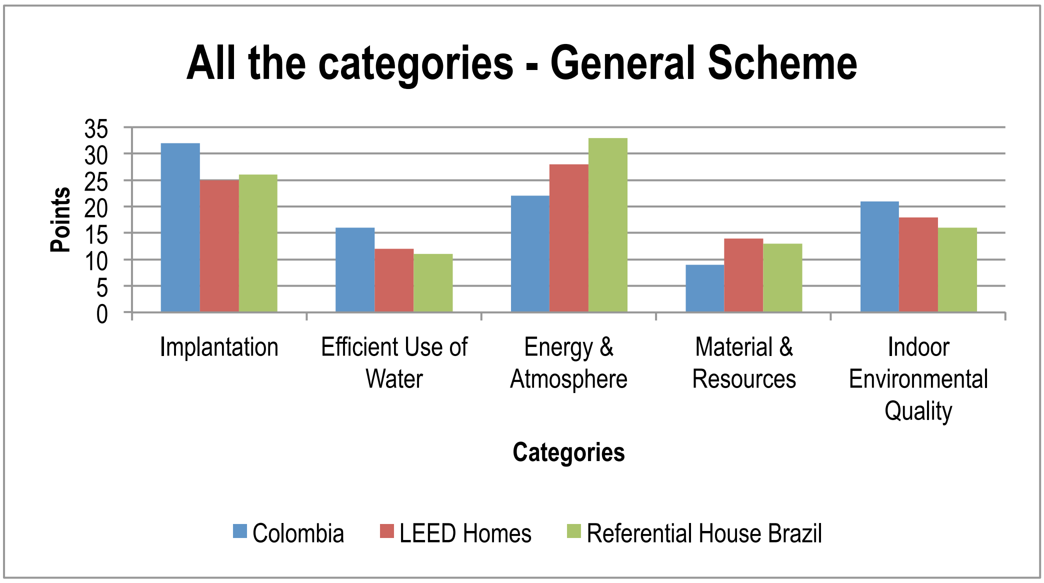

Figure 3: Comparison between categories of rating systems from Colombia, USA and Brazil

In that way, when we compare with the Referential House from Brazil and with LEED Homes from US, we can see in Colombia the most important category is Implantation, while for the others two countries is Energy & Atmosphere. For LEED, this can respond to the way of energy production in the country, linked directly with the emission of greenhouse gasses, one of the most important themes when we think about sustainability, while in Colombia this happens mainly through hydroelectric, related to water and biodiversity problems (Buendía López, 2013).

Likewise, this difference can be attributed in one or another way to the level of development in Colombia, because it exists a proportional direct relation of this with the energetic consumption, this for example in average the number of home appliances in Colombia is fewer than in USA and Brazil.

Taking into account that each of the systems certification represents an approach or own philosophy, depending on where it has been conceived, it can be seen how in Colombia the most relevant category is that which evaluates overall the place where the project is going to be develop, whose characteristics site promote pollution minimization and optimization of some work situations that facilitate the implementation of sustainable criteria. This is closely related to the planning and management of projects, one of the major problems in the country by the lack of practice of what is known today as *Systems Thinking* and *Integrative Processes.*

On the other hand, it is not surprising that the category with the fewest points have been the Materials & Resources, as well as being one of with less credits considered, because it has criteria that in the country are not very easy to achieve such as life-cycle assessment of materials, promotion of products whose ingredients are inventoried using an accepted methodology and the use of verified products that minimize the use and generation of hazardous substances. However, this does not diminish the importance of the category, because despite being the one with less points, it has few credits, which obtained a distribution of points similar to other categories. Similarly, this applies to the category of Efficient water use, which is the second to have less points globally, however, by having only 3 credits, they are those with most points when they are compared to other credits, even it is in this category where we have the credit with more weight (efficient water use indoors with 10 possible points). In this sense, it is important to note how in Colombia, despite being potency in water resources, there already is a concern to protect this resource since now.

Finally, we can say that the categories of Energy & Atmosphere and Indoor environmental quality, positioned as the second most important with similar weights, after Implantation, they are those that promote technical developments and some practical modeling of processes that are not widely used in Colombia, which are transcendental in driving the sustainable construction industry in the country. Similarly, these are credits that are undeniably connected with the promotion of high quality in the habitability of the spaces, a fact that undoubtedly affects different areas and dimensions of development and progress of the people.

6. Conclusions

According to the whole research here exposed, in this section we will describe some conclusions about the implemented methodology, the obtained results and some challenges that this study can deal:

- To have AHP as a strategy for the solution to the problem posed was an effective mechanism, because it allowed the structuration of this one under a multicriteria landscape, following a paradigm related to broad rationality, flexibility and realistic approaches compared to the traditional paradigm, in this way this allowed the incorporation of the human factor (integration of the tangible and intangible) in the search of the "best" solution to the problem (Moreno, 2002), we arrived to a Referential of Sustainable Housing according of Colombia's needs, despite the complexity of the situation. Above, taking into account also the lack of technical tools that the country still has to develop other mechanisms for the determination of the weights in this kind of certification system.

-We can say the geometric mean represents very well the most of the experts' opinions without the perturbation of the sample by extreme values. In the same way, although it was thought the panel of experts was ideal according the traditional AHP, we saw the methodology implemented by us, geometric mean, was adequate because of the possible partiality of experts in a table, while our methodology reached a balance between experts opinions. All the final obtained matrices were under 2% of inconsistency, which increase the reliability of results that in terms of Analytics or Theory of Decision allows to make decisions more easily.

- It is important to understand that this first exercise seeks to be an approximation to what a Colombian system certification of sustainable housing should be in the country. In this way, there should be more investigation about this topic that complement or change what we found, if these kind of things mean a real support for this research. In that sense, it will be necessary to work in the requisites, form of implementation, calculations, regional variations and references of the credits that we did not do in this first phase.

- Nowadays, although the entire advance the world has reached about sustainable techniques in construction industry, as the certification systems, there are things in which we have to work harder as a developing country like culture, education and awareness of the crowds, who are the final operators of the sustainable buildings. Thus, the really important thing is that certification system are responsible and search real sustainable projects more than senseless recognition, as it has been saw in some cases around the world.

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COMPLEX INTEGRATED APPROACH OF SUSTAINABLE ARCHITECTURE
Based on Properly Modifiable Site Specific Database

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Abstract

Preserving our environment has come to the forefront of our society's concerns and architects may not be indifferent. Widespread awareness of climate and other environmental change together with huge amount of the technical opportunities have triggered professional demands for architects with advanced skills. According to the new aspects and tools, the architectural design process must become more conscious. Our main task is not only to create new technical variations, but to re-define the design process taking into consideration the whole complexity of available information and data, while providing permanent control over the decisions. Design process plays a very important role in architecture, not just aesthetically, but technically as well.

Careful consideration of surrounding conditions from the earliest stage of the design process can have an enormous impact on reducing subsequent operating costs and protecting our nature. All over the world there are specific traditional solutions relating to climate in order to utilize the natural conditions for the benefit of human comfort. These traditions help us to develop really sustainable decisions in contemporary architecture.

Efficiency of design process depends on the adequacy of the data applied. Systematization and integration of all relevant information and aspects into creative design process is a crucial part of contemporary architecture. We should re-think architectural design process as a coordinated set of stages and sub-stages replacing traditional experience-related process by a more rational, and theory based approach of choices and solutions for specific design problems. There is a need for developing a systematic structural and material selection system that will enable architects to identify relevant criterias effectively and to evaluate the options accurately. Analysis of impacts, requirements, and structural performances at each design stages can be the common approach in the dialogue between architects and experts. Preventive and remedial measures should always be evaluated in the context of the whole by holistic method.

The Holistic Performance Based design method responds to surroundings by continuously fitted, properly modifiable Multilevel Project-oriented Site-specific Database. This system integrates skills, knowledge and tools of “passive” and “high-tech” design elements into a more conscious complex design process.

Keywords: Holistic, Performance-Based, Project-oriented, Site-specific, Database

1. Introduction – built environment: comfort and pollution

Shelter and comfort are the basic needs for all human beings no matter where they live. We want a comfortable place to protect us against heat/cold, humidity, environmental diseases, dangerous animals, burglary and other possible threats. We want a comfortable environment where we can live a protected and healthy life. The aim is to create a high level comfortable and stable climate for our everyday existence. Increasing functional requirements all together with growing human population and technical development resulted not only higher level of internal comfort but at the same time environmental pollution and health problems. (Fig. 1.)

Figure 1 [20, 21] Dream and reality of built environment

“Building design and construction use significant quantities of natural resources and materials. The building industry consumes 3 billion tons of raw materials annually -- 40 percent of the total material flow in the global economy. The manufacturing process of new materials is water and energy intensive and contributes to environmental degradation and pollution. Harvesting, extraction, mining, and processing new materials pollute the air and rivers and threat ecosystems and wildlife. North America, Europe and Japan consume more than 25 percent of the world's annual 4.5 billion cubic meters of wood production. According to the Natural Resource Defense Council (NRDC) [22] at present rates of destruction the rainforests will be gone by 2050. In addition, global wood production is expected to double over the next 30 years. Consumption of other raw materials and natural resources continue to accelerate. ” [23]

“The Building Sector is responsible for almost half of the energy consumption (49%) and greenhouse gas (GHG) emissions (47%) in the U.S. [24] The sector is expanding, which is bound to increase its energy consumption as it is declared in “Directive 2010/31/EU [25] of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings”. While the majority of the energy consumption, and their associated emissions, come from building operations (such as heating, cooling, and lighting), the embodied energy and emissions of building materials and products are also becoming increasingly significant. A very small amount of energy-efficiency improvement on this field could lead to significant economic savings. A building’s “energetic DNA” is hard-coded in the architectural concept. The possible deficiencies of architectural design decisions can be balanced only by costly engineering solutions.

Therefore, reduction of energy consumption and the use of energy from renewable sources in the buildings sector constitute important measures needed to reduce energy dependency and greenhouse gas emission. If we do not reduce GHG emissions, we risk triggering dangerous climate change, resource depletion, acidification, and eutrophication. The latest International Panel on Climate Change (IPCC) Fifth Assessment Report [26] confirms the necessity for immediate and sustained action on climate change, detailing how close we are to a turning point in the earth’s climate system. The underlying conclusion of the report is that the time has arrived for taking the necessary steps to preserve liveable conditions on earth. As quickly as possible, we must stop burning fossil fuels, aiming for a complete phase-out by around 2050.

And the products we select affect the quality of the spaces we inhabit. People spend appr. 90% of their time indoors in USA, and the quality of air in buildings has been proven to have significant negative health impacts on them. The indoor environment is not only a health and comfort issue. It also affects work performance and learning skills of the occupants. Many new buildings have proven to be physiologically uncomfortable and unhealthy as well. Several people, who live and work in modern houses, have complained of periodical symptoms of malaise (headache, fatigues, drowsiness, irritation in eyes and nose, dry throat, non-concentration, nausea and allergic symptoms). The choice of materials, constructions can improve or degrade our indoor air quality and we can affect that quality through the materials and products we select. (Fig. 2.)

Figure 2 [27] Polluted environment

Preserving our environment has come to the forefront of our society's concerns and architects may not be indifferent. Widespread awareness of climate and other environmental change (decreasing natural resources, pollution of environment) together with huge amount of the technical opportunities have triggered professional demands for architects with advanced skills. The successful integration of complex principles and new technologies into a creative design process in practice and education has proven elusive. [1]

In view of these environmental concerns, sustainable design embodies the following goals:

- Minimize consumption and depletion of material resources.
- Minimize the life-cycle impact of materials on the environment.
- Minimize the impact of materials on indoor environmental quality. "[28]

The basic question is how to create a really sustainable built environment to protect our natural surroundings and at the same time to provide comfortable, healthy life for people? Should we use more high-tech solutions or try to follow the passive adaptive design concept? How to find the balance and the best options?

2. Sustainability: adaptation vs. high-tech application

There is a close connection between the way we build our houses and the surrounding climate. Climate (sunshine, temperature and wind) has a crucial influence on all parameters of building such as orientation, glazing, thermal mass, insulation, ventilation and zoning. Fundamentally functional arrangement and construction of the house are to set the framework for indoor climate which is different from the outdoor climate. All over the world there were specific ways of relating to the climate. Whatever the general climate is - cold, hot, temperate, dry or humid - houses were built so that the local conditions are being utilized to a maximum. Most old cultures had a good knowledge of the local resources (climate, materials) and understood how to utilize it instead of working against it. People traditionally built their houses by hand out of local natural materials (stone, timber, grasses, burned clay etc.). Building types and constructions were developed for centuries, so they had time to have experiences how to create building shape, functional arrangement, to choose materials responding on their surroundings. Porch in front of the rooms provides shading in hot summer and sufficient lighting in winter, walls made of pise or solid clay brick had high thermal mass according to the temperate climate. (Fig. 3.)

Figure 3 [29] Traditional built example in the temperate zone (Hungary)

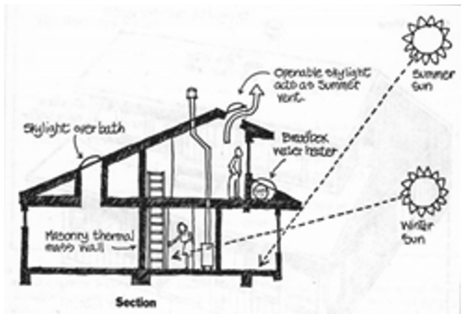

Figure 4 [31] Passive solar design

The environmental impact of ancient houses was slight. Living houses, until cc. the end of 20. Century, were mostly adaptive without crucial environmental impact. Experiences of traditions can be useful today as well. So called "passive architectural design system" [30] follows this way and relies on natural principles instead of mechanical systems to provide a non-polluting source for internal comfort. (Fig. 4.) Whether could we eliminate industrial products in our houses by this passive design method?

Figure 5 [32] Most of the modern houses consist of artificial materials and high-tech applications

Development of society and industrialization has resulted with us starting to move away from the individual houses and to begin building uniform and anonymous houses located close to factories. In the course of time, these houses have spread from the centre of the city to its enormous suburbs. Each individual, therefore, no longer has influence or understanding on the relation between their house and its external environment. In globalized market the building materials can be achieved almost from all over the world and we use a huge amount of artificial structures created by industry. (Fig. 5.) The required high level internal comfort is granted by mechanical equipment, e.g. HVAC systems and regulated mainly by high-tech solutions. Houses are centrally heated, air-conditioned and the location of the house in relation to the natural conditions is not that important any more. Buildings' functional arrangement, shape, materials are hardly determined by natural surroundings, but by industrial products, technical and economical possibilities.

Buildings today are complex concatenations of structures, systems and technology allowing modern-day building owners to select lighting, security, heating, ventilation, and air conditioning systems independently ("smart buildings"). "Smart building is about living in a machine that cares about you" [33]. (Fig. 6.) Recent advances in data gathering and analysis are opening up new possibilities for smart building management systems (BMS) -saving energy through targeted supply. Sensors are increasingly being installed in buildings to gather data about movement, heat, light and use of space. Such information may ultimately be incorporated into real-time Building Information Modelling (BIM), enabling live data to be held in the data structures used to describe building design. The lifespan of a building is currently around 50 to 100 years, while digital technology changes over a dramatically shorter two- or five year cycle. The "smart" buildings should be created as a core infrastructure into technical "applications" can be plugged. The vision of the future buildings *connect* the various pieces in an integrated, dynamic and functional way is that building seamlessly fulfils its mission while minimizing energy cost, supporting a robust electric grid and mitigating environmental impact." [34] Whether is it enough for sustainability?

Figure 6 [34] Mechanical control of internal comfort

Last period something surprising has been recognized about many so-called “sustainable” buildings. When actually measured in post-occupancy assessments, they’ve proven far less sustainable than their proponents have claimed. In some cases they’ve actually performed worse than much older buildings, with no such claims. A 2009 New York Times article, “Some buildings not living up to green label,” [2] documented the extensive problems with many sustainability icons. Systems may appear to be well engineered within their original defined parameters — but they will inevitably interact with many other systems, often in an unpredictable and non-linear way.

That means we should look towards a more complex design methodology, combining diverse approaches, working across many scales, and ensuring fine-grained adaptivity of design elements. We have to integrate skills and knowledge of “passive” and “smart” design elements into a more conscious comprehensive design process.

3. Consequences of technical integration

Design in contemporary architecture has become a lot more exploratory in recent years. Digital architecture and huge amount of construction products allows a diverse range of complex forms to be created. As technology evolves and software becomes more powerful, it enables architects to explore new possibilities. Introducing 3D software into the architectural design process has allowed contemporary architects to explore new depths and push design boundaries. The huge number of Information Technology Building Industry products (CAD etc.) gives architects the feeling that almost any geometrical shape may be physically realized. Consequentially, professionals envision increasingly unusual building types. (Fig. 7.) Houses are more often than not, too complicated and too expensive.

Figure 7 [20] Vision of a future city and built heritage of Budapest

Every building project involves the choice of building materials. Recently, we have thousands of new artificial materials and structures sold all over the world while the functions of our buildings have been changed and expanded. Selecting suitable building material options is a very complex process, being influenced and determined by numerous preconditions, decisions, and considerations. Likewise, multiple factors (cultural, economic, ecological etc.) should be often considered by the architect when evaluating the various categories of building materials. As a result, these sets of factors or variables often present trade-offs that make the decision process even more complex. Cautious consideration of contextual preconditions is crucial to defining appropriate building materials or products.

Database is the basic component of contemporary engineering calculation. The database information can be labelled according to data content, type of data affiliated in a computer program, the targeted group of stakeholders etc. Earlier database was an experience based system. Each stakeholders added their knowledge and information into the project. Elements of database were visible and accessible in documentations, maps, catalogues etc.

As part of globalization the building elements - materials and components - are arranged on internet through some product oriented building element basis. Clients may select structures and materials as they compile their specification. These extensive catalogues are continually being updated with specifications covering most common products. It seems to be used easily and quickly, but architects have some difficulties in choosing the best product from these databases because of the huge amount of elements (one database division – e.g. thermal and moisture protection - could contain more than 10 000 enterprises and their products!). (Fig. 8.) Comparison the data of several products sometimes is problematic because of the different background (standards, measurement methods, units etc.). In these databases there is no information on application of structures and materials according to the local conditions.

Figure 8 [35] Product oriented architectural database

The computer database programs through Database Management Systems (DBMSs) are a ubiquitous and critical component of modern computing. [3] A typical DBMSs needs to be compatible with many different connectivity protocols used by various client drivers. Computer Models can be created in 3D, and manufactured directly from the 3D data. Computer modelling programs rely on "sets of numbers stored in electromagnetic format. The computer database architecture is the set of specifications, rules, and processes that dictate how data is stored in a database and how data is accessed by components of a system. The digital database architecture includes data types, relationships, and naming conventions, describes the organization of all database objects and how they work together. This knowledge is implemented during the selection, designing and inspection of materials and construction components. The structure of computer databases is hidden, the architect can use it through the Dialogue Boxes, windows. (Fig. 9.) The storage and access of these data depend on the computer program so these are available only for those clients who have the appropriate software. These databases require the high level awareness of applied parameters and suitable computer program.

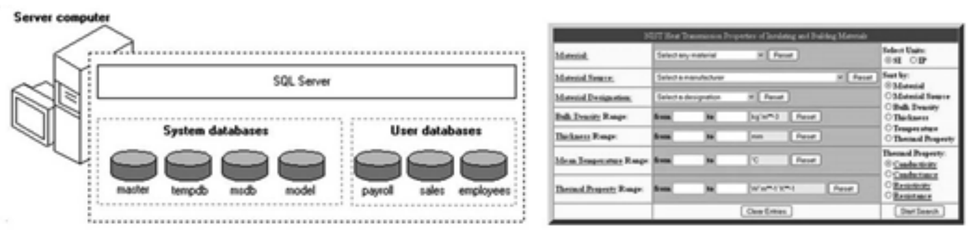

Figure 9 [36.] Computer Database Management Systems

Computer Analysis and simulation programs modelling environmental, technical and economic forces in order to quantify performance and enables us to analyse multiple design options.

Computer Aided Design systems (CAD) make the construction and drawing of building plans rapid and accurate. Projected physical dimensions and surfaces may be changed very easily. Architects – in theory - could have more control over the building design process, based on “freedom” of shaping, modification through computer modelling, simulation methods of reality. This technique does seem to be very accurate, but sometimes it can be difficult to recognize relation in between several calculation methods and parameters. Separated simulation computer algorithms sometimes result with reductionism (reductionism in science says that a complex system can be explained by *reduction* to its fundamental parts) replacing the holistic ("The whole is different from the sum of its parts" [37]) approach, because measures of building construction are separated in independent processes and complex, comparative analysis of requirements and product performances in the context of the whole is missing. (Fig. 10.) It can be sometimes problematic because of interaction in between of several parameters.

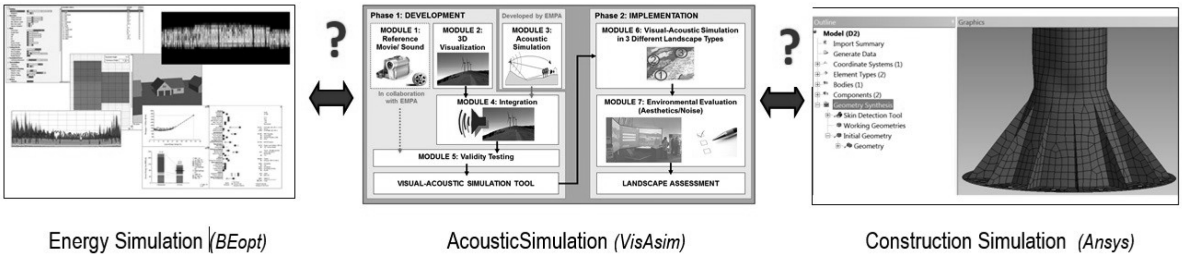

Figure 10. Computer simulation programs

4. Conclusions

According to the new aspects and tools, the architectural design process must become more conscious. Recently our main task is not only to create new technical variations, but to re-define a really conscious, continuously step by step controlled design process taking into consideration whole complexity of all available social, cultural, functional, economic, natural, structural, material and technological data, while providing permanent holistic control over the decisions. Design plays a very important role in architecture, not just aesthetically, but technically as well.

Careful consideration of surrounding impacts (climate: sunshine, temperature and wind, soil mechanics etc.) from the earliest stage of the design process can have an enormous impact on reducing subsequent operating costs and protecting our nature. The way we build should be in dialogue and reflect with local conditions instead of working against the surrounding nature. Traditional architecture relating to the climate utilizes natural conditions for the benefit of human comfort. These traditions could help us to develop really environmental friendly design decisions of contemporary architecture.

Buildings we design should be adapted to its real environment both in shape and structure providing maximum internal comfort and at the same time minimum harmful environmental impact. This seems to suggest that there is a need for developing a systematic structural and material selection system [4, 5] that will enable architects identify and prioritize the relevant criteria to effectively and accurately evaluate the trade-offs between social, technical, environmental, economic and performance issues during the construction evaluation and selection in design process.

Ibuchim Ogunkah and Junli Yang (2012) define material selection of vernacular buildings based on comparative analysis [6]. Their of the collected data pointed out that there are significant changes in building performance across countries, given their differences in building code restriction level in the use and mutual recognition of performance of materials, geographical and environmental conditions. (pp 19) (Fig. 11.) They holistically aim to develop a set of useful knowledge bases and structured ‘selection’ systems that will serve as the basis for evaluating such building materials in terms of their sustainability, during the design process of a building project. This research consists of a suggested toolkit of material selection.

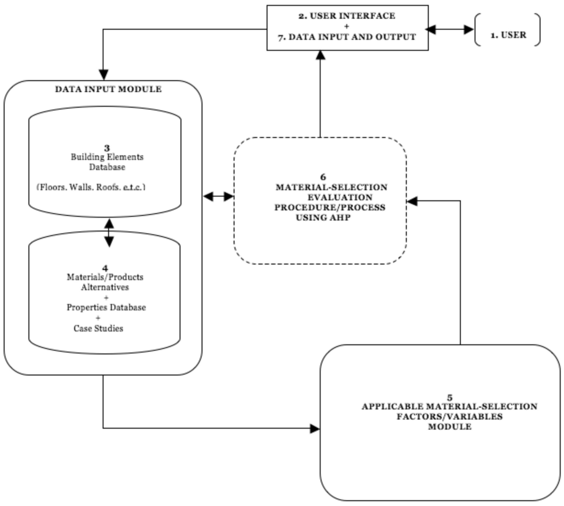

Figure 11 [6]Conceptual Model of material selection toolkit.

Therefore, to enable a structured and more comprehensive approach in the design-decision making process, it is important that the design-decision maker (architect, designer or expert) takes into account several material-selection factors or variables in order to facilitate the processes of comparing and identifying the best material option(s) across different categories. Actually the difference is how the designers interprets, synthesizes, and evaluates the collected data and techniques in their design process as result of all their perceptions, aims, convictions and skills.

Systematization and integration of all relevant information into creative design process is a crucial part of contemporary architecture. By re-thinking the architectural design process as a coordinated set of stages and sub-stages, replacing the traditional experience-related process by a more rational, and theory based approach choices and solutions for specific design problems, traditionally taken base on experience or individual thinking, can be now taken base in complex awareness and attentive to potential alternatives. [7] Preventive and remedial measures and decisions of architectural design process should always be evaluated in the context of the whole. (Fig. 12.) The house should be approached as a complete system, with specific features and performance requirements, not as a collection of independent industrial engineering disciplines (electrical, mechanical, structural, and so on), as an integrated part of a process in dialog with the surroundings and its inhabitants. Holism (from ὅλος *holos*, a Greek word meaning *all*, *whole*, *and entire*, *total*) is the idea that all the properties of a given system (physical, biological, chemical, social, economic, mental, linguistic, etc.) cannot be determined or explained by its component parts alone. Instead, the system as a whole determines in an important way how the parts behave. The idea has ancient roots. [37]

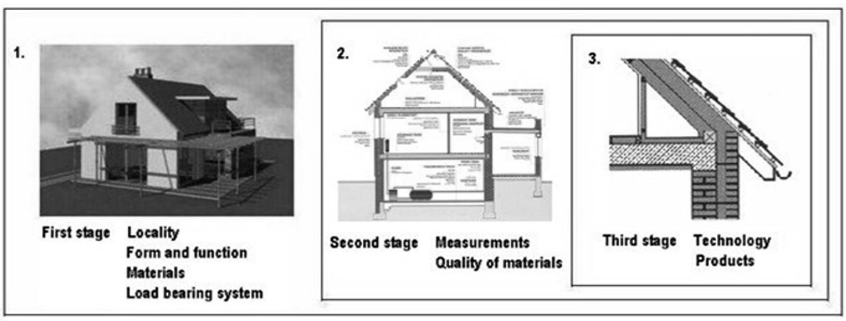

Figure 12 [8, 9, 10] Stages of holistically approached architectural design process

Analysis of impacts, requirements, and structural performances of each design stage can be the common ground of the dialogue between the architect and the experts according to the Performance Based Design method (PeBBu - CIB) [11]. (Fig. 13.) In Performance-Based Building Design evaluation of each design factors and aspects focuses on demands and on required performance in use.

Performance requirements translate user requirements in more precise quantitative measurable and technical terms, usually for a specific purpose. Steps of evaluation process are given below. Order of the performance based structural evaluation steps cannot be changed and need to be worked out for each condition (effect) due to the interaction of the parameters. We have to take into consideration the whole complexity of aspects and available data during the design process

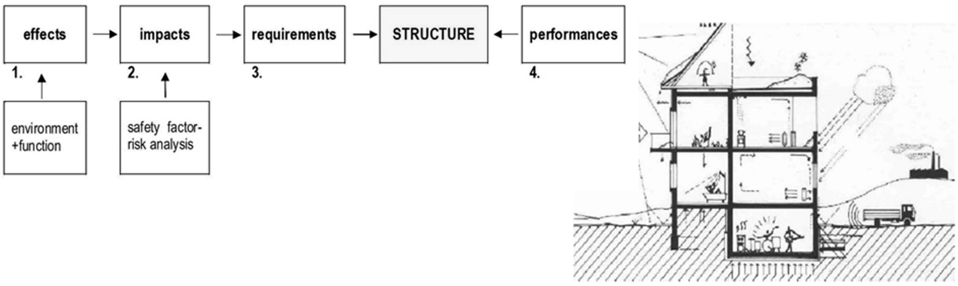

Figure 13 [12] Performance based evaluation method of architectural decisions

Efficiency of design process depends on the adequacy of the data applied. Architectural decisions can be correct if they are based on a comprehensive, real, and up to date and appropriate Database. [13] Database is always unique and local. The essential part of the decision process is a properly modifiable Project-oriented Site-specific Database, continuously fitted to the project, consisting of real, up to date and comparable data. (Fig. 14.) In this Database system, the compilation of information - according to the project and site - starts at the beginning of the design process, with the collection of the basic data of social, cultural, functional, natural, structural, material, economical, technological information. This multilevel database should be fitted to the project from the preliminary plan until construction phase. The applied systemized parameters should be controlled and consciously selected.

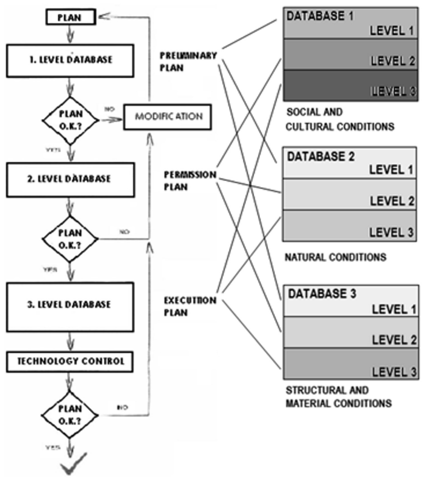

Figure 14 [14, 15] Project oriented complex database

The Holistic Performance Based design method responding on the surrounding conditions integrates skills, knowledge and tools of “passive” and “smart” design elements into a more conscious complex design process. In this design process the computer aided technologies are tools for architect, but not independent creative “intelligences” far from the human attitudes and real natural circumstances.

Holistic Performance Based (HPB) design process provides awareness whole complexity of technical knowledge for architects. By this way, the architectural and structural decisions made through the evaluation of real parameters and the complexity of the measurement will be more secure. As the attached figure shows the freedom of choice is the highest in the beginning, because later the decisions had been done earlier limit modifying of particular elements. As the project takes shape and becomes more detailed the degrees of freedom and the possibilities of choosing better alternatives are reduced. This complex attitude should be an integrated part of the designing process from the very first step. (Fig. 15.)

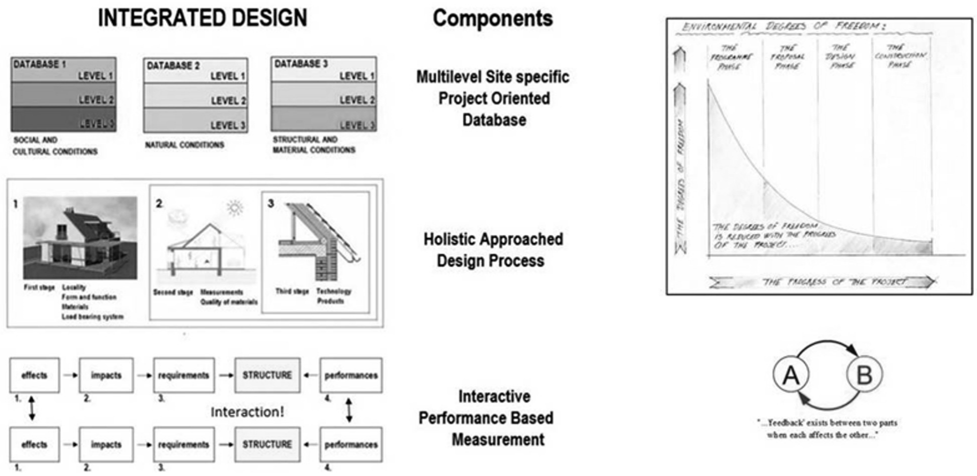

Figure 15 [16] Components of complex integrated holistic performance based architectural design

Matching of preliminary environmental parameters and required building parameters by holistic performance based evaluation method according to the multilevel project oriented site specific database is the basis of this complex design process. (Fig. 16.)

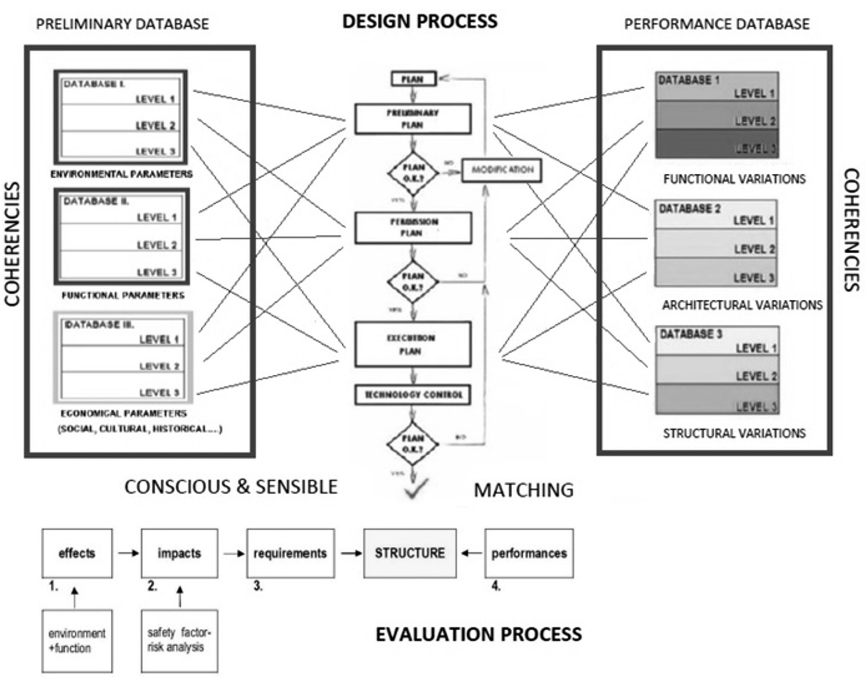

Figure 16. Summary of complex holistic performance based architectural design process based on the continuously fitted database system

This method could be used not only in design practice, but in university curriculum as well. [17, 18, 19] Tutorial practice should help students to discover how architects can capture locality, and how they can build databases to be used from the very first step of the design process. This teaching method should be always a multidisciplinary effort joining not only the various branches of architecture, but also involving IT specialists, meteorologists, civil engineers, economists, etc. We have to provide integration of several design aspects, requirements and tools into creative design process based on well systemized and determined site specific comparative database to achieve an optimum architectural and structural solution fitted to the given circumstances and demands.

ERASMUS program at Budapest University of Technology and Economics helps not only Hungarian but foreign students as well to use the complex holistic design method in their design tasks. In the comprehensive design studios the teachers of several professional fields help student to develop step by step their own optimum version for the given design program. Students match the environmental (natural, social, functional, economic) parameters to the possible architectural, functional, and structural solutions. (Fig. 17.) This conscious design process allows them to define and compare design choices in connection with performances of building and surroundings, to recognize, that each requirement criteria has different priority in several design situations.

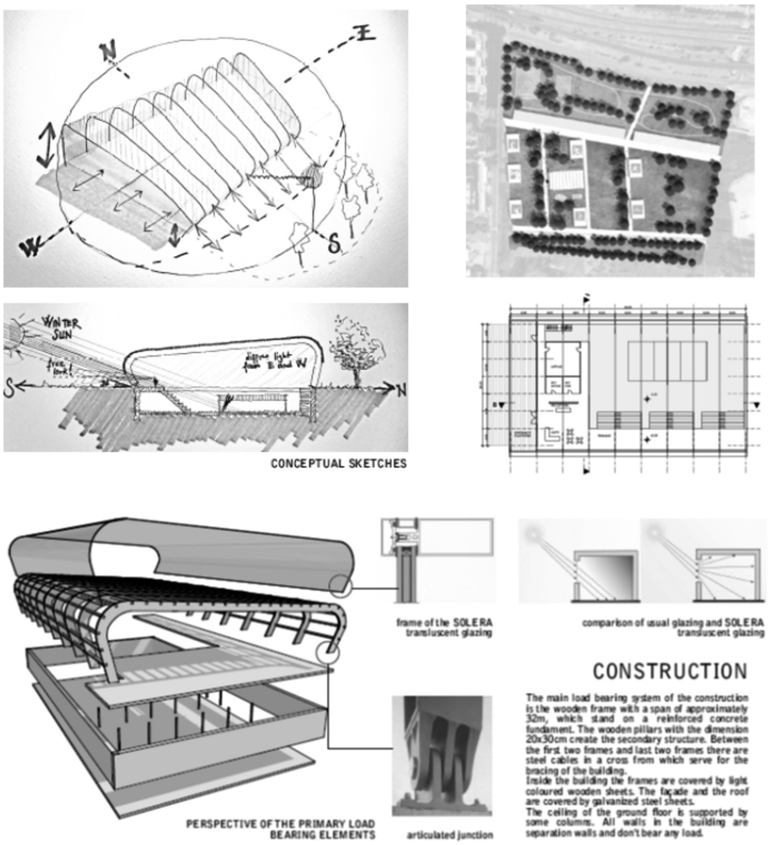

Figure 17 *Student's semester project according to on complex integrated holistic performance based teaching method [19]*

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To Follow Or Not To Follow Design Standards: A Question For Sustainable Coastal Engineering

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Abstract

This paper is concerned with what a contractor should do to fulfil his design obligations under a construction contract to assist the fulfilment of a sustainable design and/or end product. It considers this in relation to a recent Court of Appeal case law concerning coastal engineering, as this is an area where sustainability is at the forefront. This area concerns the use of relatively recent technology. It is not always clear from the provisions in construction contracts servicing recent technologies, how contractors can be protected from legal liability, even when the designer has apparently done all that is required under the contract. This is illustrated by the recent case law MT Højgaard A/S v E.ON Climate and Renewables UK Robin Rigg East Ltd and another [2015]. This paper will examine, the guidance in this Court of Appeal's judgement regarding a contractor's liability for design involving a fitness for purpose obligation, and the extent to which this may be tempered by other terms in the contract. This paper will combine such guidance with an explanation of the legal approach to the analysis and construal of contracts. In doing so, this paper will attempt to address questions which often arise concerning a contractor's design liabilities, such as, should a party to a contract follow the letter of the contract or should they follow standards set by professional organisations when carrying out their design task, and what should the parties do if there is a conflict between the terms of the contract and design standards?

Overall, it will evaluate how any conflicts may be removed with reference to current law and professional practice. The recommendations are applicable to all with design obligations. In summary they are that the proposed contract should be analysed by both parties to consider the various interpretations of provisions. To avoid disputes, a common interpretation needs to be agreed on in advance of entering into the contract. The conditions of a contract need to be clearly identifiable within the contract, unambiguously stated and a hierarchy and interpretation agreed upon by all parties to the contract in advance of the contract's application to the project.

Keywords: fitness for purpose, contract, design life, engineering

1. Introduction

Sustainability in construction is concerned with design, construction and operation, but also with contracts to enable such events and to avoid chaos. As Hibberd (2015) said, until ‘consideration of matters related to sustainability’ are ‘an intrinsic and an inherent component of one’s thinking – not a separate consideration’, contracts and especially the accompanying guidance on contracts’ will continue to play a very important role. He makes the seemingly obvious point that the contract should reflect the decisions which should have been made, however, in practice, this is not often straightforward. The process of agreeing an appropriate and effective contract is complicated by new technologies and innovations. The performance/sustainability of the structure and/or components may be uncertain. The performance, for example, of wind turbine foundations is subject to variables, which cannot always be predicted. As Scottish Development International (2010) reports:” Stable sea conditions are required for foundation installation and increased downtime is therefore to be expected with projects further offshore and in deeper waters.” (p.27). This paper considers a recent judgment of Court of Appeal which concerns the design life of the foundations of wind turbines and the design liability of its contractors. It is particularly important for designers involved in costal engineering construction projects understand their legal responsibilities and check that their contracts protect them from liability where possible. This may avoid delays, assist an efficient realisation of a smart sustainable construction, and avoid costly arbitration or litigation. It is also important to consider this because, as reported by O’Keeffe and Haggett (2012), offshore wind is likely to make the single biggest contribution towards UK government renewable energy targets across the UK because the UK has over 33% of Europe's potential offshore wind resource, with the majority of that resource lying off the coast of Scotland (p 3711).

Coastal engineering and construction contracts, including those used in the offshore oil and gas and wind farm sectors, often involve the use of design and build type contracts where the contractor is given responsibility for both the design and the construction itself. In such cases, it is increasingly common for employers to insist on absolute warranties. Many of the popular standard forms, such as the LOGIC standard contracts, include absolute fitness for purpose obligations. Contractors who accept these provisions should be aware that there is a high risk of potential liability. The contractual obligation that the work will be fit for purpose is quite different from the reasonable skill and care obligation that is more usually undertaken by designers of constructed facilities. It involves a strict liability regardless of fault. However, the all-important question in every case is "fit for what purpose?" Another question that arises with design contracts is what is meant by standard phrase design life, in the context of the contract? As Michael Curtis QC (2014) stated in his recent article, “There is no single definition that applies in all contexts.” (p1) With large projects and with coastal engineering projects the meaning of key phrases in the context of the purpose that the contractor has to achieve may be unclear. This is because it often has to be deduced from a collection of contractual documents of different authorship, containing ambiguous wording.

It is therefore not always clear from the contract, how contractors with design and build contracts can be protected from liability, even when the designer has apparently done what is required under the contract by strictly complying with the international recognised design standards referred to in the contract. This is illustrated by the recent case law MT Højgaard A/S v E.ON Climate and Renewables UK Robin Rigg East Ltd and another [2015]. The Court of Appeal judgment has helped to clarify how a designer can work out what he should do to avoid liability when things go wrong. But this is not enough. A contractor also needs to understand how contracts are construed and interpreted by lawyers, particularly by judges, as well as how key provisions are interpreted. This paper will therefore consider, with reference to case law, how designers may ascertain their legal obligations when there are conflicts between the terms of the contract concerning the designer's obligations and the design standards. It will assess current legal practice and provide guidance to contractors to assist them with working out the extent of their legal obligations under contracts regarding design.

This also requires consideration as to how contracts are interpreted by the Courts, whether there is a hierarchy of terms in a contract, and where there is a conflict, that is, inconsistency or ambiguity, between terms, how to assess which term has precedence in determining the designer's professional obligations.

2. Key Case Law

2.1 Facts: MT Højgaard A/S v E.On Climate And Renewables UK Robin Rigg East Ltd & Anor [2015]

Firstly, this paper will consider guidance given by the Court of Appeal in the currently leading case in this matter, MT Højgaard A/S v E.On Climate And Renewables UK Robin Rigg East Ltd & Anor [2015] EWCA Civ 407 (30 April 2015) (MTH). The Court of Appeal is the second highest court in the United Kingdom just above the High Court. In this case, the Court of Appeal was asked to reconsider the decision of the lower court, the Technology and Construction Court (TCC), which is part of the Queen's Bench Division of the High Court.

In 2006, E.On Climate and Renewables UK Robin Rigg East Ltd and E.On Climate and Renewables UK Robin Rigg West Ltd ("E.ON") entered a contract for €100 milllion with MT Højgaard A/S (MTH) to design, fabricate and install the foundations for 60 wind turbine generators at the Robin Rigg offshore wind farm in Solway Firth. This firth forms part of the border between England and Scotland, between Cumbria (including the Solway Plain) and Dumfries and Galloway. It stretches from St Bees Head, just south of Whitehaven in Cumbria, to the Mull of Galloway, on the western end of Dumfries and Galloway.

The Contract required MTH to carry out the Works with due care and diligence, and to ensure that they were fit for purpose. MTH's designer, Rambøll had relied on the international standard DNV-OS-J101 (J101) when carrying out the design of the foundations and the grouted connections. The reason he did this is because the fitness for purpose requirement in the contract was determined in accordance with the Specification, that is, the Technical Requirements, using

Good Industry Practice. The latter is generally defined to mean performance with the skill and prudence to be expected of an appropriately skilled and experienced contractor, in a manner consistent with recognised international standards. An objective test is applied. This is explained and elaborated upon in joint publication with Scottish Renewables (2015) at p. 4. The Technical Requirements specified that MTH must comply with the internationally recognised standard DNV-OS-J101 ("J101"). It also included a requirement that the foundations would have a service life of 20 years. So MTH complied with the contract by following J101. However, J101 contained a fundamental calculation error. MTH's designer, Rambøll was unaware of this when it carried out the design, (as were designers in general at this time). (But the fact that no-one knew the standard was faulty did not assist MTH at the TCC hearing.)

In 2009 it was discovered that movement was taking place in the grouted connections at a Dutch offshore wind farm which had a similar design to that at Robin Rigg. Shortly after completion of the works, the grouted connections in the foundations started to fail. The error in the J101 standard had resulted in a significant overestimation of the axial load capacity for wind turbines with grouted connections. In April 2010 it was found that the wind turbines at Robin Rigg were suffering from the same defects. A scheme of remedial works was developed and the remedial works were commenced in 2014. The parties agreed the cost of the remedial works which amounted to €26.25 million.

2.2. MTH: Technology & Construction Court (High Court)

E.ON then took MTH to the Technology & Construction Court for breach of contract, claiming damages for the cost of the remedial works. Mr Justice Edwards-Stuart found that MTH had indeed exercised reasonable skill and care and that it had complied with the DNV-OS-J101 standard. Neither party had been negligent. The problem, the judge said, was that the Contract and Technical Requirements stated that "The design of the foundations shall ensure a lifetime of 20 years in every respect…" The judge said that meant the contractor had warranted that the foundation structures which it designed and installed for an offshore wind farm would have a service life of 20 years. But they clearly did not fulfil this promise, as the foundations had failed shortly after completion.

The Court's reasoning relied on its examination of certain paragraph in the contract, viz., 3.2.2.2 (2) of the Technical Requirements, which stated that "The design of the foundations shall ensure a lifetime of 20 years in every aspect without planned replacement": and paragraph 3b.5.1 of the TRs which also stated that "The design of the structures…shall ensure a lifetime of 20 years in every aspect without planned replacement"; and clause 8.1 (x) of the Contract which required the contractor to complete the works such that the "Plant and the Works as a whole shall be free from defective workmanship and materials and fit for its purpose as determined in accordance with the Specification using Good Industry Practice." Note the mandatory language used, viz., 'shall' in each clause. This term is normally associated with absolute warranties. The TCC found that these clauses required MTH to provide foundations with a service life of 20 years; and that the failure of the foundations was therefore a breach of contract, including a breach of clause 8.1 (x)

Therefore, by accepting overall design responsibility for the Works, the contractor, MTH, although it did not do anything wrong, was held responsible for the risk of there being an error in the standard J101. The international standard did contain an error, which materialised, and therefore the High Court held MTH liable for the consequent damage.

2.3 Fair or Unfair?

You may consider this an unfair decision, as the contractor had been a good designer in following the approved design standard required by the contract. It does not seem right that it should be held responsible for the intrinsic error contained in the standard, which no-one knew about at the time of the damage. But in law, a warranty can be like a guarantee or entail strict liability. So it does not matter if you have done nothing wrong. You may still be liable because you agreed with your client that you would do things or provide certain things of a certain standard, which do not happen or turn out not to be of that standard, even though it is completely not your fault. If, for example, you tell your roofer that he should supply tiles which should have a ten year life and the roofer agrees to provide the tiles, but they do not last a year, because they were manufactured badly, then the poor roof tiler is responsible to replace the tiles at his own expense, even though, despite a reasonable inspection of the tiles he could not have known that they were faulty. Here the judge is saying that the contractor had warranted that the design itself, not the product that results from the design, would have a life of 20 years. Note the use of the mandatory words ‘shall’ in each of the paragraph referred to by the Court. This will usually indicate an absolute obligation, whether or not there is fault.

2.4 MTH: Appeal to the Court of Appeal

Luckily for MTH, the contractor, the Court of Appeal disagreed with the reasoning and decision of Mr Edward Stuart in the Technology and Construction Court. One would have thought the judiciary in the Technology and Construction Court were the experts in such matters, as this is a specialist court, however, when it came to the law and the interpretation of the contract the higher Court, the Court of Appeal knew better. It reversed its decision. Consequently, E.ON bears the agreed costs of the remedial works amounting to €26.25 million. They may yet seek leave to appeal to the Supreme Court. So how did this come about?

MTH had appealed to the Court of Appeal on the basis that the TCC’s interpretation of the Contract was wrong. E.ON then cross-appealed on the ground that MTH had committed other breaches in failing to carry our further testing prior to carrying out the Works, which would have discovered that there was an error in the J101 standard. Regarding the cross-appeal, the Court of Appeal did decide that MT Højgaard was in breach of the test data and experimental verification requirements, but it concluded that those tests would not have revealed the defects that had occurred, and therefore the breach did not cause any loss. Therefore, E.On was only entitled to recover nominal damages of £10 for its cross-appeal.

The Court of Appeal explained its view that the TCC’s interpretation of the Contract was wrong. It argued that the wording in Clause 8.1(x) that the works as a whole should be “fit for its purpose" was qualified by the phrase "as determined in accordance with the Specification using Good Industry Practice". It accepted that the Contract defined "Good Industry Practice" as requiring the exercise of reasonable skill and care as well as compliance with the DNV-OS-J101 standard. It concluded that MTH had exercised reasonable care and skill, and that they had followed the design standard.

The Court of Appeal particularly considered the wording in the Technical Requirements which said that "The design of the foundations shall ensure a lifetime of 20 years". The Court agreed that it was clear from the contract that MTH was required to assume full responsibility for the design as well as for the installation of the structures comprising the Works. However, crucially, the Court of Appeal made a very clear distinction between "design life" and "service life" saying that if a structure had a design life of 20 years, that did not mean that it would function for 20 years, that is, it didn't mean that it would have a service life of 20 years. What the Court said contradicted the TCC's decision that the contractor had warranted that the foundation structures which it designed and installed for an offshore wind farm would have a service life of 20 years. In other words, The Court of Appeal concluded that MTH did not guarantee or warrant that the foundations would have a 'service' life of 20 years.

This approach seems to be taking a literal interpretation of the words by limiting the guarantee to the design of the foundations. But surely this is not a common sense interpretation. Why would the client have agreed to that, when what is of vital importance to him is that the foundations will last for 20 years, e.g., "The design of the foundations shall ensure that the foundations have a service life a lifetime of 20 years [my inserts]". If the design is properly carried out, then the foundations' service life should be 20 years, just as in the case where you have agreed with your supplier that tiles he supplies must have a life of 13 years. This does not mean that there cannot be maintenance of the structure over time. There is no reason why this would detract from the obligation. The service life would end when it is not possible to replace one or more of the components essential for its operation.

The problem seems to be, as Curtis (2014) stated, that 'it is essential for a contract or specification to define precisely what the term design life is supposed to mean in the context in which it appears. Otherwise it is likely that the parties' expectations about its meaning will be very different . . .'(p 4). For example, does it mean that the foundations will function for 20 years without any maintenance or does it mean that the foundations will last for 20 years provided it is properly maintained? In reaching its decision the Court must also consider the other provisions of the contract as well as the construction of the contract as a whole, and so to shed light on the Court's reasoning for this decision, this paper will consider how the court goes about doing this.

3. Contract Interpretation

3.1 The intentions of the Parties

Firstly, it should be noted that the parties' negotiations prior to a contract being agreed are irrelevant, when determining the interpretation of contract provisions. In Chartbrook Ltd -v-Persimmon Homes Ltd [2009] UKHL 38, the House of Lords confirmed that that evidence of pre-contractual discussions should not be used as a tool of construction. However, relevant background fact or statement known to both parties may be relevant where a party claims that the written contract should be corrected to reflect the terms that were 'actually' agreed by both parties. The Court or Tribunal also does not take the subjective intentions of the parties into account when interpreting the contract. It is not interested in what they 'say' they intended to agree. Rather, the law uses an objective approach to interpretation. It will first give the words of the provision their natural meaning, so that the words that were actually used in the contract are be construed in the way that they would be understood by a (hypothetical) reasonable person, with the background knowledge available to both parties at the time the contract was made. The approach is not concerned with the way each party may argue they were used: Chartbrook Ltd -v-Persimmon Homes Ltd [2009] UKHL 38. It will then consider how the provision fits into the contract as a whole, i.e., what do the words really mean in the context that they were used?

So the trend in recent case law is that the actual language used in the contract is given priority, unless the language is ambiguous or unclear. This approach is apparent in the judgment of the Court of Appeal. It provides a useful summary of the principles of contract interpretation. In a key passage, at para 87, the Court's judgement delivered by Lord Justice Jackson states that, "a court seeking to construe the contract between E.ON and MTH must postulate a reasonable person (X) having all the knowledge available to those two parties. The court must consider what X would have understood clause 8.1 of the conditions and TR paragraph 3.2.2.2 (2) to mean. This is an iterative process, which involves checking each of the rival meanings against the other contractual provisions and investigating its commercial consequences".

The Court of Appeal did agree with arguments that the fitness for purpose requirement was determined in accordance with the Specification (the Technical Requirements) using Good Industry Practice, which, in summary, meant performance with the skill and prudence to be expected of an appropriately skilled and experienced contractor, in a manner consistent with recognised international standards. The problem, the Court argued, is that the Technical Requirements are inconsistent with the Contract conditions which required "due care, professional skill, adherence to good industry practice, and compliance with the Employer's Requirements. But the Court found this resolvable since the contract had provided a hierarchy of terms.

3.2 The Hierarchy of Terms in a Contract

It is usual with complex commercial contracts for a number of people to be involved in negotiating the different parts of the contract. This can make it challenging to know which terms, which are given in provisions of the contract, should be given priority over others, if there is any conflict in the language or interpretation. The contract will consist of a number of contractual documents, prepared by different people. These will include for example, the main terms and conditions, as well as/or technical requirements, specific schedules or appendices that deal with certain issues such as 'defined' terms, payment arrangements, service levels and the delivery timetable especially on larger projects. But it is not always clear which are the most important terms to be followed where there is conflict between them. So the parties often insert a 'hierarchy' or 'order of preference' clause (also referred to as a provision) into their contracts to safeguard against potential discrepancies between an agreement's various provisions and parts of the contract. Such clauses typically provide that, in the event of a conflict or inconsistency between the language and terminology used in contractual provisions (in this case "design life", "service life" and even "lifetime"), or parts, certain clauses or parts will prevail over others to resolve the conflict. However, the Courts do not jump straight to this hierarchy clause. They first attempt to reconcile any contradictory or overlapping clauses.

Recent Court cases demonstrate that the Courts are reluctant find that the contract documents are inconsistent with each other. They would rather attempt to give effect to an interpretation which avoids this, or reconciles any conflict: RWE Npower Renewables Ltd v J N Bentley Ltd [2014] EWCA Civ 150. The Court's judgment in MTH Højgaard A/S explains that in the contract in question, where there is inconsistency between terms of a contract, the terms which are the 'contract conditions' must be followed, because the hierarchy of terms clause says that the contract conditions are above the Technical Requirements in the contractual hierarchy of terms. The Court seemed to be implying that the TCC did not seem to have considered the order of hierarchy of the provisions of the contract when considering the contract as a whole.

The Court of Appeal found that clause 5.3 of the contract provided that the contract conditions which required "due care, professional skill, adherence to good industry practice, and compliance with the Employer's Requirements, take precedence over other contractual documents, and the Employer's Requirements came fourth in the order of precedence. The judgement noted at par 102 that the phrase "Good Industry Practice" is defined in the List of Definitions (a document which has parity with the conditions of contract in the order of precedence) and that although obligation requires the exercise of reasonable skill and care, as well as compliance with J101, it did not require or impose any form of warranty as to the length of operational life. Since the contractors had complied with these contract conditions they had fulfilled their obligations, despite the fact that the international standard was flawed.

The Court of Appeal argued that the overall drafting of the Technical Requirements was inconsistent with an intent to impose an absolute guarantee of a 20 year operational lifespan, since the 'detailed' 'input' requirements of the Technical Requirements (which required, among other things, compliance with J101) were inconsistent with an 'output guarantee' of a 20 year lifespan.

The Court concluded that one could not conclude that MTH gave a warranty requiring a 20 year service life (as opposed to design life) based on the individual provisions of the Technical

Requirements (para 106). The Court finally added that a reasonable person in the position of E.On and MTH would know that the normal standard required in the construction of offshore wind farms was compliance with the international standard, but that such compliance was not absolutely guaranteed, to produce a 'service' life of 20 years (para 104).

4. Discussion

So after deciding that the hierarchy of terms clause resolved this matter, the Court seems to cover its tracks by also justifying their decision by referring to the objective approach, the views of the reasonable man in the position of the parties. Firstly, regarding the hierarchy of terms clause, it has been recently held in RWE Npower Renewables Ltd v J N Bentley Ltd [2014] EWCA Civ 150, that it is only where there is a clear and irreconcilable discrepancy that the hierarchy clause should be resorted to. Effectively, it is a clause of last resort, not first resort. A clear and irreconcilable discrepancy does not seem to have been identified. It may be argued that the Court has not reverted to the hierarchy clause as a last resort, and its decision may be open to appeal on this point

Designers clearly must do what is required under the contract according to the standard required under the contract, to which they have supposedly agreed. Whether or not the designers will be successfully sued for damages for breach of contract for the consequences of errors in the design standard they could not have been aware of, will depend on the standard of care required by the contract. However, where a design standard is required to be followed, and the quality or duration of the standard of care required is uncertain due to conflicting wording in various provisions, or because of the effect of other provisions in the contract, it may be difficult to ascertain what were the intention of the parties at the time they made the contract.

It is unusual for a professional designer to agree to a guarantee his design will be fit for purpose or that the design life will be fit for purpose. However, a contractor, in a design and build contract is responsible for the design as well as building it, and is required to produce a structure fit for purpose- whether it is a bridge or wind turbine generators. This goes to the root of the contract. Unless the structure can do the job it is of no value. However the Court of Appeal seem to have got around this difficulty by arguing that there is a difference between the design life and the service life of the structure. But this seems to contradict current knowledge. It is standardly accepted that wind turbines are typically designed for a 20 year design and service life. For example, Windmeasurmentinternational states that 'Every machine has a set design lifetime based on how long the parts are expected to last. . . . The components of a wind turbine are typically designed to remain operational for twenty years.' So both the design life and the service life should be at least 20 years. This reality contradicts the view of the Court of Appeal which focuses much more on the construction of the provisions in the contract, rather than on a prior investigation of the commercial reality, The latter, as the above explains, indicates that it is likely that a reasonable man in the position of the parties would have intended to agree to guarantee a design and service life of 20 years. The Court of Appeal in MTH does not clearly seem to have considered this.

The Court did refer to some helpful guidance about the construction of contracts, even if it did not take it too seriously. Lord Jackson in the Court of Appeal cited the judgment of Lord Clarke in Rainy Sky SA v Kookmin Bank [2011] UKSC 50;[2011] 1 WLR 2900 who observed that "...if there are two possible interpretations of a provision, the court is entitled to prefer the construction which is consistent with business common sense". What makes more sense than for the contractor to be liable for a 20 design and service life of a turbine when this is standardly accepted by the industry as normal?

Lord Jackson also cited the judgment of Lord Collins SCJ in the case of Re Sigma Corp(in administrative receivership) [2009] UKSC 2; [2010] 1 All ER 571 in which it had been held that an "...over-literal interpretation of one provision without regard to the whole may distort or frustrate the commercial purpose". In this paper's view, both the views of Lord Clarke and Lord Collinscould have been considered more seriously, with more attention given to the commercial realities, when attempting to ascertain the intentions of the parties at the time they entered the contract. This step should have determined the outcome of the case.

4.1 Recommmendations

With complex projects or those involving new technology, it is worth paying for the extra time and fuss involved in having an experienced lawyer to ensure that contracts are clearly drafted to reflect the precise agreement between the parties, as accurately as possible. This will avoid incurring far more costs further down the line.

The proposed contract should also be analysed in the context of addressing the following questions. Are any of the provisions relating to design responsibilities open to misinterpretation or ambiguity? Could a provision be read in different ways? What do the clauses mean in the wider context of the contract as a whole? Could the provision be misunderstood? Consider how the provision could be applied to what may go wrong. Is this the application you intended?

Where there are conflicts between the provisions of the contract, and a hierarchy of terms clause/provision is not given in the contract, then the conditions of the contract will somehow need to be identified. They go to the heart of the contract, and so what they say impliedly takes priority over other provisions. But identifying which provisions are conditions should not be left up to the Courts. They may not get it right, with resulting further appeals, costs and delays to projects. To avoid such disasters, it should always be clearly stated in the contract what are the condition of the contract, i.e., 'It is a condition of the contract that …' and if some of the provisions have similar or conflicting wording, then it needs to be clearly, unambiguously stated in the contract which ones which ones have priority, should a conflict arise. All parties to a contract should be made be given clear notice of the conditions and priorities of provisions in the contract before agreeing to it or signing it. Such notice should be in writing through legal representatives to avoid disputes along the lines that these are unusual provisions which were not drawn to attention. If there is any likely conflict regarding the interpretation of the words or phrases in a contract, this must also be sorted out before the contract is agreed. One interpretation of them should be agreed by the parties.

It is therefore recommended overall, that where a clause is of vital importance to the employer or contractor, that party needs to obtain agreement with the other party to the effect that it does have such importance, and then, this must be highlighted in the contract. This means that the wording in the clause should be very clearly stated and the clause marked in a prominent position as the main condition of the contract having priority over all other conditions of the contract. For example, if E.ON had really wanted an absolute binding 20 year service life warranty, to avoid later argument, it should have insisted on that provision featuring prominently and unambiguously within the conditions of contract, rather than being closeted away in the Technical Requirements.

5. Conclusions

The MT Højgaard A/S case demonstrates the problems that can arise with complex contracts when various documents from different sources are incorporated at different levels into a contract. Contractors/designers need to assess their potential liability regarding inconsistencies between them, and attempt to remove any inconsistencies before agreeing to the contract.

The Court of Appeal supported the previous comments of the High Court that if the contract wording is sufficiently clear, an express obligation to construct a work capable of providing a 20 year service life can override the obligation to comply with the plans and specifications, which includes complying with the design standard. Then the contractor would be liable for the failure of the work, notwithstanding that it had been carried out in accordance with the plans and specifications.

It must be clear from this paper that fitness for purposes obligations for contractors who are designers or designer-builders should be avoided, excluded or limited, if possible. This is because if the product fails, a party may be liable for all the damage incurred, even if they exercised reasonable skill and care, and even if they followed the stipulated design standards to the letter.

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Energy generation and matching in a net zero-energy building in Finland

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Abstract

All new buildings in the EU are to be nearly zero-energy buildings (nZEB) by the end of 2020. Energy efficiency, reduced demand, and onsite renewable energy systems, are key characteristics of nZEBs; when this features are combined, the generation from the supply systems may exceed the energy demand of the building. Such has been the case in the zero energy building named Villa ISOVER®. It integrates photovoltaic panels, solar collectors, a ground-source heat pump and grid interactions, and adheres to strict regulations by the National Building Code of Finland. As well, a monitoring system records data from several channels such as energy generation and demand measurements, which allows to analyse the generation, demand, import and export of energy. In this paper, the data is first used to calculate the zero-energy balance of the building. Next, two indices: the onsite electrical energy fraction (OEFe) and the onsite electrical energy matching (OEMe) are calculated. The OEFe indicates the proportion of the total electrical demand which is covered by the onsite generation, and the OEMe indicates the proportion of the total electrical generation which is consumed in the building and system rather than being exported or dumped. The seasonal and time-resolution dependencies of these indices as well as different calculation methods have been studied. A series of outcomes have been deducted based on the measurement data. The annual net energy consumption of this building in 2014 is 15 kWh/m2a, which is thus, strictly speaking, a nearly zero-energy building. Furthermore, both the PV generation and electrical load are seasonal dependent, though in reversed behaviour: while generation is high during summer and low during winter, the load is low during summer and high during winter. This contrast leads to poor annual OEFe and OEMe, at 16% and 22%, respectively. Said indicators are indeed sensitive to time-resolution, depending on the available measurements and calculation method: coarser time resolutions may lead to overestimations of the matching capability. Finally, the recorded exchange with the electrical grid is seasonal-dependent: the normalized net-exported energy can be as high as 60% during summer, and as low as -40% during winter.

Keywords: Zero energy buildings, real measurement, matching analysis, grid interactions, onsite photovoltaic.

1. Introduction

All new buildings in the EU are to be nearly zero-energy buildings (nZEB) by the end of 2020. Energy efficiency, reduced demand, and onsite renewable energy systems, are key characteristics of nZEBs; when this features are combined, the generation from the supply systems may exceed the energy demand of the building. While this may at first appear to be a beneficial situation, it may represent an unfavourable condition for the distribution grid, and even for the user. For the grid, handling the surplus energy can be a challenge during peak hours. This is particularly risky when photovoltaic panels are present, as solar power is usually available around noon, when the grid utilization is high. For the user, exporting energy may not be the most attractive option. Self-consumption tends to be the preferred way to use of onsite generated energy, as the savings from avoiding electricity purchases are usually larger than the income from selling excess electricity to the grid. Thus, attention should be paid to the match between energy generation and demand, so as to identify the proportion of the generation which may be consumed onsite, and to predict how high the surplus fed to the grid could be. The purpose of this study is to analyse the generation, demand and interaction with the grid of a nZEB in southern Finland, and to study the behaviour of match indicators based on different methods and time-resolutions.

2. Zero-Energy Building Villa ISOVER®

Villa ISOVER® is a building conceived by ISOVER® and Fortum® to test the performance of a zero-energy building and its interaction with the electrical grid. It is a single-family house with a 175 m² net floor area built for the Housing Fair 2013, which was the winner of a design competition. The building is located in Hyvinkää, southern Finland. It integrates PV panels, Solar-thermal Collector (SC), a ground-source heat pump (GSHP) and an air handling unit (AHU); there is no connection to an external heating network, as the GSHP and SC fulfil the heat demand. A key feature allowing this configuration is the highly efficient thermal insulation. Thus, the building follows the design principle of first minimizing consumption and then using the locally available energy resources to fulfil the remaining needs as far as practical. A monitoring system keeps track of several heat and electricity onsite measurements, such as PV generation, electricity import and export to the grid, heat generation by SC and GSHP, and domestic hot water (DHW) demand, among others. As well, solar radiation and inside and outside temperatures are monitored. The data has a time-resolution of 1 hour. The building is presented in Figure 1.

Figure 1: Villa ISOVER® depicted from four directions [ISOVER®, 2013]

3. Energy Monitoring and Matching Analyses

3.1 Energy Monitoring Analysis

The original recorded data is based on a recording resolution of 1 hour over the year of 2014. The PV generation after the inverter is depicted in Figure 2, where a significant seasonal dependence can be seen. During the summer time, peaks of a magnitude of 6-7 kW can be noticed, whereas during the winter time, the magnitude of the PV generation after the inverter is mostly lower than 1 kW. The recording system also records the grid interactions between the building and the electrical grid. The electrical power imported from the electrical grid to the house and the electrical power exported from the house to the electrical grid are both recorded.

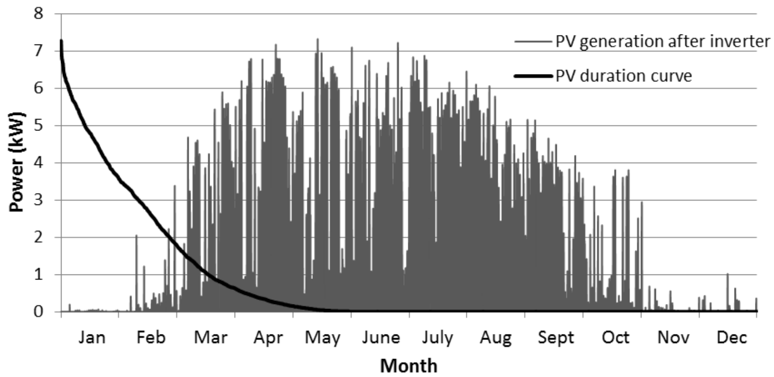

Figure 2: The recorded hourly PV generation after inverter

Figure 3 and Figure 4 depict the recorded hourly power imported from and exported to the electrical grid. As shown in Figure 3, the electrical power imported from the electrical grid also shows a seasonal-dependent characteristic. During the months of October to April, i.e. the winter time, the magnitude of the hourly electrical power imported from the electrical grid is between 0 kW and 5 kW. During the months of May to September, i.e. the summer time, the magnitude of the hourly electrical power imported from the electrical grid is within a range of 0-3.5 kW. The generally higher magnitude for the imported electrical energy in the winter time is mainly due to the higher heating load during the winter season, which can cause a more frequent operation of the GSHP and the AHU heating unit, as well as pumps and auxiliary equipment. On the other hand, during the summer season, the space heating load and the AHU heating load are quite low, and the DHW heating load can be mainly covered by the SC heating power, leading to a much less frequent operation of the GSHP and a lower total electrical consumption. Moreover, as shown in Figure 4, during the summer season the solar resource is sufficient, which means that the PV generation helps to cover the onsite energy load, which leads to less imported energy.

As can be seen in Figure 4, the hourly exported power to the electrical grid also shows a significant seasonal-dependent characteristic, with a much higher magnitude during summer than during winter. During the summer season, the exported power from the building to the electrical grid can reach a magnitude around 7 kW, whereas during the winter season, the exported power is mostly around zero. The main reason is that during summer, the electrical load is low due to the lower heating load, whereas the PV generation is sufficient due to the abundant solar resource. This leads to a significant export situation. During winter, the PV generation is quite low due to the poor solar resource in Finland, whereas the electrical load is very high due to the higher heating load. Therefore, during the winter season, most of the onsite PV generation will be consumed onsite, and almost nothing will be exported.

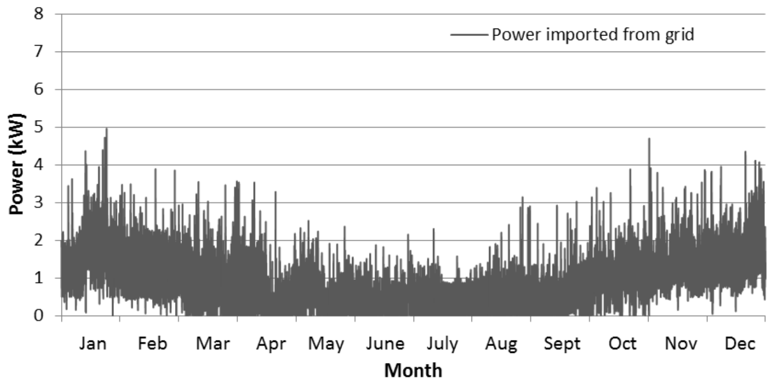

Figure 3: The recorded hourly imported electrical power from the grid

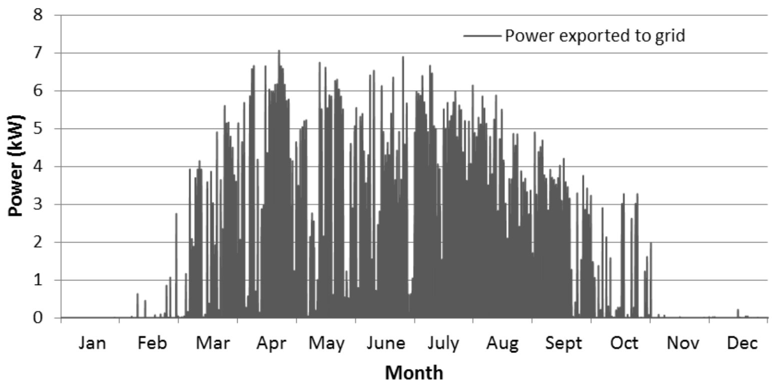

Figure 4: The recorded hourly exported electrical power to the grid

In addition, from the aforementioned hourly PV generation and the grid interactions, i.e. the hourly electrical energy imported from and exported to the electrical grid, the total electrical load can be correspondingly calculated via the following Equation (1):

$$L(t) = G(t) + I_p(t) - E_p(t) \quad (1)$$

Where the *G(t)* is the generation after the inverter, $I_p(t)$ is the electrical power imported from the electrical grid, $E_p(t)$ is the electrical power exported from the building to the electrical grid, and *L(t)* is the calculated total hourly electrical load. Figure 5 shows the hourly total electrical load calculated with Equation (1). The seasonal dependent characteristic can also be seen in Figure 5. During the winter season, the magnitude is mainly between 0.5 and 3 kW, while the peaks can reach 4.95 kW. During the summer season, the magnitude is mainly below 2 kW, while the peaks can reach 3 kW. The higher electrical total load during the winter season is mainly due to the higher heating load, which stimulates a more frequent operation of the electric heat pump.

Moreover, Figure 5 also shows a duration curve for the hourly total electrical load. It can be seen from the duration curve that peaks of 3-5 kW are actually quite rare in the electrical load. The maximum peak was 4.95 kW. There was only 0.09% (8 hours) of the year when the electrical load power was higher than 4 kW. There was only 1.2% (104 hours) of the year when the electrical load power was higher than 3 kW. Moreover, the percentage of time when the electrical load power is higher than 2 kW reached 10.4% (928 hours) ─ thus, still a quite small percentage for 2 kW. On the other hand, we can see that the percentage of time when the electrical load power is below 1 kW reached 57.5% (5033 hours), which indicates a base load level below 1 kW in the monitored building. By checking the ranges in the duration curve, it can be noticed that actually for more than 57% of the time (4974 hours) the electrical load is between 0.2 kW and 1 kW, which can result from the base load of ventilation fans, pumps, and the regular operation of household equipment such as refrigerator, freezer, and lights. Moreover, Table 1 shows the annual measurement data for the PV generation after the inverter, the annual imported electrical energy from the electrical grid, the annual exported electrical energy to the electrical grid, and the annual total electrical load.

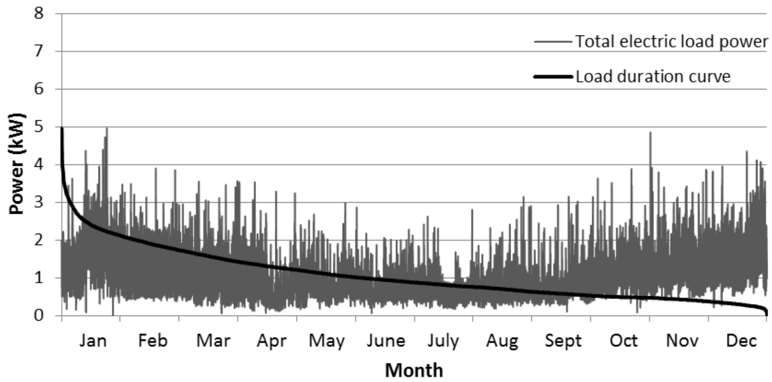

Figure 5: The hourly total electrical load and its duration curve

Table 1: The annual measured data concerning energy consumption

	Annual PV generation after inverter	*Annual electric energy imported from the electric grid*	*Annual electric energy exported to the electric grid*	*Annual total electric load*
Total (kWh/a)	*6612*	*7786*	*5149*	*9249*
Per unit area (kWh/m²a)	*38*	*44*	*29*	*53*

3.2 Energy Matching Analysis

From these recorded data, we can also calculate the matching indices and the grid interaction indices of the building. We use the onsite electrical energy fraction (OEFe) and the onsite electrical energy matching (OEMe) to analyse the matching [Cao et al. 2013]. The OEFe indicates the proportion of the total electrical load which is covered by the onsite PV generation, rather than imported from the electrical grid. The OEMe indicates the proportion of the total electrical generation which is consumed in the building and system rather than being exported to the electrical grid. There are two ways to calculate the OEFe and the OEMe:

Method 1:

$$OEFe = 1 - \frac{\int_{t1}^{t2} Ip(t)dt}{\int_{t1}^{t2} L(t)dt} \quad (2)$$

$$OEMe = 1 - \frac{\int_{t1}^{t2} Ep(t)dt}{\int_{t1}^{t2} G(t)dt} \quad (3)$$

Method 2:

$$OEFe = \frac{\int_{t1}^{t2} Min(L(t);G(t))dt}{\int_{t1}^{t2} L(t)dt} \quad (4)$$

$$OEMe = \frac{\int_{t1}^{t2} Min(L(t);G(t))dt}{\int_{t1}^{t2} G(t)dt} \quad (5)$$

Where the *L(t)* is the electrical load power, *G(t)* is the generation power, *Ip(t)* is the electrical power imported from the electrical grid to the building, *Ep(t)* is the electrical power exported from the building to the electrical grid. Method 1 is calculated by subtracting the proportion of the electrical energy which is imported from or exported to the electrical grid, whereas Method 2 is calculated by finding the minimum value between the generation and the load, which is the matched part between the generation and the load. From the illustration in Figure 6, Area I is the portion imported from the electrical grid; Area II is the portion exported to the electrical grid; Area III is the matched portion between the generation and the load. "dt" is the time-resolution used in the recording or the simulation system. If the recording system for certain building(s) includes the channels for the total PV generation (cumulative measuring system), the power imported from the electrical grid (cumulative measuring system), and the power exported to the electrical grid (cumulative measuring system), Method 1 can be used, and the results of OEFe and OEMe from Method 1 will not be influenced by the time-resolution. However, if the recording system for certain building(s) only includes the channels of the total PV generation (cumulative measuring system) and the total electrical load power (cumulative measuring system), Method 2 can be used; however, the results of OEFe and OEMe by Method 2 will be influenced by the time-resolutions, due to the averaging effect by comparing the generation and load. Moreover, it should be mentioned that when $\int_{t1}^{t2} L(t)dt$ is equal to zero, OEFe in Equations (2) and (4) should be equal to one, whereas when $\int_{t1}^{t2} G(t)dt$ is equal to zero, OEMe in Equations (3) and (5) should be equal to one.

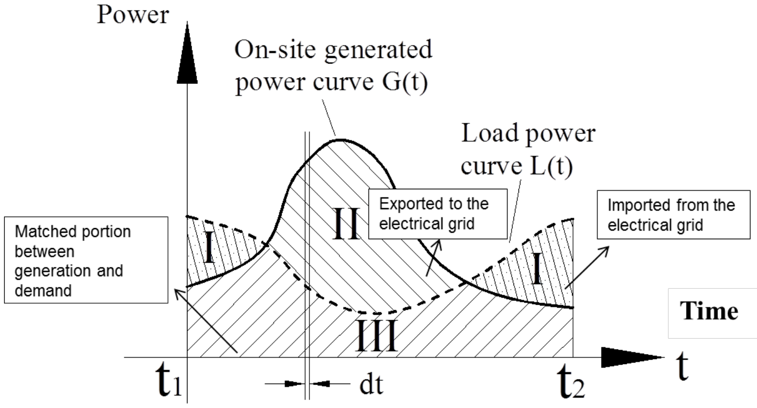

Figure 6: Illustration of the matching between the generation and the load

Figure 7 and Figure 8 show the hourly OEFe and hourly OEMe based on the calculation Method 1, and thus they are accurate values of the hourly OEFe and hourly OEMe referring to the real situation. As shown in Figure 7, the hourly OEFe shows a very clearly seasonal-dependent characteristic, with very frequent and high levels in the summer season due to the sufficient solar resource, whereas during the winter season, the hourly OEFe presents a generally low value with several peaks, mainly due to the higher electrical load during the winter season. This indicates that during the summer season, more onsite electrical load can be covered by the onsite PV generation, whereas during the winter season, most of the onsite electrical load cannot be covered by the onsite PV generation, i.e. it is covered by electricity imported from the electrical grid. On the other hand, as shown in Figure 8, the OEMe are in a reversed manner, with quite high magnitude during the winter season, indicating that the PV generation is sufficiently used in the building during the winter season. However, during the summer season, the OEMe is quite fluctuating, and reaches a minimum peak below 5%, which indicates a very poor summer self-utilization for the onsite PV generation, i.e. a large amount of PV generation is exported to the electrical grid.

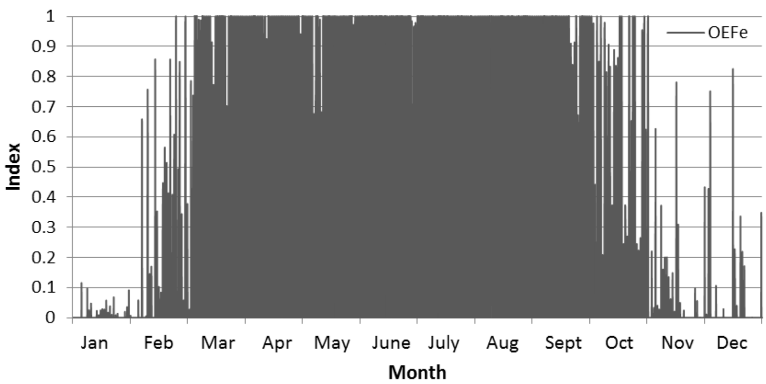

Figure 7: The hourly OEFe calculated with Equation (2) in Method 1

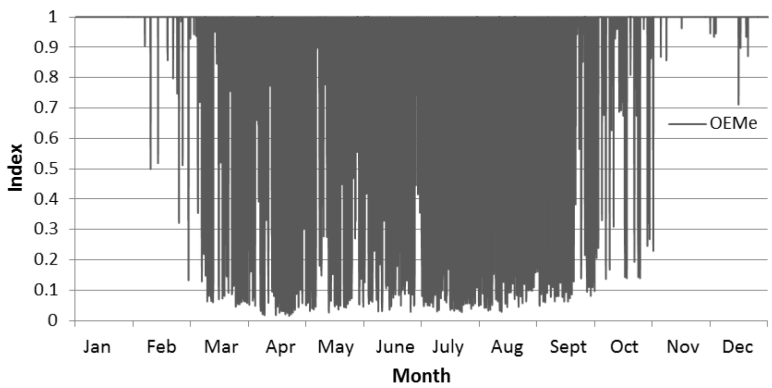

Figure 8: The hourly OEMe calculated with Equation (3) in Method 1

Table 2 presents the annual OEFe and annual OEMe with different calculation methods and time-resolutions. It can be found that with Method 1, the annual OEFe and OEMe are 15.8% and 22.1%, respectively, which indicates a quite poor matching capability. However, with the calculation Method 2, it is found that the results are overestimated by the coarser resolutions. Under the 1-hr resolution with Method 2, the annual OEFe and OEMe are 17.5% and 24.5%, respectively. Under the 1-day resolution with Method 2, the annual OEFe and OEMe are 38.6% and 54.0%, respectively. Under the 1-month resolution with Method 2, the annual OEFe and OEMe are 44.0% and 61.6%, respectively. Therefore, with a coarser resolution, due to the averaging effect by comparing the generation and load, the matching capability is overestimated. This kind of averaging error normally happens in the numerical simulations, when it is impossible to input a real high-resolution (such as 1-min or 1-s based resolution) weather, electrical device, generation, and load data [Cao and Sirén, 2014]. In simulations, normally a coarser resolution such as 1 hr is used. Another situation which will lead to the error in Method 2 is when the recording channels for certain buildings are limited to the total electrical generation (by cumulative measuring system) and total load data (by cumulative measuring system). Furthermore, it can be that Method 2 with 1-hr resolution is not quite deviated from the accurate results by Method 1. However, if the generation level is quite different from the existing system, the error can be quite different. We should conduct more research for different high-resolution generation and load patterns.

Table 2: The annual OEFe and annual OEMe based on different resolutions and calculation methods

Resolution / Indicator		*1 hour*	*1 day*	*1 month*
Annual OEFe	*Method 1*	*16%*	*16%*	*16%*
Annual OEMe	*Method 1*	*22%*	*22%*	*22%*
Annual OEFe	*Method 2*	*17%*	*39%*	*44%*
Annual OEMe	*Method 2*	*24%*	*54%*	*62%*

With Equation (6) [Salom et al. 2014], the normalized variable for the net exported energy $\overline{ne(t)}$ for the building can be calculated as

$$\overline{ne(t)} = \frac{Ep(t) - Ip(t)}{Edes} \qquad (6)$$

It represents the grid interactions of the zero-energy building. *Edes* is the designed capacity for the grid interactions, and *Ep(t)* and *Ip(t)* are the exported and imported power to/from the electrical grid, respectively. In this study, *Edes* is assumed to be 10 kW. Figure 9 presents the hourly normalized net export energy curve. It can be seen in the figure that during the summer season a significant amount of on-site generation is exported. The peak normalized net exported power can reach more than 60% of the designed capacity of grid interactions. However, during the winter season, the net exported energy shows a prevailing negative value due to the import of the electricity from the electrical grid. With Equations (7) and (8), we can define the peak power generation indicator and the peak power load indicator, which indicate the utilization ratio of the designed capacity for the grid connection by the peak generation and by the peak load, respectively:

$$\overline{G(t)} = \frac{Max(G(t))}{Edes} \qquad (7)$$

$$\overline{L(t)} = \frac{Max(L(t))}{Edes} \qquad (8)$$

According to the measured data, the peak power generation indicator is 73%, while the peak power load indicator is 50%. This means that the peak power generation can account for 73% of the designed capacity of the grid connection, whereas the peak load can account for 50% of the designed capacity of the grid connection.

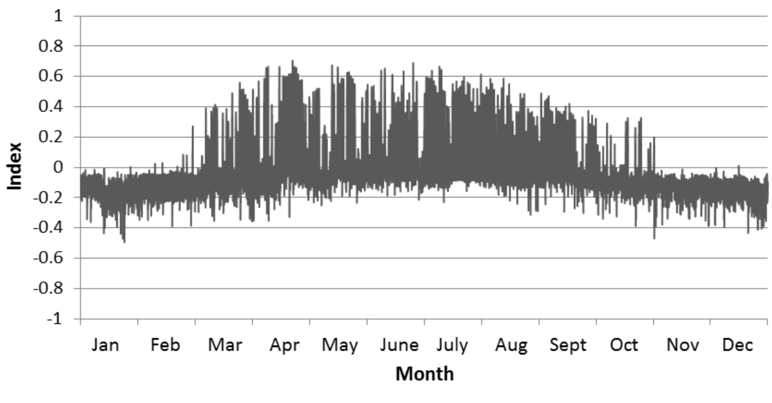

Figure 9: The normalized hourly net exported energy

4. Conclusions

Villa ISOVER® is a building conceived by ISOVER® and Fortum® to test the performance of a zero-energy building and its interaction with the electrical grid. It is a single-family zero-energy house built for the Housing Fair 2013. The building's energy systems have been metered, offering the opportunity to study the energy consumption and production in some detail. According to the measurement data, the annual net direct energy consumption of this building in

2014 is 15 kWh/m^{2}a, which is thus, strictly speaking, a nearly zero-energy building. Through the analysis of the measured data, a set of conclusions have been reached:

1. The PV generation shows quite significant seasonal dependent characteristics. The peak PV generation during the summer season is higher than 7 kW, whereas during the winter season the peak has a magnitude below 1 kW.
2. The electrical load is also dependent on the season, but shows a reversed behaviour: it peaks at around 5 kW during the winter season due to the frequent operation of the GSHP and AHU heating system, but it peaks at only around 3 kW during the summer season.
3. The contrasting behaviour between PV generation and electrical load leads to a quite poor annual OEFe at 16% and annual OEMe at 22%; these indicators are seasonal-dependant, as well.
4. Coarser time-resolutions may lead to overestimations of the matching capability depending on the measurement and calculation methods. In this case study, the matching results seem to be satisfactory with the hourly resolution but not with the daily and monthly resolutions.
5. The recorded imported and the exported power from/to the electrical grid show a seasonal-dependent characteristic, with higher export and lower import during the summer season compared to those during the winter season.
6. Under the assumption that the designed capacity of the grid is 10 kW, the normalized net-exported energy will peak at more than 60% in the summer season, whereas it has a negative peak below -40% in the winter season.

To summarize and conclude, it is not only meaningful to achieve the zero-energy balance during a pre-defined duration of time, but also to maximize the energy matching of the building's own generation with its demand and minimize its exerted impact on the grids.

Acknowledgements

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How can sustainability issues be considered in the public procurement process?

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Abstract

Sustainability has become a key issue in the construction industry. Currently most of decisions on awarding public building contracts are usually based on the lowest bid. The awarding authorities do not always consider quality indicators such as technical value, energy performance, environmental issues etc. Nonetheless, a holistic consideration of sustainability aspects in the tendering and awarding stage has not yet been implemented to a sufficient extent. This paper provides an overview of the current public procurement situation and emphasises the need for considering sustainability aspects within the range of selection and award criteria in the tendering procedure in order to improve the life cycle quality of building projects. Consequently requirements for the design of selection and awarding criteria are presented, with a particular focus on social, economic and environmental aspects. A part of their characteristics are based on comparability and applicability to existing building certification systems. With respect to legal boundaries, relevant frameworks will also be examined by outlining the options for the national implementation of the directive on public procurement (Directive 2014/24/EU), as proposed in the Austrian federal procurement law. However criteria are presented, regarding the technical requirements on the one hand and the relevant suitability of the bidders on the other hand. Based on a literature review on sustainable public procurement, this paper contributes to the question what kind of sustainable issues can be used and in what way to support the awarding of construction contracts, not only based on the lowest price. Therefore it is investigated, how awarding and selection criteria can influence the procurement decision. Furthermore in this context also the weighting of such criteria is important, that these aspects are contributing to a holistic approach in terms of an integrated project delivery. Overall, this paper should create a better understanding on how sustainability issues can be considered in the procurement process, whilst raising awareness for the need of an integrated project delivery. However this should help to improve the effective utilisation of production factors towards a life cycle orientated holistic approach.

Keywords: Sustainable Procurement, Selection & Awarding Criteria, Performance-based Approach, Integrated Project Delivery

1. Introduction

Fighting climate change is one of our main contemporary tasks. The United Nations stated 17 post 2015 sustainable development goals (United Nations, 2015) to adopt 'The 2030 Agenda for Sustainable Development'. Therefore goal number 7 affordable and clean energy, number 9 industry innovation and infrastructure along with goal number 11 sustainable cities and communities and the overall target of goal number 13 on climate action are further related to construction activities. Approximately 40 % of the global energy use is related to buildings as well as 50 % of the resource consumption is linked to construction activities (UNEP SBCI, 2003). Therefore the contribution of construction industry, to reach these sustainable development goals is very crucial. Considering these issues it becomes obvious, they can only be seen from a systems perspective, regarding all their interactions. Which means focusing on single aspects can help, but only to a limited extent. Consequently an overall integrated approach is needed to reach a sustainable development. Additionally this would benefit from synergies as well as cost savings and spillover effects. Based on integrated policies, the procurement process sets up legal boundaries for developing a construction project. Contributing towards a holistic life cycle orientated approach, key aspects of an integrated project delivery have to be focused and taken into account. In the following the procurement process and its influence towards a more performance-based approach, which is necessary to overcome current obstacles, is going to be considered.

2. Public Procurement

The procurement process influences the construction project in many different ways. Beyond its significance in terms of construction management and economics, the legal relevance of this key factors are equally important. Currently a strong focus is just on the economic aspects especially on the initial costs, neglecting follow up and utilisation expanses. Based on the market share of public procurement, this indicates a good starting point for implementing a paradigm change towards a more life cycle orientated approach. Moreover the procurement process influences both the quality of individual processes, the planning workflow and the overall quality of the project, as well as the number of construction process disruptions and thus the amount of additional costs claimed.

2.1 Policies and legal frameworks

Over the last few years several initiatives targeting the public responsibility have been published and comprehensive research was undertaken to improve procurement performance. Based on European and national initiatives, there are policies proposed to focus on additional aspects during the tendering procedure. One of the main commitments has been stated within in the white paper on public procurement in the EU and COM 96 (583) final and COM 98 (143) final. This was continued by the COM(2001) 274 with a focus on *"Commission interpretative communication on the Community law applicable to public procurement and the possibilities for integrating environmental considerations into public procurement"*. This resulted in the

European directive 2004/18/EC supporting the awarding of contracts based on the most economically advantageous tender.

Based on the goals of a sustainable development this shows the need to set up criteria to support the decision-making process focusing on a life cycle performance. Therefore in a first step the European directive 2014/24/EU enables tendering decisions based on a more life cycle orientated perspective.

2.2 Green and sustainable public procurement

In the past few years, strategies are designed supporting a sustainable development on international and national level. In this context, green public procurement (GPP) indicates the attempts of public authorities to procure goods services and works e.g. buildings with reduced environmental impacts over their life cycle. Therefore the work of the CEN/TC 350 on sustainability of construction works delivers a set of indicators, to assess environmental impacts of buildings cf. EN 15978. However GPP mainly focuses just on environmental aspects of products and services, whereas sustainable public procurement widens up the focus targeting all three pillars of sustainable development (ecological, economical and social issues).

Targeting a holistic approach, these aspects need to be considered in the tendering procedure, therefore criteria are needed to be defined taking into account these goals applied and linked to the particular building project. To enable a proper decision-making process, their objectives need to be defined at the beginning of the procurement process. Consequently they need to be stated clearly in the call for tenders especially how they are going to be assessed during the evaluation of tenders and also their weighting needs to be determined, to guarantee a transparent tendering procedure and therefore supporting an integrated project delivery.

3. Methodology

Based on the investigation of the current state on public procurement, requirements towards more sustainable procurement decisions are assessed. Therefore the basis of this contribution is an on-going research project dealing with the following selected research questions (RQ):

- RQ1: How can sustainability be considered in the procurement of construction works?
- RQ2: Which aspects can be used, to define such criteria?
- RQ3: What are the requirements for such criteria?

In order to consider the requirements for sustainability aspects, which can be used in the procurement of construction works, it is necessary to make a structural analysis of current approaches. Based on a comprehensive literature review (Wall and Hofstadler, 2016) the recent strategies and developments over the last few years in green and sustainable procurement have been assessed. Following a holistic approach, considering environmental, social and economic aspects of sustainability a set of indicators in terms of a multi criteria analysis is needed (Zavadska and Antucheviciene, 2006). Hence a key component of analysing the procurement system is examining the perspectives and approaches of multiple stakeholders of construction projects, to identify on which information and what criteria their decision-making process is based on. Following the hermeneutic circle, the findings of these investigations are reworked and therefore procurement stages as well as tender elements are analysed based on legal frameworks to identify possibilities towards a more performance-based approach. The requirements presented in the current contribution are the basis for an expert survey to gain empirical data for future needs and designs of such criteria.

4. Current situation of public procurement

Construction industry is characterized through highly competitive markets. Furthermore mainly the initial costs are taken into account for awarding the tenders. As a result service and quality is suffering as companies are forced to cut costs in order to survive these harsh conditions. To challenge these circumstances public procurement therefore has to make use of its crucial influence based on the market share and promoting a life-cycle-orientated and sustainable development. Using the 'most economically advantageous' tender could be helpful, for considering additional criteria, which are focusing more on a holistic approach. As illustrated in fig.1 there are several requirements on sustainable construction, which can be linked to the rise of building certification schemes (e.g. BREEAM, DGNB, LEED) on the left side and on the right side to normative requirements especially for the building products.

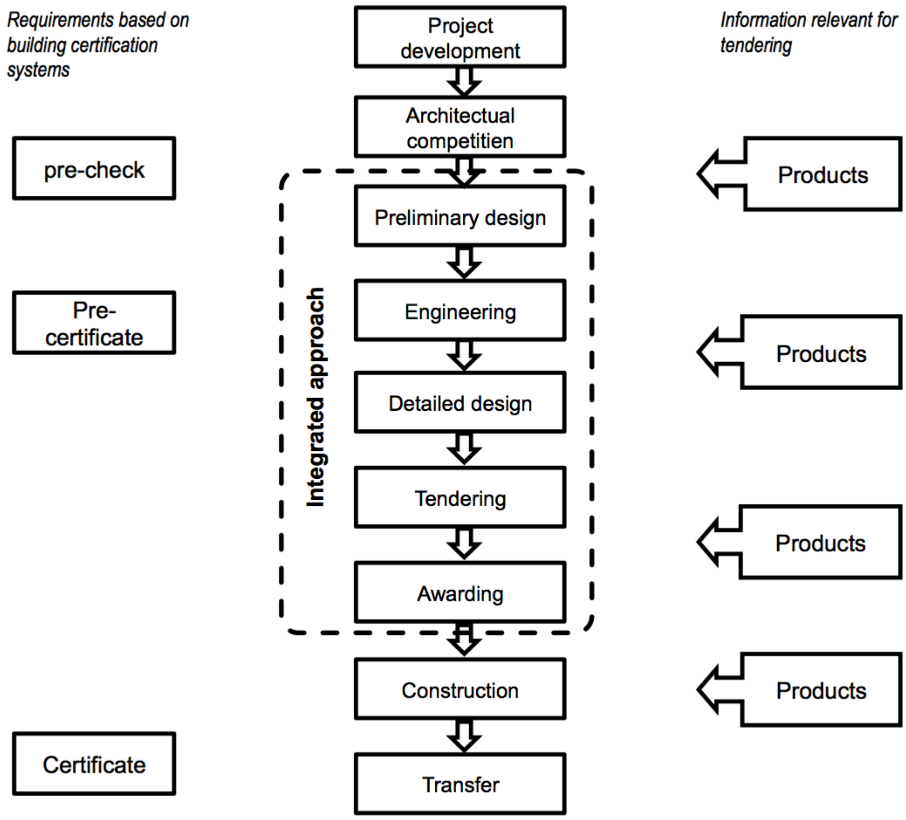

Figure 1: Construction project stages with requirements based on building certification systems and product-based information regarding the procurement and tendering decision cf. Wall 2016

Over the last few years, in terms of sustainable construction targets building certification systems are seen as a suited tool to consider these aspects in a measurable way. Otherwise more information on the environmental aspects and properties of building products are available. Various databases (e.g. baubook in Austria or WECOBIS and ökobaudat in Germany) are providing information on environmental impacts of different construction products and building components. Based on the methodology of life cycle assessment according to EN ISO 14040 et seq. their ecological performance can be determined. This information can be communicated with the help of environmental product declarations (EPDs), representing a suitable format to notify ecological aspects of products and building components in a standardized way. They can support decision-making in early planning stages. Nonetheless different building concepts can be compared in terms of their environmental aspects. Following their standardized information, they can also be used in the procurement process to indicate the consideration of sustainability aspects and can be seen as a good method for verification and quality management during the construction phase. Another important issue is the weighting of additional quality aspects to base the tendering decision on. A case study in Finland, Sweden and Denmark (Parikka-Alhola et al, 2006) investigated a range from 5-20 % for the quantification of additional aspects in the tendering procedure. Based on the chosen weighting it is not always obvious, if they can influence the final awarding decision.

One of the main problems of construction contracts is, that they are related to different spheres, legal boundaries and are influencing construction management and information flows. In fig.1 the sequential workflow is indicated by the single project stages. Targeting a life cycle orientated approach, all these conditions need to be evaluated and properly assessed to describe a construction contract.

Overall, decision support is demanded, in terms of organized efforts to produce, disseminate and facilitate the use of data and information to improve tendering decisions towards a life cycle consideration. This leads to the recognition, that decision processes are at least as important as decision themself on which the tender is going to be based on. To improve the decision-making process towards a holistic approach, a research focus is on how awarding decisions are made and what affects them. Therefore policy makers need insight on how current barriers (like quality of project development, organisational obstacles) can be removed through common-sense steps such as simplifying communications and making choices more clear. The challenge is to create awareness by stakeholders in different areas (environmental management and policy decision-making). In this context besides the ecological issues especially the processes in the design and engineering stage need to be considered more comprehensively. The interactions on product level and the overall performance of buildings are strongly influenced by planning processes. A life cycle optimized building can only be achieved through integrated planning processes providing the basis for a successful combination of the production factors. Focusing on such an approach, the question rises how can a sustainable performance be defined and considered during the procurement and tendering stage. How can such issues be measured and controlled? How and to what extend can they be implemented into the procurement stage? Especially if focusing on performance-based aspects, which are highly related to individual experiences and knowledge. How can such information be taken into account to base the tendering decision on?

Therefore requirements towards a more performance-based approach are presented in the following chapter, which can be seen as possible key performance indicators influencing the procurement process among the life cycle of a building.

5. Requirements towards a performance-based approach

Integrated project delivery is used, to identify the most suitable solution for a problem also considering its life cycle performance. Following this approach a more holistic thinking is triggered in construction industry. The overall aim is to enable and support competition based on sustainable innovations. In this context the procurement process is identified as a very crucial stage in the overall project delivery, because the influence at this stage is suited best, to implement a more life cycle based focus, which needs to be based on quality of related processes. Process quality is defined through the planning and construction processes as well as preparing the commissioning of buildings. Thus performance and quality of the building is significantly influenced at the early project stages. Consequently a more integrated and cooperative model is used to focus on the life cycle quality and responsibility aiming at the project development (AIA 2007).

Therefore a strong focus is not only on product level, especially the process level is addressed. Assessing the life cycle of products as well as completed buildings, their quality is acknowledged but the processes, which have been necessary to achieve such a performance, are often neglected and ignored. However they are contributing towards a more systematic decision-making process, which leads to a better overall project performance. Therefore especially the related planning and project management processes need to be targeted.

Supporting a quality-based (architectural) competition helps to promote innovative solutions and a more life-cycle-orientated project development already in early planning stages. The common project workflow is chronologically and sequentially structured, each task is processed, after the previous one is finished. This leads to a strict planning and working schedule. But in times of increasing complexity of building structures as well as the demand for advanced integrated building systems, each of the stages are linked together, based on contemporary requirements of planning and implementing such systems. For a comprehensive planning and processing of these tasks integrated information is needed. Consequently a more integral project workflow including all participants and involved stakeholders towards a holistic optimization of the project is targeted. Especially the process-related aspects need to be emphasized and should already be considered at the procurement stage of construction projects.

A performance-based procurement can only be achieved if the chosen issues for tendering can be planned, defined measured and justified to comparable for the evaluation of the different tenders. Therefore criteria are needed serving as indicators, index numbers and measureable values. Key figures can provide information based on facts. Indicators are describing qualitative and quantitative relationships, which cannot be measured directly. For measuring process quality indicators need to be identified in accordance to the particular project stages and tasks. In the following fig. 2 several aspects towards a performance-based procurement are listed.

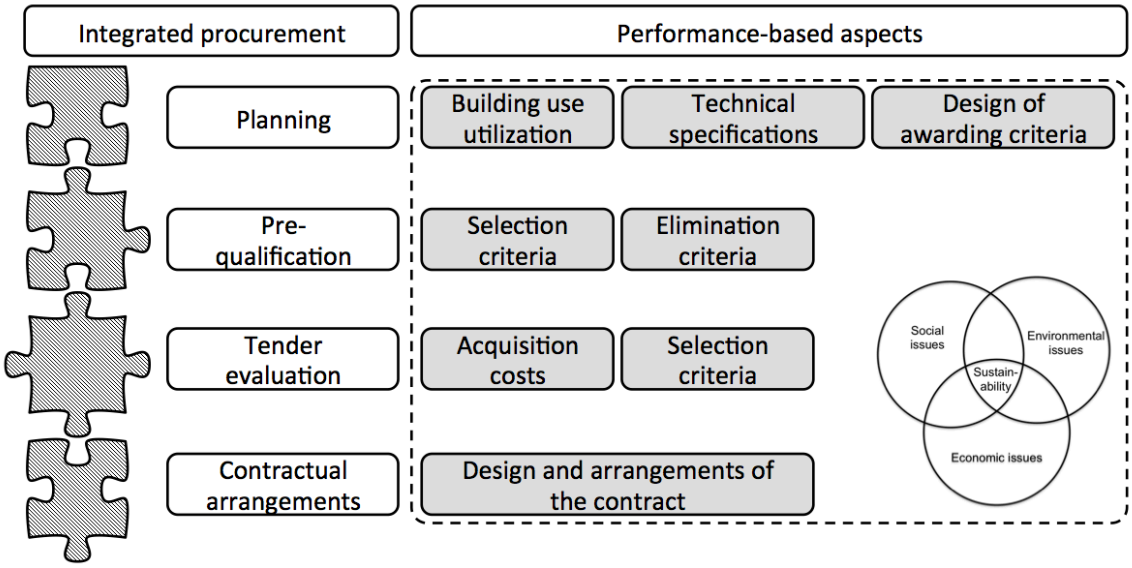

Figure 2: Aspects of an integrated procurement following KfW (2014)

Quality and qualification of the contractors is highly relevant for an integrated project delivery process and therefore needs to be examined. Their suitability and handling by project managers show a significant contribution towards a successful project realisation as mentioned by Hwang and Ng (2013). This correlation has also been stated by the Austrian court of audit in its statement on public financial control cf. ACA (2006). Additionally the ECJ confirmed in Case C-601/13 Ambisig 03/26/2015, using a criterion which takes into consideration the composition of the team, the experience, the academic and professional background of the employees, for enabling an evaluation of teams especially for the performance of the contract.

Another aspect seems to be the corporate philosophy of the contractor, related to the organizational issues of the project team, in terms of their company culture and how projects are realised. These aspects are very crucial for an integrated project development because it leads to the communication culture and information sharing among project participants for creating a cooperative climate between clients and contractors. This underlines quality standards and performance-based aspects of project management and project delivery. Internal project structures and organizational behaviour towards clients and subcontractors are highlighted based on the principles of the corporate philosophy of the enterprise (IG Lebenszyklus, 2015). This includes employment relationship, staffing schedule, and a proactive and solution-orientated working approach on the building project. In this context also the internal personal contribution can be seen as a crucial aspect towards a high quality performance on the construction site. This is discussed at the moment in Austria with the ‘fair procurement initiative’ focusing on the quality and qualification of employees influencing the later project performance. Performance-based tendering decision can therefore include expert interviews with key persons discussing their problem solving capacities and to assess their qualification and applicability for the project specific requirements.

Quality management and documentation during the construction period leads to an evidence-based knowledge management system, which considers all the information flows from the beginning of the planning stages to the construction stages, generating information to improve the commissioning phase of the building with its building technologies as a basis for monitoring activities and facility management tasks later on (influencing the total sustainable performance of a building). In this context lean thinking can be applied. This means information on what to do, when, in what quality and based on which conditions to guarantee optimal information flow as well as operational management. This can be used as part of selection criteria on prequalification see fig. 2.

Suitable criteria are used to specify the quality of the contractor to perform a specific task and how to handle a certain project. Therefore the technical competences can be targeted, which means professional entitlement but also financial and economic performance criteria that are linked to the specific project and/or construction works. For an easier verification of such issues, there are platforms (e.g. ANKÖ, PQ-VOB) providing information on performance records of contractors.

Finally the weighting is a very crucial point, because in the call for tenders the importance of such selection and awarding criteria has to be announced, that there are no spurious aspects, which are not that relevant for the final tendering decision. The awarding should be based on the technical and economically advantageous tender. Therefore usually a jury is necessary to support the awarding process. Especially if judging functional construction concepts on behalf of safety and environmental performance aspects. The awarding committee can assess intended workflow processes and problem-solving skills of the involved key persons with standardised interviews. Therefore the jury members should be involved right from the beginning on to define specific criteria in the call for tender and providing a consistent consideration of these issues and their weighting factors through tendering and awarding. This is stated e.g. by the Austrian National Committee of ITA (2014) on suggesting a procurement model for infrastructure projects. Following these suggestions the composition of the committee is crucial to gather experts from all the different backgrounds, related to the type and special requirements of the particular project. It is crucial for a successful project delivery to concentrate their competences and background knowledge considering all the clients and users requirements.

6. Discussion

Facing climate change public procurement is seen as a suitable tool to apply innovation policy. In this context current backward thinking in terms of focusing just on the initial costs combined with organisational obstacles need to be changed. A special focus is on the type of contract, showing a higher likeliness for design-built contracts considering green innovations cf. Monahan et al (2014). Currently there are still several barriers to sustainable public procurement. In their studies Uyarra et al (2014) reported a lack of interaction of procuring organisations and low competences of procurers resulting in difficulties in negotiating risk management issues due to the higher requirements of the building projects. Considering life cycle aspects, the procuring organisation has to be aware about their future needs and usage requirements. The determination of needs is often barley conducted, accompanied by insufficient understanding creating barriers to innovative sustainable solutions. If the procurer does not know what he is looking for it's not easy to set up functional specification and awarding criteria to evaluate the tenders for the most innovative (best suited) solutions. Despite numerous political statements and commitments towards sustainable construction, the state of the art in awarding public building contracts is mainly related to the lowest price. In the end only the building qualities are considered and visible, the processes, which have been necessary to undertake, are not seen anymore. Unfortunately they have a crucial impact on the success of the project. Therefore the goal is to identify the key-processes, which are needed to achieve a high performance building. Towards a more life cycle orientated consideration of buildings, a holistic approach is needed and has to be integrated and interdisciplinary designed. A crucial aspect in this context relays on the early project development stages that are of fundamental importance towards the final building performance. The current situation is more linked to single normative solutions, which are recognized more unsatisfying as also mentioned in the final report on major building projects (BMVI, 2015). Therefore a cultural chance is suggested, towards more cooperative project workflow characterised with comprehensive information exchange to focus on the project details and contents. This could help to overcome incomplete information and fragmented knowledge management. Towards a life cycle orientated building process, these information need to be considered during the procurement process. Overcoming the sequential process workflow, consequently a more performance-orientated approach is suggested like Uttam et al. (2014). Based on the literature review (Wall and Hofstadler 2016) a lack of interaction within the procuring organizations and the contractors has been identified, which causes different understanding and a reduced and disrupted information flow. To overcome these obstacles fundamental elements for enabling cooperative procurement have to be promoted. In fig. 3 the requirements towards a more performance-orientated approach are illustrated following Owen et al. (2010).

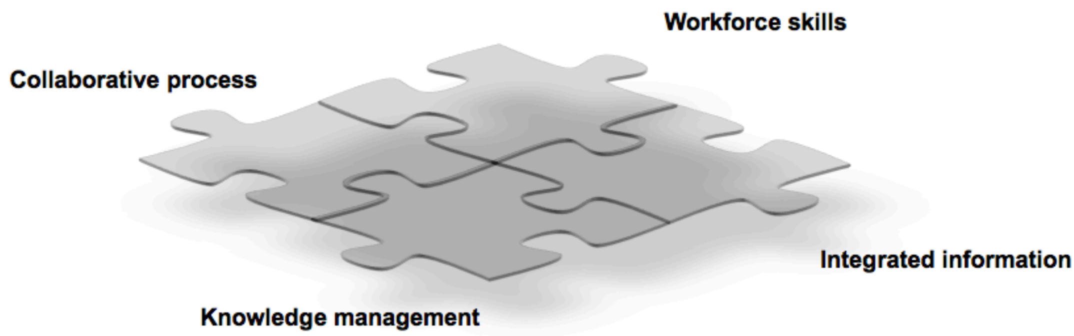

Figure 3: Requirements towards a more performance-orientated approach

Collaborative processes, workforce skills integrated information and knowledge management are the requirements to overcome silo mentalities combined with cultural prevail and document-based information exchange. Bresnen and Marshall (2000) stated the importance of partnering for improving construction performance directly, by promoting stronger client and contractor interaction. To reach these conditions, organisational and cultural change is necessary, especially in context of implementing sustainability aspects and focusing on the life cycle of a building. Incorporating environmental, economical and socio-functional issues into project delivery, this will help to consider a more comprehensive life cycle perspective, and enabling newer greener technologies and fostering innovative developments, this approach is supported by Hwang and Ng (2013). In their work they investigated the contribution of project managers to green construction projects, they stated the need for knowledge and skills to deal with the increased requirements of sustainable building projects. Eriksson and Westerberg (2011) proposed a holistic procurement framework, dealing with a broad range of factors related to procurement and showed, that relationships among clients and contractors are influencing project performance (e.g. trust and commitment among project partners). Similar approaches are introduced e.g. by IG Lebenszyklus (2015), setting up requirements towards a cooperative project culture pushing a performance-based approach providing optimal project conditions for an integrated project delivery. Evidence is provided by taking care of the clients' definition of requirements, stetting a focus on project management and project workflow. Additionally keeping in mind legal and financial boundaries to deal with these issues in terms of risk management.

Currently there are several initiatives focusing more on changing the procurement model towards the most economically advantageous tender. They are targeting the project itself and with the help of a performance-orientated procurement a holistic life cycle optimization can be achieved, because the interdisciplinary organizational structures are more and more important. This demands a more cooperative project delivery, which cannot be reached with common sequential waterfall approaches.

Focusing on the implementation of such a performance-based approach, it can be linked to future developments of procurement models like cooperative procurement and competitive dialog procedure. Therefore legal requirements are important focusing on the type of procurement and the chosen framework (e.g. project is awarded on a lump-sum basis or as a total). However the legal procurement framework conditions need to be considered. This highlights equal and uniform treatment of all bidders and a transparent awarding decision, which is based on expert knowledge. Therefore the used criteria have to be defined, measureable and assessable regarding to various sustainable aspects of building performances.

7. Conclusions

This contribution underlines the need for a cooperative procurement approach to achieve the goals of a sustainable development in the construction sector. Answering the research questions stated at the beginning, RQ1 a consideration of the whole life cycle of a building or construction project can only be realised with the help of integrated design and delivery solutions. Therefore life cycle orientated issues have to be used for formulating criteria, which can be used for a performance-based cooperative tendering procedure. They can be divided into selection and prequalification criteria to support these processes (RQ2). The requirements for such criteria (RQ3) are based on the building utilisation, technical specifications, also economical performance issues and the overall organisational structures, which are linked to the contract. This procedure is all about information management, contents and knowledge need to be processed, transferred and communicated among the involved stakeholders. Consequently tools like building information modeling can support these ambitions and providing a platform for exchange and a basic ideal surrounding for improved workflows to reach the goals of an integrated design and project delivery.

8. Acknowledgements

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Built environment and its parts: towards an integrated study of the construction as a system using an evolving technological knowledge

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Abstract

To consider the built environment as a single system is in contrast with the tendency towards specialization and analysis. Multiple changes are now taking place simultaneously in the planning process, the construction techniques, the organization of a building site, the production of materials and the technical information. All this is driven by a progressive specialization of knowledge and an increasingly important role of data and tools coming from different scientific apparatus. The richness of building methods is always evolving to meet very different requirements in extremely varied conditions and environments. This, however, makes the understanding of the construction and the environment as a 'system' difficult and, consequently, all of the various elements that must contribute to forming the system. All this is in a scenario dominated by "Big Data" and computerized processing of information that seem to make natural language completely inappropriate to the task. In this situation and in our role as professors involved in the training of future professionals, we are committed to defining a method for dealing with the processing of information relating to construction within a system that permits operating at the level of analytical details without losing the connection to the system in general.

The study presented here is based on the use of cognitive maps to represent the parts as a general whole of the construction as a system, through a coded breakdown of sentences that convey information. Considering the need to maintain all the usual forms that architects use in their design work, as well as relying on known and familiar examples of constructions, we link basic elementary concepts to the most widespread architectural journalism. Essentially, examples of solutions which refer to parts of the construction system empower designers to grasp the essential function of the parts to reach a complete and organic understanding of them in relation to the system itself. Starting from the five main themes that compose the construction system (ground anchoring, structure, enclosure, roofing and systems), we synthesized in a few booklets the basic information necessary for an architect to understand the construction and its parts as a 'system'.

Keywords: construction system, innovation, knowledge, concept map, information

1. Introduction: transforming information while maintaining the usual forms as much as possible

To study the construction as a system, it is not enough to know the various elements that compose it; obviously, it is equally important to know their connections, otherwise the operation of the system is not comprehensible. Today, however, technological knowledge usually relies on publications illustrating long list of different types of building elements, distinguished, for example, by materials, forms or dimensions (i.e.: Di Chiara, 1990,Zaffagnini, 1992). Even, the most recent overviews of the architectural elements, such as the one presented at the Venice Biennal exhibition in 2014, ignored their organization as a system (Koolhaas, 2014).

Construction as a system is considered mainly when management and engineering problems, such as automation, are faced. It happens only when new building systems are introduced, but it almost never happens when we are dealing with traditional techniques (Van de Sompel, 2004). Objectively, we cannot deny that a great difficulty exists to entail general aspects when it’s necessary to deepen the analysis and study of details.

For this reason, reminding that technological knowledge transmission has always been basically visual (i.e., Encyclopédie by Diderot and d’Alembert), in this study, we tried to find out graphic forms of its presentation according to its systemic nature. Therefore, we found out a corresponding form to those purposes in the methods proposed by Novak and Gowin (1984). Conceptual maps allow a visualization of knowledge in which it’s possible to go deep without loosing sight of the system essence as a whole (Figure 1).

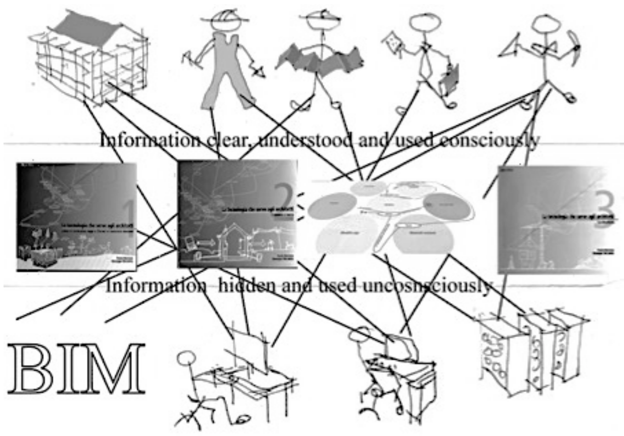

Figure 1: Fundamental strategy: connecting all elements

We applied that method taking care that the graphic forms were similar to those commonly used by the professionals of the sector.

The research presented here deals with a new way of communicating technological knowledge; through a series of steps, the study demonstrates how we succeeded in maintaining traditional forms.

In order for this communication to be made easy to understand, we have tried to maintain a form very similar to that which characterizes traditional communications, i.e. the forms of representation and content commonly used in the industry.

To understand both the theoretical principles that have guided the research and the underlying structure of the presentation of technological knowledge in a new form, it is useful to follow the studied transformation process.

2. Transformation process

2.1 Completing the transmitted information

The traditional form of communication used by industry professionals when attempting to transmit information on the building system prefers to present the study of details to present the parts which make up the represented element.

This description is generally incomplete because it only describes the part or parts, while ignoring the reasons underlying that choice, or at least not defining the way in which the represented element was or is planned to be made (Figure 2).

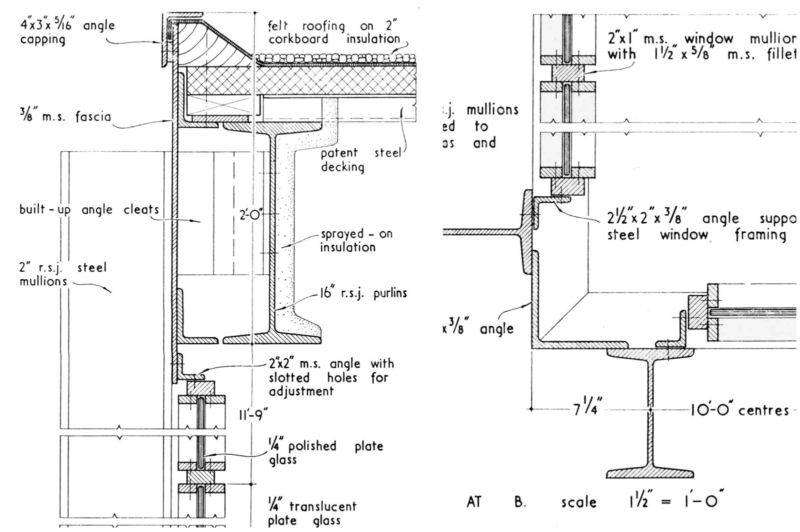

Figure 2: Details and traditional captions

For this reason, a first improvement on the 'traditional' type of communication may be achieved by introducing information concerning not only 'what' is being talked about, but also 'why' it is there and 'how' one intends to make it or has made it.

We studied this transformation of information in a way intended to maintain as much as possible the characteristics of understandability of the traditional forms of communicating technological information to make them more comprehensive and organized.

2.2 Linking the information contained in the traditional forms of communication with the unified classifications

The study of technologies entrusted to the presentation of particular examples of buildings or specific projects is inevitably very partial. Only in specialized books, albeit theoretical, can one trace the different technological solutions for the building elements of the architecture.

To obtain the same result, no longer with a theoretical presentation but through the study of a series of examples, the descriptions must be given such as to make it possible to compare alternative solutions presented in other examples, framing particular problems within more general ones.

This is possible if, in the analysis of the example, a direct reference is made to some order of classification of the different solutions (Figure 3).

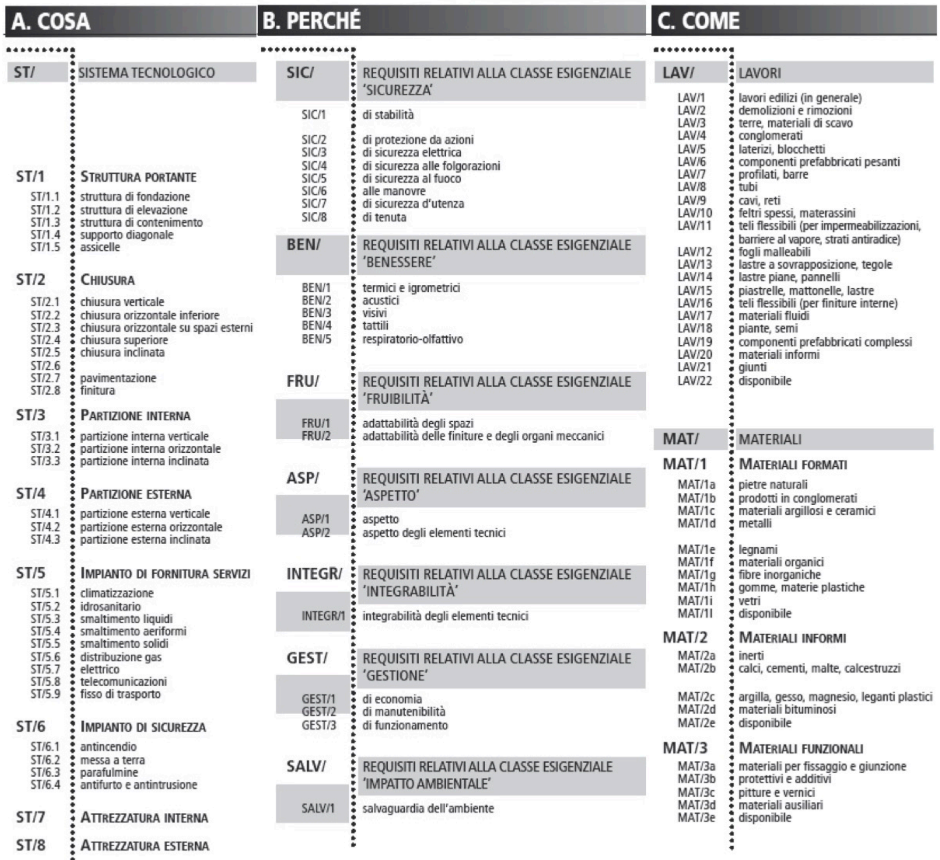

Figure 3: The classification system, 'what', 'why' and 'how'

There are institutions and bodies for standardizing which produce coded classifications, grouping the possible construction choices that exist for each element. They also encode the requirements the elements must satisfy, and every possible processing type that may be used for executing the various building forms that the elements themselves can assume.

These classifications have been used in the descriptions/captions that we have produced to define the items that refer to 'what', 'why' and 'how'. The technological information contained in the description was thus coded and formally linked to unified systems of classification well known to designers.

2.3 Identifying the constructive alternatives by ordering examples according to unified classifications

By assigning each element of the example to the classifications and then scrolling through these, one can find similar solutions in the same class and constructive alternatives in other classes. The finding of an example in a given class means it is possible to use it in the various examples given.

Figure 4 shows the table highlighting the location of the examples in the classification of 'how'. There is a similar organization in the other two fundamental classifications.

It is thus possible to use these tables as indexes when searching for examples with particular characteristics (Van de Sompel, 2004).

C. COME

LAV/	LAVORI	ESEMPI
LAV/1	lavori edilizi (in generale)	1 12 20 27
LAV/2	demolizioni e rimozioni	
LAV/3	terre, materiali di scavo	6
LAV/4	conglomerati	1 2 4 5 6 7 8 11 12 13 14 15 16 17 18 19 20 21 24
		25 26 27
LAV/5	laterizi, blocchetti	17 18 20 22
LAV/6	componenti prefabbricati pesanti	2 5 6 10 14 17 20 25 26
LAV/7	profilati, barre	2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 21
		22 23 25 26 27
LAV/8	tubi	9 14 23
LAV/9	cavi, reti	9 10 12 15 16 19 23
LAV/10	feltri spessi, materassini	14 19
LAV/11	teli flessibili (per impermeabilizzazioni,	6 9 12 17 19 20 23
	barriere al vapore, strati antiradice)	2 10 14 15 16
LAV/12	fogli malleabili	12 19 26
LAV/13	lastre a sovrapposizione, tegole	3 6 7 8 17 18 19
LAV/14	lastre piane, pannelli	3 4 5 6 7 10 11 12 15 16 17 19 20 26 27
LAV/15	piastrelle, mattonelle, lastre	4 9
LAV/16	teli flessibili (per finiture interne)	
LAV/17	materiali fluidi	6 25 26
LAV/18	piante, semi	1 7
LAV/19	componenti prefabbricati complessi	4 5 9 10 11 12 15 17 19 20 21 22 23 24 26 27
LAV/20	materiali informi	14 16
LAV/21	giunti	8 11 13 15 17 19 23 25 27
LAV/22	disponibile	
MAT/	**MATERIALI**	
MAT/1	**MATERIALI FORMATI**	
MAT/1a	pietre naturali	16 17 18 22
MAT/1b	prodotti in conglomerati	2 5 7 9 10 12 14 17 18 20 26
MAT/1c	materiali argillosi e ceramici	18 20 22
MAT/1d	metalli	2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
		21 23 24 25 26 27
MAT/1e	legnami	4 6 7 9 12 15 21 22 27
MAT/1f	materiali organici	9
MAT/1g	fibre inorganiche	4 8 9 19
MAT/1h	gomme, materie plastiche	5 6 8 9 12 14 15 16 17 19 20 23 26
MAT/1i	vetri	5 10 10 10 11 15 15 15 22 22 23 26
MAT/1l	disponibile	27
MAT/2	**MATERIALI INFORMI**	
MAT/2a	inerti	6 9
MAT/2b	calci, cementi, malte, calcestruzzi	1 2 4 5 6 7 8 9 11 12 13 14 15 17 19 20 21 24 25
		26 27
MAT/2c	argilla, gesso, magnesio, leganti plastici	5 11 14 20
MAT/2d	materiali bituminosi	20
MAT/2e	disponibile	7 9
MAT/3	**MATERIALI FUNZIONALI**	
MAT/3a	materiali per fissaggio e giunzione	12 14 16 17
MAT/3b	protettivi e additivi	6 9 19 26
MAT/3c	pitture e vernici	
MAT/3d	materiali ausiliari	26
MAT/3e	disponibile	

Figure 4: The alternatives in 'how'

2.4 Identifying the construction problem faced by the detail analyzed.

In the ‘construction’ system, the study of a construction detail is useful for understanding the reasons for the solution in light of the problem addressed. The problem, which in general can be summarized in an intuitive form, is useful for starting the return from the particular to the general, which is necessary in order not to lose sight of the unity of the ‘construction’ system (Figure 5).

If the examples are chosen with the aim of addressing, in a certain order, the constructional problems to be studied, it is possible to present a topic using the form of rhetorical question and answer.

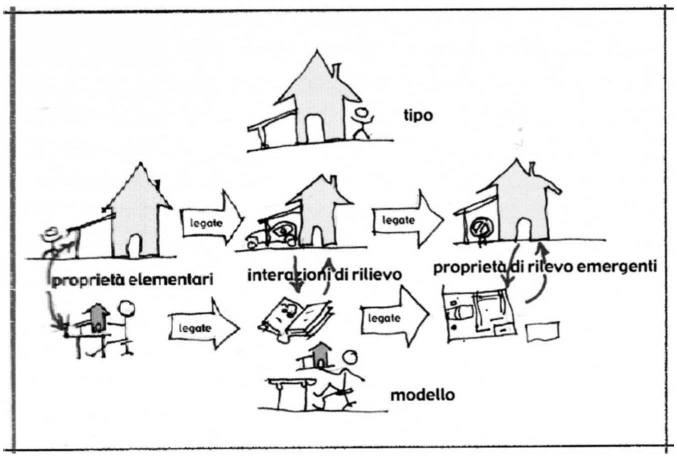

Figure 5: A synthesis process of a constructive problem

The rhetorical question and the related answer is ‘constructed’ and positioned on a concept map.

2.5 Constructing a discourse on the topic

Without disturbing the ‘systems theory’ by Ludwig von Bertalannfy, and sharing that technology as a subject is presented, for the main part, graphically, our contribution concerned the visualization of the construction system using maps.

All the problems detected in the various examples can thus build a discourse on the theme that frames the element studied in the construction system. The form given to this work comes from the application of J.D. Novak and D.B. Gowin (1984) applied pedagogical studies described in their famous work “Learning how to Learn”.

This approach led to the organization of a general and articulated explanation regarding a construction element starting with a crucial question containing some concepts, followed by a series of rhetorical questions that contained other concepts explained by the subsequent relative answer (Figure 6).

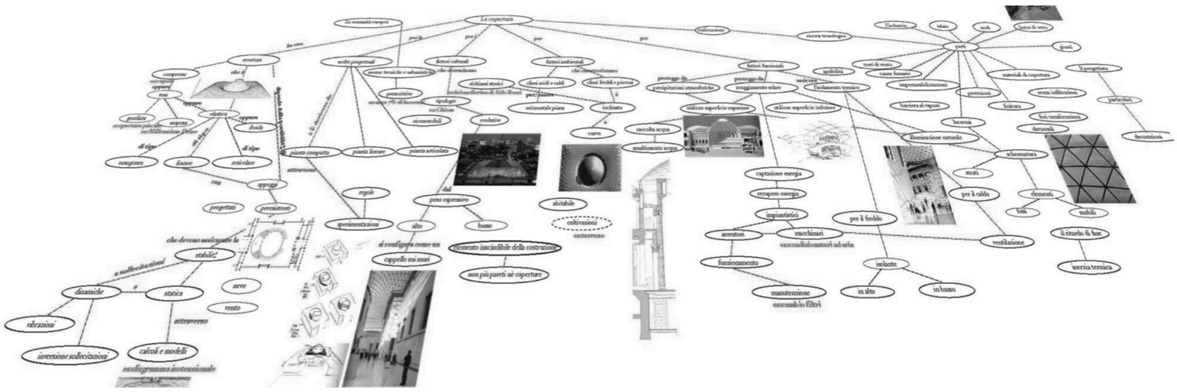

Figure 6: Map with concepts grouped into sets

Such a form of communication, or form of explanation, concentrates the key objects of the discourse in the concepts covered. However, by reporting the various concepts in a concept map, one runs the risk of having a confused form. To avoid this, the concepts have been grouped into sets.

2.6 Linking the description of the detail with the construction from which it was taken

Every good professional knows that, in addition to the reasons for the particularities of a detail presented, there are also reasons that allow one to arrive at a full analysis of the project. For this reason, it is interesting to describe the project in its entirety.

If the construction system is useful for understanding construction problems, the architecture system can be especially useful for helping people to understand the design choices made. Therefore, we determined it was equally essential to recall a brief description of the architectural design (Figure 7).

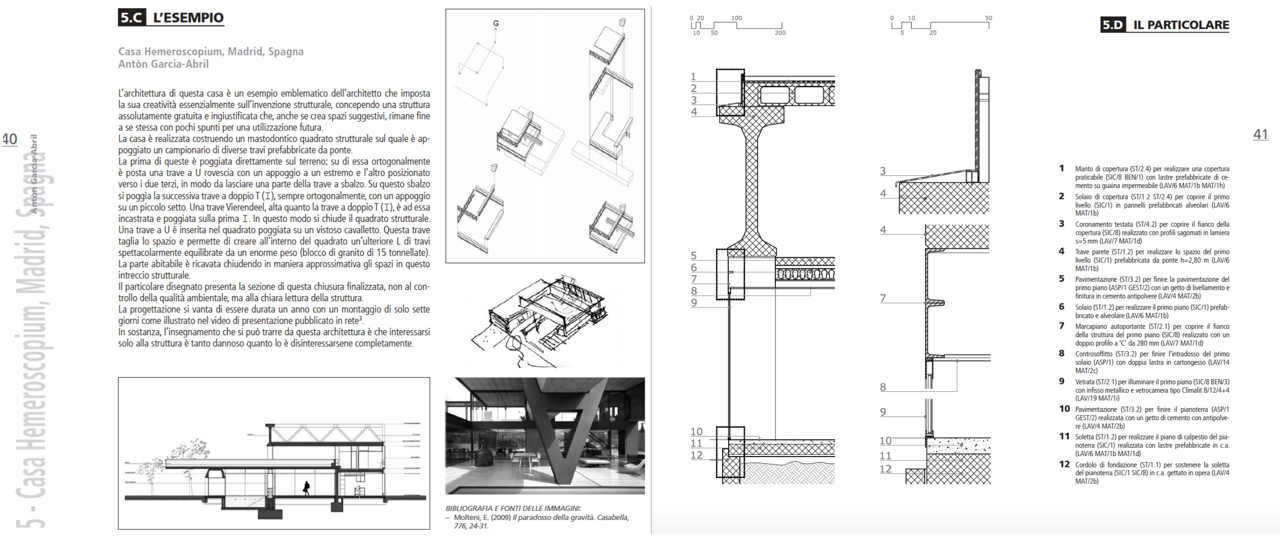

Figure 7: Description example

We believe this is the moment when one can address the essential reasons that led to the design of that particular element. In essence, through the design one can explain the detail.

2.7 Linking the detail in the construction with other similar details

As the detail is born of a designer's choice from among the many that he/she could have made, reference to such alternatives delves into the issue of the element in the study of the detail. To do this, the caption of the individual items of the elements studied is organized according to the system of unified classifications adopted. The link to the classifications allow one to conceptualize the problems and construct a clarifying rationale about them. At the same time, given that this conceptualization is closely linked to a well-defined example, one does not run the risk of making a crippling theoretical discourse.

2.8 Achieving a close connection between the elements of the construction system

In constructing discourses on different themes, sets appear that are part of several theme domains. For example, the concepts defined in the discourse on the 'structure' may also be present in the study of other elements (e.g. envelope or roofing). The concepts that recur in several elements thus constitute such links. Indeed, it is then possible to construct a multi-dimensional concept map defined by identical sets belonging to multiple themes, because a set that is a circle in a two-dimensional representation, it is a sphere in a three-dimensional one (Figure 8).

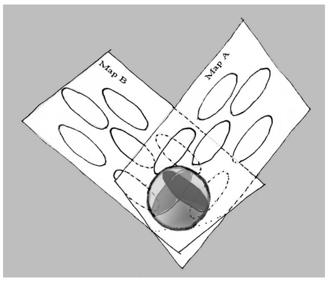

Figure 8: The set is a circle in a 2-dimensional representation, a sphere in a 3-dimensional one

This graphical representation, which is possible with new computer equipment, is impossible on paper. Also, the representation of the concept map, very clear with the new computer equipment, looks very complicated in paper form.

2.9 Connecting with traditional architectural journalism

The writings that are produced following this systematization of information are, for obvious reasons, greatly reduced. The information on choices of technologies is rather concise and one feels, therefore, the need to return to traditional forms of communication.

It was decided, therefore, to give each identified concept a reference bibliography where the reader can find a description of the same concept in a more extensive form.

This communicative aspect is in no way secondary to the discourse made; rather it is a key element in any in-depth analysis because, as Diderot remarked, the bibliography allows a panoramic vision of the concept discussed.

3. Application of the method

It seemed possible to concentrate the whole discourse on the building as a system in five papers published in as many booklets. It is evident that it would have been easier to make a more detailed breakdown of the themes discussed; however, wanting to show that it was possible to concentrate technological knowledge to the maximum, we employed a reduced breakdown.

The five themes identified are: ground anchoring, structure, envelope, roofing and floor plans, systems and secondary internal elements.

3.1 How content in publications are presented

The discourse on construction elements thus identified occurs through examples chosen to represent the various forms with which the elements themselves are materialized in architecture.

All the booklets contain a number of examples, i.e. constructions presented according to the form described. The concepts identified in the discussion of the example constitute the core of the general discourse presented in the concept map. Each example is shown in four pages in which one finds all the contents and information as described above (Figure 9).

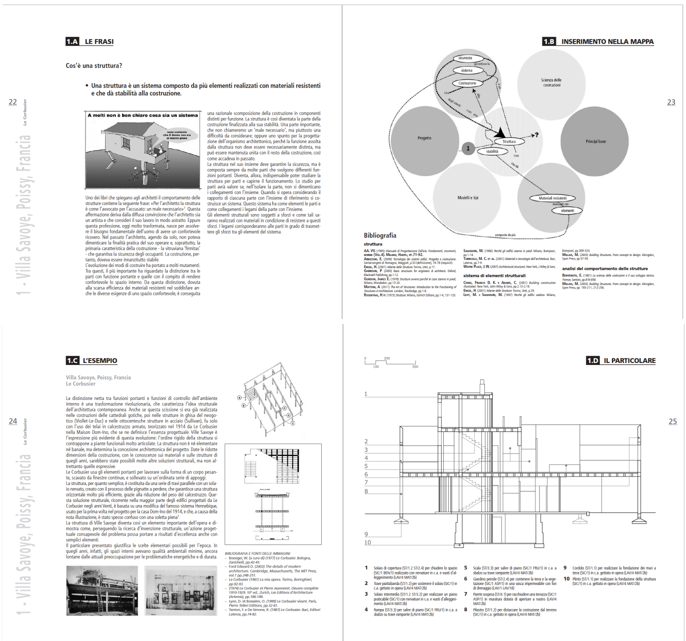

Figure 9: Contents of the four pages and reports

In this representation, the essence of our work is concentrated in an innovative form. With this graph we wanted to highlight the series of connections that exist between the information which, being presented in the traditional form, do not generally highlight the references that are indispensable for communicating the technological knowledge in a comprehensive way so that the system-construction engages with the system-architecture.

4. The construction as a set of forms materializing in the architecture

Underlying this discourse are examples that exemplify the choices used to represent the various forms in which the construction elements in the architecture materialize. Even if one adopts the concept maps, one should not lose sight of the fact that the information is not aimed only at knowledge, but rather is also a handy tool for an applied use. Basically, what we have proposed is essentially a refinement of the design procedures based on reasoning on the cases (CBR- Case Based Reasoning).

5. Discussion

Having wanted to maintain a very tight link between the proposed method and information commonly used by designers leads to our main intention which is a complete revolution of the communicative form. One can note that despite the current massive introduction of computer graphics, the journalistic style used by designers has not changed: what is usually presented is simply an adaptation or a reduction of the computer processing according to the traditional forms of the drawings, perspectives and false photographs, leaving everything unchanged.

What we are proposing, even if we consider only the organization of the captions of the drawings, is definitely a step towards more accurate communication. In publications today, one can see, in the captions of drawings, of the same element one is presented as "*flashing*", another as "*completion of waterproofing*" and yet another as "*aluminum profiles*". It would have been clearer, however, to write a caption organized thusly: "*Flashing (what) for completing the waterproofing (why) using an aluminum profile (how)*".

Bringing order and communication, keeping the building as a system in mind, also involves communication such as we propose.

6. Conclusion

The publications are small-format (15x21 cm) of about 150 pages printed in black and white. The small size depends on the choice of matching the number of sentences contained in the map to the number of examples presented. Increasing the number of examples would surely enrich the volume, but processing them would lead to the need to increase the phrases needed for describing the element well. Therefore, this would make the conceptual map unwieldy, which, already with the limited number of concepts, would make it difficult to deal with the graphics problem. Only a complete computerization of the text could improve this rigid schema.

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Beyond the Built Environment as a Sustainable System: a New Approach to Modelling

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Abstract

This paper deals with the evaluation of sustainability as a theoretical, methodological and operational tool to support and improve learning on regenerative transformations of the built environment. In contrast with the scale-centred approach underlying the existing sustainability evaluation systems of buildings and urban areas, we propose i-UrBE (**i**ntegrated-**Ur**ban **B**uilding **E**valuation) an evaluation approach which draws on a socio-ecological interpretation of the built environment and is finalised to support a regenerative urban and building design. In our approach, the evaluation of the sustainability of a building or an urban plan is focused on *reciprocity* of interactions between human and non-human world, is carried out in a socio-ecological space that we define *urban matrix* and is based on few holistic indicators. These last are conceived as crucial tools reporting about what we define the *reliability* of an action, i.e. the ability of an action addressed to sustainability of buildings or an urban context to stimulate and transform into capacity the regenerative socio-ecological potential of a specific place.

Moving our work from the theoretical to the operational level, in this paper, we describe the evolution of i-UrBE approach for evaluating/assessing the regenerative sustainability of built environment focusing on *reciprocity* and *reliability* as crucial keys for an integrated urban-building evaluation. The paper underlines the relevance of *reliability* assessment based on few holistic indicators. In our evaluation approach, *reliability* reports on *reciprocity* by highlighting the 'co-creative' qualities of a design action addressed to a building to stimulate regenerative socio-ecological relationships shaping the built environment. At the operational level, *reciprocity* and *reliability* help to: (i) deal with sustainability in a pragmatic way on qualities inherent in an integrated process of urban-building design; (ii) improve knowledge generation on sustainability by enabling actors to identify trends, navigate sustainable transformations and highlight uncertainties associated with their actions.

Keywords: Regenerative Sustainability, Integrated Evaluation, Built Environment, Holistic Indicators.

[1] The paper is the result of a collective work. Attributions are as in the following: section 2, subsection 2.1, and section 3 are by Valeria Monno; section 1 and subsection 2.1.1 are by Emilia Conte; the abstract, subsection 2.2 and section 4 are by Valeria Monno and Emilia Conte.

1. Introduction

Evaluation systems in building and urban development have increasingly become a common language on sustainability among actors involved in making cities and urban areas smart, a fundamental tool to orient design and planning choices and influence the market. However, the large investments in this field have not produced the expected results, leaving significant margin for such systems development (Heinonen et al., 2015). One of the reasons determining scarce results is considered the lack of integration among different scales of evaluation of sustainability and in particular between the urban and building level. For example, considering urban sustainability as achievable through the evaluation of building sustainability has now become a new cliché, a sort of a 'necessary' activity to deal with climate change, energy savings or gas emission reduction in a smart way. Although necessary, this kind of building sustainability is not sufficient to speak about urban sustainability and improve it.

According to such a diagnosis, several solutions have been proposed in order to relate the urban and building sustainability better. These include the search for an intermediate scale of evaluation or multi-scalar evaluation frameworks. If, on the one hand, these solutions have not yet produced meaningful results, on the other they have generated an obsessive search for and proliferation of indicators and assessment systems that currently depicts a jeopardizing scenario (Reith and Orova, 2015) which risks to threaten the quality of results. From our point of view, in order to imagine and implement sustainable urban development a new approach is necessary.

2. i-UrBE: a socio-ecological interpretation of urban complexity

i-UrBE is a research project aimed at constructing a possible approach to tackle the urgent need for a cross-scale methodological framework for designing sustainability in the city by overcoming the limits shown by existing evaluation approaches linked to a scale-centred perspective, a linear conception of time and an archaic vision of integration among the socio-economic and environmental dimensions of sustainability. In contrast to dominant managerial approach to design and implement sustainability in the city, which sees evaluation procedures as an important tool to account for the results (Cole et al. 2013) and improve investment quality, in our research evaluation is conceived as an active learning process helping the design process. i-UrBE does not respond to a need for more complex and sophisticated evaluation technologies and tools. It offers a method and a tool enabling learning on what means and implies designing and planning sustainability in a spatially sensitive perspective. Despite the learning perspective could reduce the operability, efficacy and efficiency of i-UrBE, its use is a way to admit that when we deal with the evaluation of sustainability from an integrated, spatially sensitive perspective there is the constant need for doubt and dialogue (van der Knapp 2004).

In order to transcend the scale-centred perspective, our approach to the sustainability evaluation hinges on socio-ecological system (SES) interpretations of the built environment (Moffat and Kohler, 2008; Gandy, 2006). These are seen as indispensable to dismantle the anthropocentric vision on interactions between natural and urbanised worlds and a conception of urban complexity as resulting from interactions among clearly bounded and isolated physical systems that, from our point of view, is at the base of the scale-centred approach.

According to SES, urban complexity can neither be reduced to the opposition between urban and natural worlds (Moffat and Kholer, 2008) nor disaggregated in a set of isolated social and ecological systems reciprocally interacting in some obscure way. Built environment is something more than the sum of the built (physical, economic, cultural and social) parts of cities and ecosystems from which it depends on (Hassler and Kholer, 2014). It reflects the socio-ecological relationships created by political decisions and the culture of design through which we interconnect in a specific way technical, environmental, economic, socio-cultural and political dimensions shaping urban life. If reconsidered from this point of view, nature is anything but a product of urbanisation and its metabolism (Kaika and Swyngedouw, 2014).

Anchoring this SES perspective to interpretations of urban complexity as assemblage (Latour, 2005; Gandy, 2008), the built environment can no longer be taken as a dead background for human and non-human life (Kaika and Swyngedouw, 2014). It evolves from complex and networked relationships among human and non-human agents (Monno and Conte, 2014). Any agent composing the built environment is a socio-ecological system in itself: it is a bridge between natural and human worlds which is shaped by and shapes the built environment. Each building, neighbourhood or infrastructure is individually a socio-ecological agent/node in the built environment. Therefore, the idea of the built environment as a socio-ecological networked assemblage includes a vision of urban space as emerging from the bottom-up, through the dynamics producing it.

Consequently, i-UrBE abandons a widespread idea of the built environment as an indefinite whole to be disaggregated into a collection of man-made objects (human-non human systems) interacting individually in a more or less complex way with local ecological dynamics or wider ecosystem through impacts or flows of matter and energy. It considers the built environment as a spatial context of interactions (assemblage) among different socio-ecological agents (buildings, infrastructures, public spaces, ecological dynamics, decisions, people, etc.) connecting urbanised and natural worlds in a specific spatial configuration. Although determined by a specific vision of urban space (i.e. the anthropocentric one), any agent can change the spatial context.

However, none of the agents can be considered in isolation from the spatial context in which it interacts. The set of networked socio-ecological relationships configures the spatial complexity and the sustainability of both the built environment and any individual agent/node composing it. This set of socio-ecological relationships determines the built environment metabolism, its influence on agents, as well as its spatial extension, and the level of quality of life (human and non-human) of the assemblage of agents.

Coherently to SES perspective on the built environment, i-UrBE evaluation approach also abandons the generic definition of sustainability intended as a process of integration of the economic, environmental and social dimensions of implementation to focus on the transformations of the built environment in terms of regenerative behaviour (Monno and Conte, 2014). Rather than merely reducing, and then assessing, environmental social and economic impacts, and/or evaluating sustainable design choices comparing their performances to agreed sustainable targets, i-UrBE aims at supporting design choices triggering the transformation of the regenerative potential of the built environment into capacities (Mang and Reed 2012). As underlined by du Plessis (2012), "the regenerative paradigm provides an alternative that is explicitly designed to engage with a living world through its emphasis on a co-creative partnership with nature based on strategies of adaptation, resilience and regeneration" (p9).

In i-UrBE carrying out an integrated evaluation does not mean to discover a new scale for evaluating sustainability (as for example a neighbourhood), but understanding how to change the specific set of socio-ecological networked relationships shaping unsustainable metabolism and therefore working on those crucial relationships of *reciprocity* and interdependence linking agents composing the built environment so to make it regenerative.

2.1 From theory to practice

i-UrBE is thought of as the result of an evolutionary exploration method. This last facilitates new discoveries and the growth of knowledge since it proceeds by trial and error-elimination and is based on the idea that "as much as the experimenting agents, humans no less than other organisms, base their tentative problem-solutions on already acquired knowledge, wherever their trials go beyond what is already known they 'cannot go but blindly'" (Vanberg, 2014, p101). The trial and error-elimination method generates a continuous move from theories to practice. Therefore, the construction of i-UrBE proceeds cyclically: the evaluation approach is translated into an integrated urban-building assessment framework for the evaluation of sustainability of the built environment and, then, critically analysed also involving experts in the field of sustainability evaluation.

i-UrBE evaluation approach is still under construction. At the current stage, it is the result of just one trial and error elimination cycle assuming as a test-bed of our socio-ecological approach an assessment framework for the sustainability of buildings.

The first provisional structure of the integrated assessment was determined by the need to make explicit the multiple urban-building socio-ecological (sustainable and unsustainable) reciprocal interdependences. In order to achieve this goal, and following the SES perspective, the built environment in which a building is localised was redefined as *urban matrix*. Within this definition, the *urban* alludes both to the urbanised space and to the urbanisation of nature. Hence, the *urban matrix* is more than the neighbourhood in which a building is situated: it is a multi-scalar space defined by the metabolic interactions among agents/nodes composing the neighbourhood and the sustaining ecological dynamics. The borders of *urban matrix* are defined by its metabolism, meaning by that the assemblage of socio-ecological networked material and immaterial flows and relationships connecting the agents composing the built environment to ecological dynamics. Within the *urban matrix*, a building is an agent/node contributing to and shaping the *urban matrix* metabolism. Therefore, it is through metabolism that the built environment and a building interact.

The integrated assessment framework was also determined by the need to make explicit the *urban matrix* metabolism by identifying the multiple *urban matrix*-building sustainable and unsustainable reciprocal interdependences. At this purpose, we identified as categories of analysis of the *urban matrix* metabolism its physical structure, flows of matter and energy, environmental quality, and lifestyles. The sustainable building was instead described through its performances, as used in the most popular assessment systems, but reorganised in the following macro-categories: site, indoor and outdoor environment, operation and technical design. The vulnerability of *urban matrix* was chosen as a parameter able to represent at what extent a design action addressed to a building can change the *urban matrix* metabolism and if such a change can be able to activate an *urban matrix* resilient behaviour (Conte and Monno, 2012).

2.1.1 A focus on the evaluation of sustainable buildings: the need for *reliability*

To allow the assessment of a sustainable building in a SES perspective on the built environment we introduced the *reliability* concept. *Reliability* is a concept largely used in several fields of study to connect the effectiveness of an action to an expected behaviour of a system. Usually, this concept represents the ability of an agent –human or not human– to behave in an expected way during time, and the likelihood of an action to be effective. For example, in engineering fields it is adopted in relation to maintenance operations (EN 13306:2010); in the construction field it refers to a maintenance action capable of triggering an integrated and cooperative functioning among different components interacting in a building system. We retained the engineering definition of *reliability* of a system as being able to perform cooperatively. However, working in a socio-ecological system and a regenerative perspective, we dismissed its deterministic features. We then defined the *reliability* of a building as the ability of a sustainable building, basing on its design choices, to activate a cooperative integrated system of interactions between the building itself and the built environment (Conte and Monno, 2012). Thus defined *reliability* is a connector among scales of evaluation and a crucial conceptual tool to carry out both theoretically and operatively an integrated approach to sustainable design. *Reliability* could be assessed through few holistic indicators thought of as a combination of indicators representing a specific macro-category of analysis obtained through a comparison between macro-categories describing the sustainability of both buildings and the *urban matrix*. Such indicators measured those performances of a building inducing a vulnerability change in its context, i.e. impacts of a sustainable building on the built environment.

2.2 A critical analysis of the assessment framework

Once built the i-UrBE assessment framework (Fig.1), we verified if it was able to relate the sustainability of a building to the multiple dimensions shaping *urban matrix* metabolism. Our analysis showed that it was able to focus on socio-ecological relationships rather than on social, economic and environmental characters of urban and building sustainability. By relating the sustainable building to the variations of vulnerability of the *urban matrix*, it also helped to correlate better local and ecological scales of evaluation as well as natural and cultural worlds. Comparing i-UrBE integrated assessment framework to the existing assessment systems, it showed what is missing in them and how it could complement them helping to make the design more powerful and the evaluation more transparent.

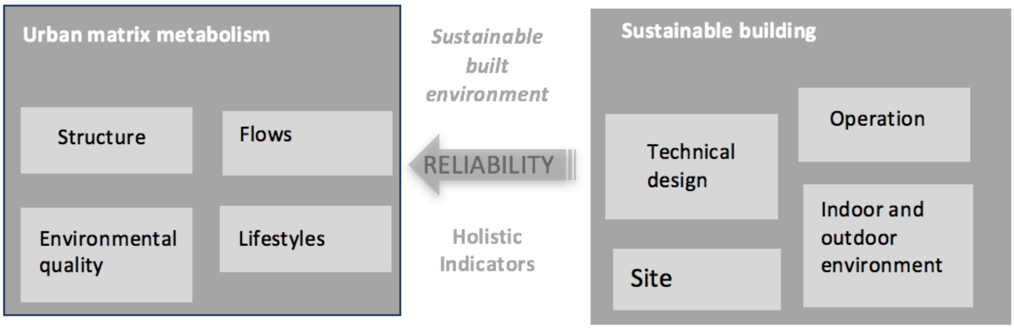

Figure 1: i-UrBE provisional assessment framework

Nevertheless, an inter-scalar perspective on the assessment was still recognisable, so weakening the integrative potentialities of i-UrBE evaluation approach. Furthermore, the regenerative perspective had not properly been incorporated in the assessment framework. Although expressing the *urban matrix*-building relationships, the variations of vulnerability showed a strong focus on resilience. The assessment of *reliability* was focused on the building and its impacts on the *urban matrix*, rather than on the interactions between the building and the *urban matrix*.

Parallel to this critical analysis, we discussed our approach to the integrated evaluation with some experts who actively work in the field of building and urban sustainability at the regional and national level. Experts were involved through semi-structured interviews and personal communications (face-to-face conversations). In depth, semi-structured interviews and face-to-face conversations were intended to grasp both technical and tacit knowledge as well as potential improvements and inadequacies of the existing evaluation systems of sustainable buildings and neighbourhoods when contextualised in an urban context. They also concerned issues related to inter-scalar urban-building relationships and the idea of urban complexity.

In both interviews and personal communications, we asked experts to give us their opinion about the efficacy of current evaluation systems in orientating design for sustainability and describe what causes the shortcoming of their action. They ascribed the modest efficacy of their action to contextual institutional, cultural and political constraints, rather than to the evaluation systems they had used for assessing urban or building sustainability. In particular, the experts emphasised the extremely usefulness of these systems in promoting sustainability of buildings. Yet, when obliged to reflect on the efficacy of these systems, experts could not avoid arguing that they should be considered as an initial step towards urban sustainability mainly aimed at changing the current unsustainable culture underlying the process of production of the city.

From experts' point of view, existing evaluation systems can help to measure the sustainability of a building intended as a producer of environmental pressures. However, they can only slightly challenge dominant economic driven conceptualisation of what is a sustainable building and what constitutes its contribution to the sustainability of the urban context in which it is situated. These systems are mainly used to favour the improvement of the (energy) efficiency of urban environments and buildings. Although buildings could reduce pollution, natural resources depletion and gas emissions in the atmosphere, the environmental urban quality still remains underestimated, social aspects undervalued and no meaningful regenerative clues of built environment could be detected. For the experts, one of the most important problems with the current evaluation systems is the absence of a multi-scalar perspective, which prevents them from linking sustainability of a building to urban sustainability and vice versa.

As far as the experts' opinion on our assessment framework is concerned, they found interesting both i-UrBE approach and the concept of *reliability*. They perceived the socio-ecological approach as a perspective capable of filling the absence of an integrated and inter-scalar evaluation and assessment. For them, i-UrBE approach pushes current mainstream ways of evaluating sustainable buildings towards a new way of conceiving the relationships between the building and the built environment. After we explained the meaning of *reliability*, experts started to think about the interactions among a sustainable building and the urban context.

For example, one of them argued that in order to consider a building sustainable, a new set of actions should be imagined beyond the existing approaches. These actions would imply reconstructing parts of a city to restore the relationships connecting buildings to the ecosystems, or transforming existing buildings so to regenerate the urban environments according to the ecological dynamics shaping the nature in the city. However, from their point of view, our approach and assessment framework could complement but not substituting the existing systems.

Interviews and face-to-face conversations confirmed the result of our critical analysis of the assessment framework. The *reliability* concept was too related to the performances of a building. Although being a useful conceptual tool to assess a potentially integrative building-urban reasoning, *reliability* only partially responded to the need for considering reciprocal interactions between buildings and the *urban matrix*. There was not a clear relationship between vulnerability and *reliability*. Hence, we were unfit to define and identify meaningful holistic indicators. Consequently, in the assessment process the use of *reliability* did not allow us to really understand if the interactions between a sustainable building and the *urban matrix* triggered an interdependent and regenerative process of the built environment.

By paraphrasing Costanza (2014), we had to admit that making the transition to the world we want is not easy since "in many ways we are locked-in, trapped, and in a very real sense "addicted" to the current regime" (p43). Both the concept of *reliability* and the holistic indicators had to be reframed.

3. *Reciprocity* as a regenerative quality of sustainable built environment

In order to make i-UrBE more adherent to the socio-ecological perspective as described above, we focused on *reciprocity* as crucial spatial quality of any sustainable built environment. *Reciprocity* implies the existence of co-constituting and mutually supportive spatial interactions among the agents composing a sustainable built environment seen as socio-ecological networked assemblage. Accordingly, we adopted a new definition of *reliability* that draws on the regenerative approach (Mang and Reed 2012), as it emphasises co-creativity among human and non-human worlds (du Plessis 2012). Co-creativity emphasised by the regenerative approach assures the interdependence which should characterise a socio-ecological sustainable built environment. Within this last, the co-creative performances do neither belong to a building nor to its ecological dynamics: they represent the potential and existing regenerative socio-ecological relationships which mobilisation requires the involvement of local communities seen as an active (and not impersonal) agent of sustainability.

Having in mind the idea of *reciprocity* as regenerative, co-creative quality of the built environment, in i-UrBE evaluation approach *reliability* is reconceptualised as the ability of a design action to trigger a system of interactions among different agents composing the built environment (for example buildings, ecological dynamics, local communities) so to exploit its regenerative potential and transform it into regenerative capacities. *Reliability* has to express the ability of a design action (a plan, a project, a technical solution) to activate a co-creative system of interactions between the building and the *urban matrix*. Furthermore, *reliability* can no longer be a feature of an agent defined by generic actors: it has to be reconceived as a result of a democratic, collective judgment involving ethical issues and concerning responsibility, accountability and transparency of decisions and decision-makers.

This new focus on *reciprocity* and the co-creative performances signals a crucial shift in i-UrBE assessment framework. The new assessment framework describes the features of *reciprocity*, i.e. the kind and direction of transition towards sustainability triggered by the design process in the built environment (Fig. 2). Besides considering *reliability* in terms of the impacts produced by a sustainable building on the different kinds of metabolism of an *urban matrix*, the assessment of *reliability* also focuses on the transformations of *urban matrix* metabolism into a regenerative one. In particular, in the new assessment framework, *reciprocity* helps to define the kind and the ‘degree’ of *reliability*, and, hence, it helps to understand and navigate the transformation activated by sustainable building design actions in the *urban matrix* showing its changes towards co-creative performances.

At the present stage of the research, we have identified four evaluation criteria expressing *reciprocity* and that can help to assess *reliability* through holistic indicators. The evaluation criteria are: cooperation, regeneration, adaptation and alignment. These criteria are crucial to signal the regenerative, co-creative character of transformations enacted in the built environment. If the regeneration of existing situations of crisis and cooperation between natural and human systems are a basic characteristic of a regenerative metabolism, adaptive capacity between natural and technical systems has to be activated in order to deal with the uncertainty underlying any design activity and guarantee the resilience of built environment to stresses and disturbances (Mang and Reed, 2012; du Plessis, 2012). Last but not least, a process of alignment between economic development requirements and socio-ecological worlds of life has to be detectable. The evaluation criteria stress the relevance to adopt design choices beyond the dominant economic culture, technological constraints and contextual limiting imperatives.

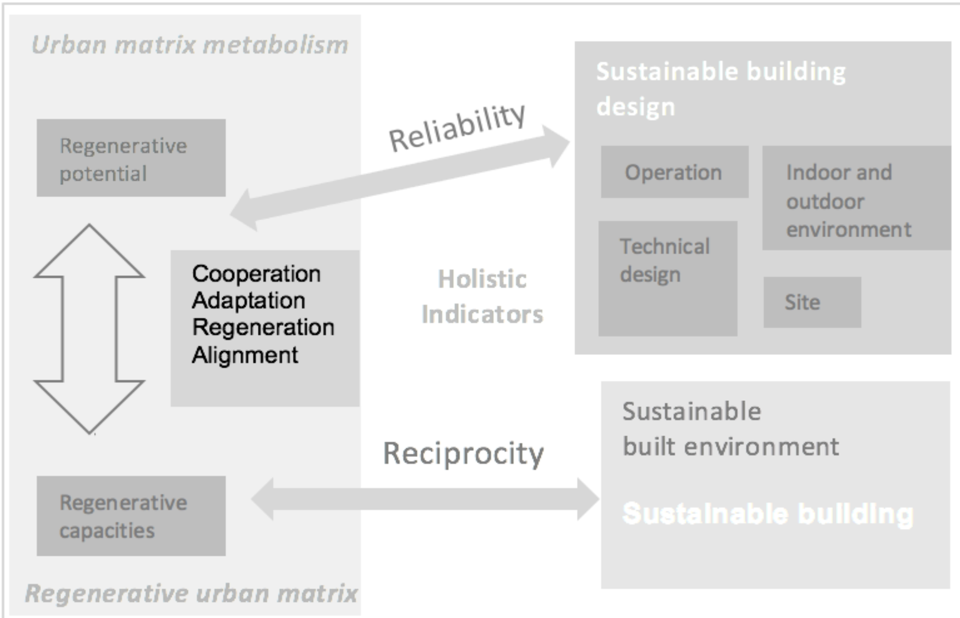

Figure 2: i-UrBE revised assessment framework

Operatively, the assessment framework enables to analyse how the regenerative potential of *urban matrix* shapes the sustainable building design and how, reciprocally, a sustainable building transforms that regenerative potential into capacities. However, due to the new definition of *reliability* in our assessment framework, the sustainability of a building can no longer be related to usual macro-categories describing its performances. They have to refer to the meta-design choices (a system of design actions) and their ability to trigger a regenerative process of a place. The vulnerability of the *urban matrix* remains an important parameter in the assessment. It still describes the variations of *urban matrix* resilience and metabolism and their regenerative direction. *Reliability* specifies the characteristic of that direction highlighting the kind of sustainability that is pursued through sustainable meta-design choices. The improvement of the assessment framework is showed by its ability to be applied to both urban and building design. In fact, for example, a sustainable urban plan has to produce reliable buildings.

Indirectly, *reciprocity* and the new definition of *reliability* highlight the transformative capacity, transversality, openness, and flexibility of the design process. The transformative capacity signals what and how much has been changed by the design process in the *urban matrix* metabolism. The transversality refers about the ability of a design action to interconnect socio-ecological relationships and shows the kind of interconnectedness (weak/strong). The openness highlights what has been ignored or lost in each of the four metabolic relationships and if there is any possibility to change the project of a sustainable building or neighbourhood. The flexibility coincides with the possibility to adapt the project to changing situations.

4. Conclusions

This paper argues that the problem of spatial integration in the design and evaluation of sustainability of the built environment cannot be solved by working within the current existing approaches supporting and supported by evaluative and assessment frameworks. In fact, they have been flourishing within a vision of the world in which social and ecological systems are separated and observed through detached, scalar and hierarchical dimensions and structure of analysis. The paper then proposes i-UrBE, an integrated urban-building approach based on a SES reconceptualization of the built environment and the regenerative perspective on sustainability; it is an approach suitable for designing, evaluating and assessing sustainable built environments. In a socio-ecological perspective on the built environment, spatial integration is a challenge and an opportunity to radically restructure sustainability in the city and support its design through evaluation. Furthermore, considering that evaluation is more than an accounting activity, why not use it as a learning tool to promote the cultural shifts required by the regenerative sustainability perspective, proceeding in practice in parallel to the theoretical issues?

Following these premises, the paper discusses opportunities and challenges which have emerged throughout i-UrBE development. In particular, the paper stresses the theoretical and operative relevance of both a socio-ecological perspective on the built environment and the concepts of *reciprocity* and *reliability* of the action in structuring the spatially integrated evaluation process.

Reciprocity and *reliability* of an action in i-UrBE open up new development prospects for the integrated evaluation and assessment of sustainability of the built environment since they help to:

- report on the socio-ecological and regenerative performance of the process;
- consider actions in a co-evolutionary and integrated spatial perspective;
- contextualise the action without disconnecting it from proximate and distant spatial relations;
- focus on meta-design actions;
- measure the ability of an action to stimulate the co-creative and adaptive capacities of the context and the level of activation of its regenerative potential;
- actively involve a wide range of actors, many of those are only rarely considered in the design and evaluation process;
- show potentialities of actions directed towards a regenerative development process.

In particular *reliability* stimulates innovation of available knowledge and current technologies – particularly those fielded and used in recent decades as an attempt to move towards a sustainable development– and encourages experimentation (de Vries and Peterson, 2009). At this stage of the research, we refrain from identifying the holistic indicators to assess *reliability* and the methods to measure them. As we have shown, *reciprocity* and r*eliability* assessment cannot be the result of an expert activity which randomly involves communities with the aim to complement or complete certain phases of the assessment and in relation to certain requirements of the evaluation procedure. Design choices, evaluation criteria and holistic indicators for measuring *reliability* can only be defined through a collective effort involving expert and local knowledge. Their dialogic and democratic construction will not exclude conflicts so to highlight what has still to be done towards the construction of a socio-ecological co-creative built environment.

Although in an ongoing process of development, i-UrBE already proposes a different way of thinking, speaking about, designing and evaluating sustainability in the city that we suggest can efficiently contribute to sustainability implementations. By focusing on *reciprocity,* the co-creative performances in the *urban matrix*, and *reliability* of buildings, i-UrBE offers a possible operative way to overcome the limits of existing scale-based frameworks for designing and evaluating sustainability in the city, thus making our judgment on sustainability more consistent.

Acknowledgments

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Building Information Modelling: Point of Adoption

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Abstract

Building Information Modelling (BIM) is the current expression of construction industry innovation generating a wide range of augmented market deliverables, new requirements and emergent roles. For organizations to cross the innovation chasm, they need to progressively implement complementary tools, workflows and protocols. Such multifaceted implementation is not instantaneous but passes through recursive periods of implementation readiness, capability acquisition, and performance maturity. Similarly, BIM diffusion within organizations is not a frictionless derivative of BIM implementation, but a function of competition dynamics and institutional isomorphic pressures. While there are a number of academic studies and industry surveys covering organisational readiness, software implementation or innovation diffusion, there is no single conceptual construct to describe, explain and test BIM adoption as a single construct connecting all these concepts. Based on published research and experiential knowledge, this paper introduces the Point of Adoption (PoA) model which integrates these concepts into a single visual model. The PoA model – not only clarifies the connection between these concepts but – facilitates the assessment of current organisational abilities, and clarifies a step-wise approach to BIM adoption and continuous performance improvement.

Keywords: BIM Implementation, Performance Assessment, Innovation Diffusion

1. Introduction

Building Information Modelling (BIM) is an expansive knowledge domain. Over the past few years, much research has been conducted into the connotations and impact of BIM tools and workflows on the construction industry. BIM has been repeatedly described as a 'disruptive technology' (Smith & Tardif, 2009, p. 32) instigating a 'process change' (Eastman, Teicholz, Sacks, & Liston, 2011, p. vii), or as an 'unbounded' and 'systemic' innovation (Harty, 2005, p. 51) (Taylor & Levitt, 2004, p. 84). These and other descriptions invariably position BIM as the *current* expression of innovation within the industry, and that BIM technologies, processes and policies are significantly impacting industry's deliverables, relationships and roles. While there are numerous studies relaying the many benefits of BIM, there are far fewer studies identifying the steps taken by organisations to realise these benefits. To remedy this shortfall, this article presents a performance model which overlays the concepts of BIM readiness, BIM implementation, and BIM diffusion.

2. Research Methodology

This section introduces the methodology used in developing the Point of Adoption model. The exercise builds upon and further extends the BIM Framework (Succar, 2009) by employing its existing conceptual constructs – terms, classifications, taxonomies, models and frameworks – to identify, explain and test new constructs. Through the 'BIM Framework's Conceptual Reactor' (Figure 1), a theory-building exercise is conducted using three iterative stages (J. R. Meredith, Raturi, Amoako-Gyampah, & Kaplan, 1989) (J. Meredith, 1993). The first stage develops a *description* of reality; identifies phenomena; explores events; and documents findings and behaviours. The second *explanation* stage builds upon descriptions to infer a concept, a conceptual relationship or a construct; and then, develops a framework or a theory to explain and/or predict behaviours or events. Finally, the third *testing* stage inspects explanations and propositions for validity; tests concepts or their relationships for accuracy; and tests predictions against new observables. The proposed Point of Adoption model follows a cyclical path as the one described by J. Meredith (1993) from describing; to explaining; to testing; and then back to describing. First, the model is generated through process of inductive inference (Michalski, 1987), conceptual clustering (Michalski & Stepp, 1987) and reflective learning (Van der Heijden & Eden, 1998) (Walker, Bourne, & Shelley, 2008). Second, conceptual models are developed to visually *explain* the knowledge structures. Third, each model is *tested* through either a focus group, peer-review questionnaire, or focus groups (Succar & Kassem, 2015).

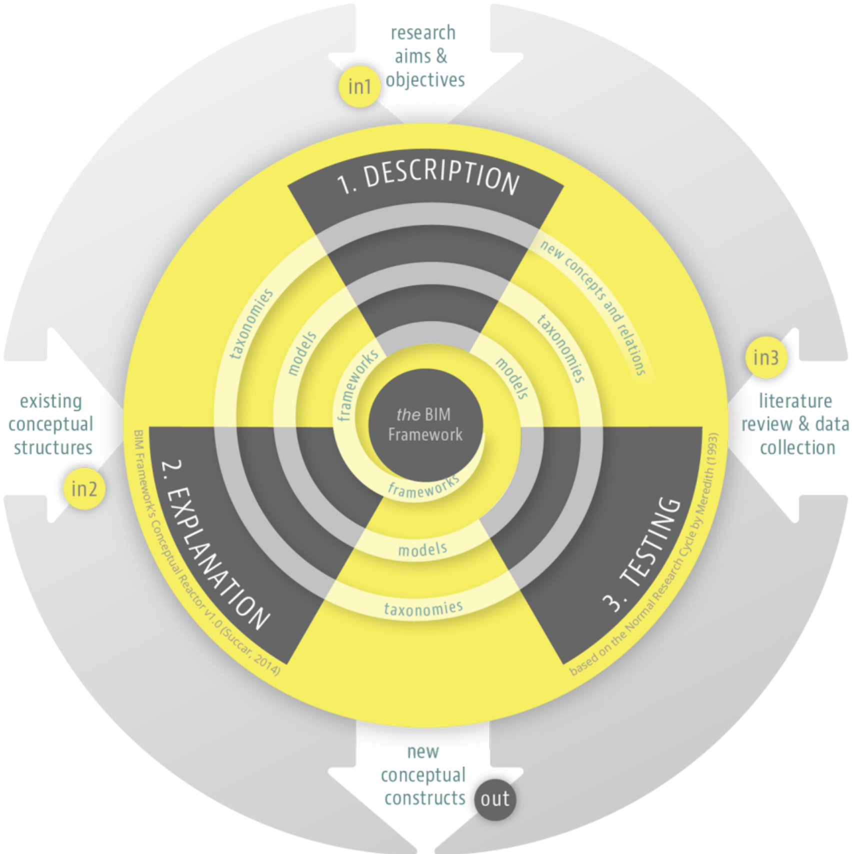

Figure 1. The BIM framework conceptual reactor

3. Terms, Concepts and their interaction

Before introducing the Point of Adoption (PoA) model, it is prudent to delimit a number of terms. The terms used to describe the act of implementing an innovative system/process are often confused with the terms used to describe the spread of this system/process within a *population* of adopters – be it within an organization or across a market. This delimitation is both artificial and necessary: it is *artificial* as other researchers can recalibrate the connotations of the same terms to fit their own unique purposes. It is *necessary* due to the availability of a large number of relevant diffusion models (Pierce & Delbecq, 1977) (Saga & Zmud, 1993) (Fadel, 2012) which do not differentiate between the stages of implementation - e.g. between acceptance and routinization as in Cooper and Zmud (1990) - the mechanics of diffusion, and the pressures causing the shift from one stage to another.

In introducing and delimiting these terms, we also limit ourselves to BIM as an innovative set of tools, processes and policies within the construction industry. This limitation is also both artificial and necessary: it is *artificial* as implementation/diffusion models introduced later are arguably applicable to other innovations within and outside the construction industry (e.g. to GIS and PLM). It is *necessary* due to the dearth of investigations covering innovation diffusion within the construction industry (Taylor & Levitt, 2004) thus warranting – as exemplified below - a focused attention on industry-specific and, by extension, BIM-specific terms.

3.1 BIM Implementation

Implementation refers to the wilful activities of an identifiable player[1] as it adopts a novel system/process to improve its current performance. More specifically, *BIM implementation* refers to the set of activities undertaken by an *organizational unit* to prepare for, deploy or improve its BIM deliverables (products) and their related workflows (processes). BIM implementation is introduced here as a three-phased approach separating an organization's *readiness* to adopt; *capability* to perform; and its performance *maturity*:

- BIM readiness is the *pre-implementation status* representing the propensity of an organization or organisational unit to adopt BIM tools, workflows and protocols. Readiness is expressed[2] as the *level of preparation*, the *potential to participate*, or the c*apacity to innovate*. Readiness can be measured using a variety of approaches – product-based, process-based, and overall maturity (Saleh & Alshawi, 2005) – and signifies the planning and preparation activities preceding implementation;
- BIM capability is the wilful *implementation* of BIM tools, workflows and protocols. BIM capability is achieved through well-defined *revolutionary stages* (object-based modelling, model-based collaboration, and network-based integration) separated by numerous *evolutionary steps* (Succar, 2009). BIM capability covers many technology, process and policy topics and is expressed as the *minimum ability* of an organization or team to deliver a measureable outcome; and
- BIM maturity (or *post-implementation*) is the *gradual and continual improvement* in quality, repeatability and predictability within available capabilities. BIM maturity is expressed as *maturity levels* (or performance improvement milestones) that organizations, teams and whole markets aspire to. There are five maturity levels: [a] Ad-hoc or *low maturity*; [b] Defined or *medium-low maturity*; [c] Managed or *medium maturity*; [d] Integrated or *medium-high maturity*; and [e] Optimised or *high maturity* (Succar, 2010).

3.2 BIM Diffusion

In contrast to *implementation* which represents the successful adoption of a system/process by an organization, diffusion represents the spread of the system/process across the organization. That is, the diffusion of a solution occurs after the solution has been adopted (Peansupap & Walker, 2005) or what we term as the *Point of Adoption* (PoA). However, the mere acquisition of an innovative solution (e.g. a software) "need not be followed by widespread deployment and use by acquiring organizations" (Fichman & Kemerer, 1999, p. 256).

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[1] Depending on the 'scoping lens' applied, BIM players are either individuals, groups, organizational units, or whole organizations. BIM players, deliverables and their requirements have been extensively covered in earlier works (Succar, 2009).
[2] Definitions adopted from the e-commerce context as used by the Asia-Pacific Economic Cooperation (APEC), Center for International Development (CID) at Harvard University (CID, 2014).

E. M. Rogers (1995, p. 5) defines diffusion as the "process by which an innovation is communicated through certain channels over time among the members of a social system", a definition that covers the increase in "number of firms using or owning a technology (inter-firm diffusion) [and the] more intensive use of the technology by the firm (intra firm diffusion)[3]" (Stoneman & Diederen, 1994, p. 919) (Mansfield, 1963). Diffusion is also identified as the third and final phase of the well-noted Schumpeterian Trilogy: "invention (the generation of new ideas), innovation (the development of those ideas through to the first marketing or use of a technology) and diffusion (the spread of new technology across its potential market)" (Stoneman & Diederen, 1994, p. 918).

There are numerous studies dedicated to innovation diffusion across a population of adopters (Bass, 2004; Kale & Arditi, 2010; Mansfield, Rapoport, Romeo, Wagner, & Beardsley, 1977; E. M. Rogers, 1995). These studies either explain and expand-upon the S-curve diffusion pattern (Cumulative Normal Distribution) (Everett M Rogers, Medina, Rivera, & Wiley, 2005) consistently encountered when analysing the spread of innovation; or introduce *diffusion models* that "depict the successive increases in the number of adopters and predict the continued development of a diffusion process already in progress" (Mahajan, Muller, & Bass, 1990, p. 2).

According to Geroski (2000), there are two main types of diffusion models providing insights into the manner and speed of technology adoption – the epidemic model and the probit model. The 'epidemic' diffusion model attributes the diffusion of technology (software in particular) to a given population's knowledge of its existence; its comparative benefits; and the spread of its use through word of mouth. As a result, in the epidemic model the spread of innovation is largely affected by the transfer of knowledge and information among the involved population. As it focuses on a whole population of adopters, the epidemic model is interested in the gradual, unfolding impact of a new system/process on a market through its aggregate use. This contrasts with the 'probit' and 'salience' diffusion models which focus on the effect of *individual decision-making* on the spread of innovation and account for the differences in adoption time between individuals due to their distinct goals, needs and abilities (Geroski, 2000, p. 614; Strang, 1991).

This individual decision-making affecting diffusion follows three identifiable patterns – contagion, social threshold and social learning (Young, 2006, p. 4):

- Contagion represents how an industry player (e.g. an engineer or an engineering company) adopts an innovative system/process upon *contact with another player* who has already adopted it;
- Social Threshold represents how an industry player adopts an innovative system/process when *enough similar players* have adopted it; and
- Social Learning represents how an industry player adopts an innovative system/process when *enough proof is available* of prior adopters finding it worth adopting.

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[3] To avoid conceptual overlap, the spread of a solution within an organizational unit will not be referred to as intra-diffusion but as improved implementation (or higher level of maturity) across the whole organization.

These diffusion models and patterns have been shown to collectively describe and help predict the incremental diffusion of technological solutions across a population. However BIM is not solely an innovative technological solution proliferating incrementally across the construction industry (Fox & Hietanen, 2007) (Mutai, 2009) (Gu & London, 2010) but a an organizational and *systemic* innovation (Taylor & Levitt, 2004) of complementary technologies, processes and policies. While BIM may be initially classified as a *technical innovation* (Murphy & Wardleworth, 2014), it will need to be urgently reclassified - upon its transformative adoption by organizations - as an *organizational innovation* characterised by the "generation, acceptance, and implementation of new ideas, processes, products or services" (OECD, 2005; Thompson, 1965, p. 2).

As covered in depth in earlier research (Succar, Sher, & Williams, 2012) and briefly explored in Figure 1, BIM adoption by an organization passes through three adoption points pertaining to three capability stages. Even if multiple organizations pass through the first Point of Adoption (PoA) separating pre-BIM status from minimum BIM capability (Stage 1), the spread of *modelling* practices among this population does not necessarily or automatically translate into a diffusion of multidisciplinary *collaboration* or interdisciplinary *integration* practices (Stages 2 and 3 respectively). Similarly, BIM is not a mere technological solution but reflects a combinatory and mutational diffusion of technologies, workflows and protocols (Merschbrock & Munkvold, 2014) (Yoo, Richard J. Boland, Lyytinen, & Majchrzak, 2012). This multi-stage, multi-faceted, and multi-component nature of BIM – resembling a *complex adaptive system* (Johnson, 2002) - prevents the effortless application of technology-centric diffusion modelling and invites the development of more representative BIM adoption models.

4. Point of Adoption Model

The Point of Adoption (PoA) model combines many of the concepts introduced earlier (Figure 2). In addition to distinguishing between invention, innovation and diffusion (Stoneman & Diederen, 1994), the three implementation phases – readiness, capability, and maturity - are also depicted). As explained further below, PoA is a term that identifies the juncture(s) where organizational readiness transforms into organizational capability:

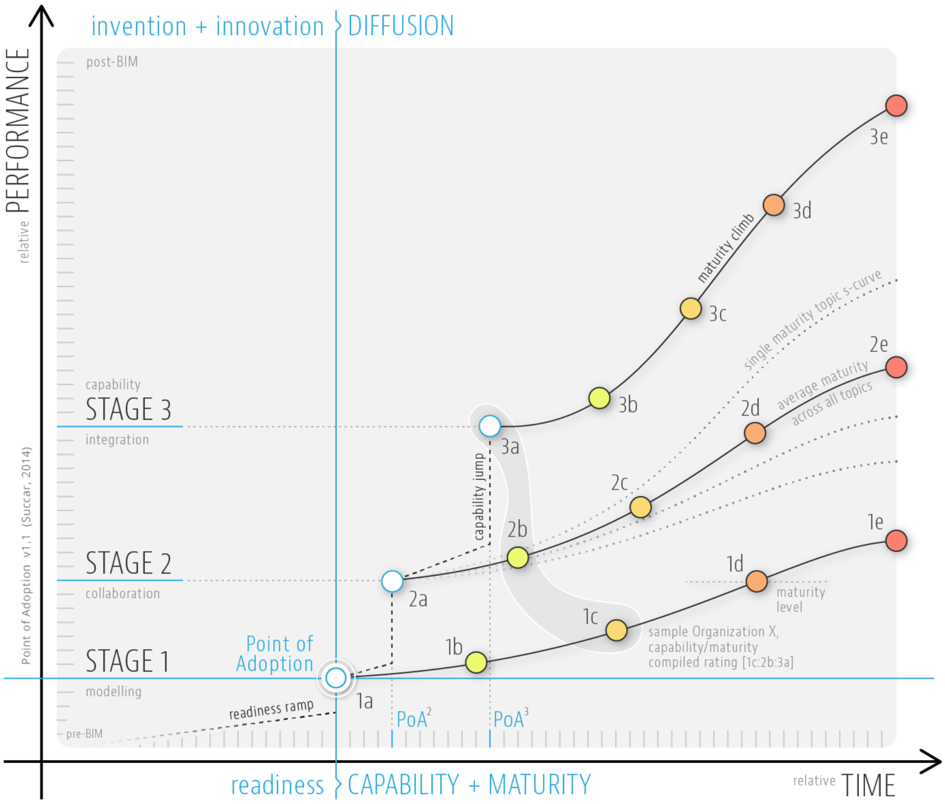
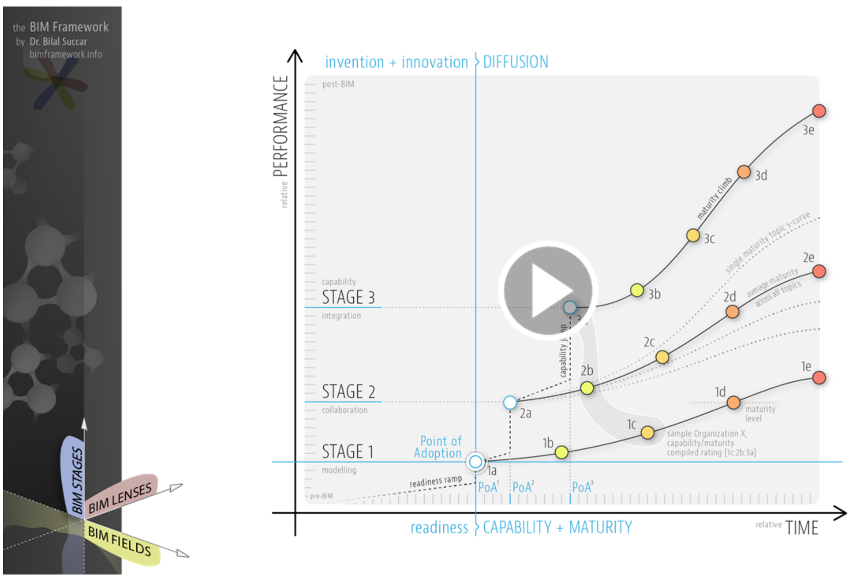


Figure 2. Point of Adoption model v1.1 (full size, current version)



Video 1 . Point of Adoption Video (YouTube Link[4])

[4] Point of Adoption (PoA) video on YouTube: https://www.youtube.com/watch?v=weMqv31Np_4 (16:33)

As explored in Figure 2 and clarified in Video 1, transformative BIM adoption starts at the Point of Adoption (PoA) when an organization, after a period of planning and preparation (readiness), successfully adopts *object-based modelling* tools and workflows. The PoA[5] thus marks the initial *capability jump* from no BIM abilities (pre-BIM status) to minimum BIM capability (Stage 1). As the adopter interacts with other adopters, a second capability jump (Stage 2) marks the organization's ability to successfully engage in model-based collaboration. Also, as the organisation starts to engage with multiple stakeholders across the supply chain, a third capability jump (Stage 3) is necessary to benefit from integrated, network-based tools, processes and protocols. Each of these capability jumps is preceded with considerable investment in human and physical resources, and each stage signals new organizational abilities and deliverables not available before the jump. However, the deliverables of different organizations at the same stage may vary in quality, repeatability and predictability. This variance in performance excellence occurs as organizations climb their respective BIM *maturity curve*, experience their internal BIM diffusion, and gradually improve their performance over time[6].

The multiple maturity curves depicted in Figure 2 reflect the heterogeneous nature of BIM adoption even within the same organization (e.g. sample Organization X in Figure 2 has a compiled rating of 1c, 2b and 3a). This is due to the phased nature of BIM with each revolutionary stage requiring its own readiness ramp, capability jump, maturity climb, and point of adoption. This is also due to varied abilities across organizational sub-units and project teams: while organizational unit A1 (within organization A) may have elevated *model-based collaboration* capabilities, unit A2 may have basic modelling capabilities, and unit A3 may still be at the readiness stage preparing to implement BIM software tools. This variance in ability necessitates a compiled rating for organization A as it simultaneously prepares for an innovative solution, implements a system/process, and continually improves its performance.

5. Conclusions

The Point of Adoption (PoA) model represents the sequence and relationship between multiple performance assessment concepts. By overlaying the readiness, implementation, invention, innovation and diffusion concepts into a single term, and into a single visual representation, the PoA model clarifies the progression of BIM adoption within and across organisations. Also, through well-defined BIM Capability Stages and BIM Maturity Levels, the PoA model offers a simplified template for measuring BIM performance as well as for planning structured BIM adoption activities.

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[5] The Point of Adoption (PoA) is not to be confused with the critical mass 'inflection point' on the S-curve (E. M. Rogers, 1995) (Everett M Rogers et al., 2005); or with the 'tipping pint', the critical threshold introduced by Gladwell (2001).

[6] The X-axis in Figure 2 represents time relative to each PoA, not as an absolute scale. That is, this version of the chart does not represent a snapshot view of compiled capability/maturity at a specific point in (absolute) time.

The PoA model has several theoretical and practical implications. At the theoretical level, it demonstrates how (a) BIM is a multifaceted innovation; (b) current theories of innovation diffusion may be inadequate for studying BIM diffusion; (c) it is possible to overlay the concepts of readiness, implementation and diffusion into a single adoption model; and (d) the need for a more in-depth theoretical study to underpin BIM adoption and multifaceted innovation diffusion.

At the practical level, the PoA model highlights (e) the simultaneous coexistence of varying BIM abilities within the same organisation; (f) the need to account for these variances when certifying organisations or pre-qualifying tender participants; and (g) the need to revise or discard the prevailing market maturity assessment methods which do not account for such variances.

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The Use of BIM in the Singapore Construction Industry: Opportunities and Challenges

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Abstract

The Singapore government has been actively promoting the use of Building Information Modelling (BIM) in the construction industry. Since 1 July 2015, all plans of new building projects with gross floor area (GFA) of 5,000 sq. m. and above have to be submitted in BIM format. Moreover, raising productivity in all sectors has been the top priority. On the safety part, the government has introduced a number of initiatives, with the main aim of reducing fatalities to 1.8 per 100,000 workers by 2018. Taking advantage of these initiatives, there are opportunities to maximise the potential of BIM to help improve productivity and safety in the industry. Semi-structured interviews were carried out from January to December 2014 to find out the industry's views on the current state of BIM, productivity and safety in the construction industry in Singapore. It was revealed that despite the support from the government and the opportunities offered by BIM, the industry faced a number of challenges in the implementation of BIM. They include collaboration, technical, legal issues, time and cost consideration. Many of the respondents acknowledged that BIM has a lot of potential, yet this had not been maximised. Much more needs to be done to further utilise BIM for improving productivity and safety in the industry. Hence, the paper highlights an intelligent system which has been designed to provide solutions for the challenges and create opportunities for the industry to derive greater benefits from BIM. The system incorporates both productivity and safety performance, using BIM as the platform.

Keywords: BIM, challenges, opportunities, productivity, safety

1. Introduction

1.1 Overview

The Singapore government has been actively promoting the use of Building Information Modelling (BIM) in the construction industry. It has identified BIM as a critical tool in the national productivity drive, which has the aim of raising the level of productivity in all sectors of the economy, including construction. Since 1 July 2015, all plans of new building projects with gross floor area (GFA) of 5,000 sq. m. and above have to be submitted for development approval in BIM format. On the safety part, the government has introduced a number of initiatives, with the main aim of reducing national fatalities to 1.8 per 100,000 workers by 2018. Singapore's Workplace Safety and Health Council (WSHC) outlined the national WSH 2018 vision, which is "A safe and healthy workplace for everyone and a country renowned for best practices in WSH" (WSHC, 2010). Taking advantage of these initiatives, there are opportunities to maximise the potential of BIM to help improve productivity and safety in the industry. However, the implementation of BIM by the firms is not without challenges. The paper outlines the opportunities offered by BIM and some of the challenges encountered by some of the firms in the construction industry of Singapore on their BIM journey. The paper also highlights an intelligent system which has been developed to address the challenges. The system was designed to provide solutions for the challenges and create opportunities for the industry to derive greater benefits from BIM.

1.2 Singapore's BIM Roadmap

Governments worldwide, including Denmark, Finland, Norway, South Korea, UK, and USA play an important role in leading the construction industry in BIM adoption. Singapore is one of a few countries in Asia which have implemented BIM (Wong *et al.*, 2009). Others are Hong Kong, PRC and South Korea. In Singapore, the Building and Construction Authority (BCA) implemented the BIM Roadmap in 2010 with the aim that 80 percent of the construction industry would use BIM by 2015. This is part of the government's plan to improve the construction industry's productivity by up to 25 percent over the next decade (BCA, 2011). The latest survey on BIM adoption (Lam, 2014) shows that almost all the firms in Panel One of the public-sector panel of consultants have adopted BIM (Figure 1). However, the adoption rate was not that high for contractors (Figure 2).

BCA introduced a number of initiatives to prepare the industry, following the BIM Roadmap (Figure 3). After the first BIM Roadmap was launched, a National BIM Steering Committee, comprising representatives of professional institutions, trade associations, major government procurement entities and regulatory agencies, was set up in 2011 to provide a governing framework to steer the implementation of the BIM Roadmap (BCA, 2013b). The committee led the development of the "Singapore BIM Guide" and "BIM Particular Conditions". Platforms such as BIM Manager Forums have been organised to discuss and address technical issues faced by the industry.

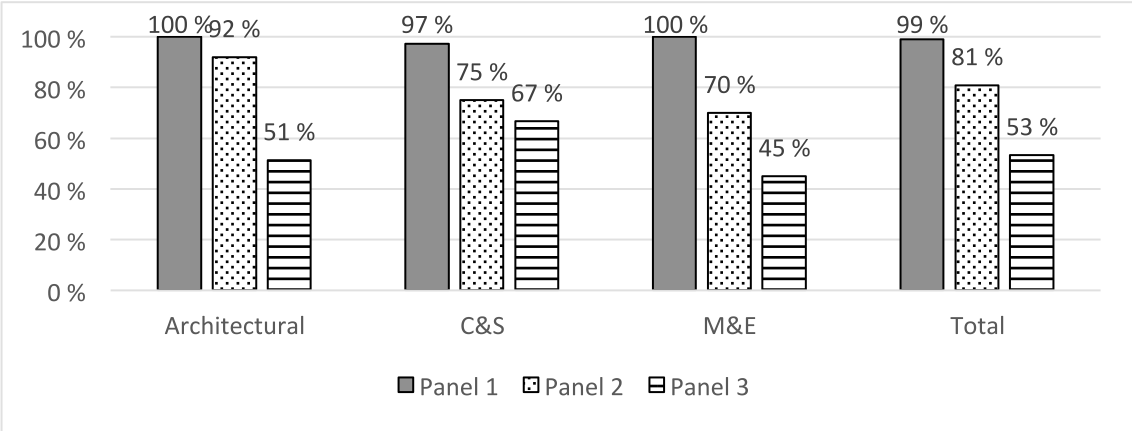

Figure 1. BIM adoption landscape of the public sector panel of consultants in the Singapore construction industry. Source: Lam (2014).
** Tendering limits:*
Panel 1: S$90 million
Panel 2: S$42 million
Panel 3: S$14 million

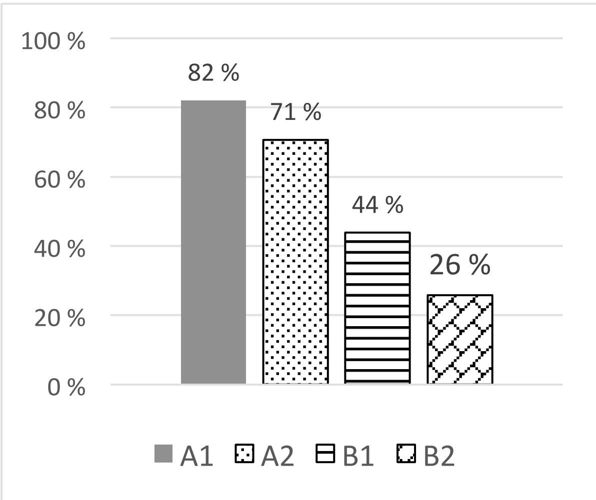

Figure 2. BIM adoption landscape of the Grade A1-B2 contractors. Source: Lam (2014).

** Tendering limits:*
Grade A1: unlimited
Grade A2: S$90 million
Grade B1: S$42 million
Grade B2: S$14 million

One of the initial challenges recognised in the BIM Roadmap is the need to obtain the manpower and financial resources needed to build up BIM expertise. To meet the high demand for skilled BIM manpower, BCA had been working closely with relevant Institutes of Higher Learning (IHLs), BCA Academy and BIM vendors to organise training and incorporate BIM in academic programmes. To overcome the challenge of obtaining the financial resources, the BCA BIM Fund provides incentives to construction firms to adopt BIM.

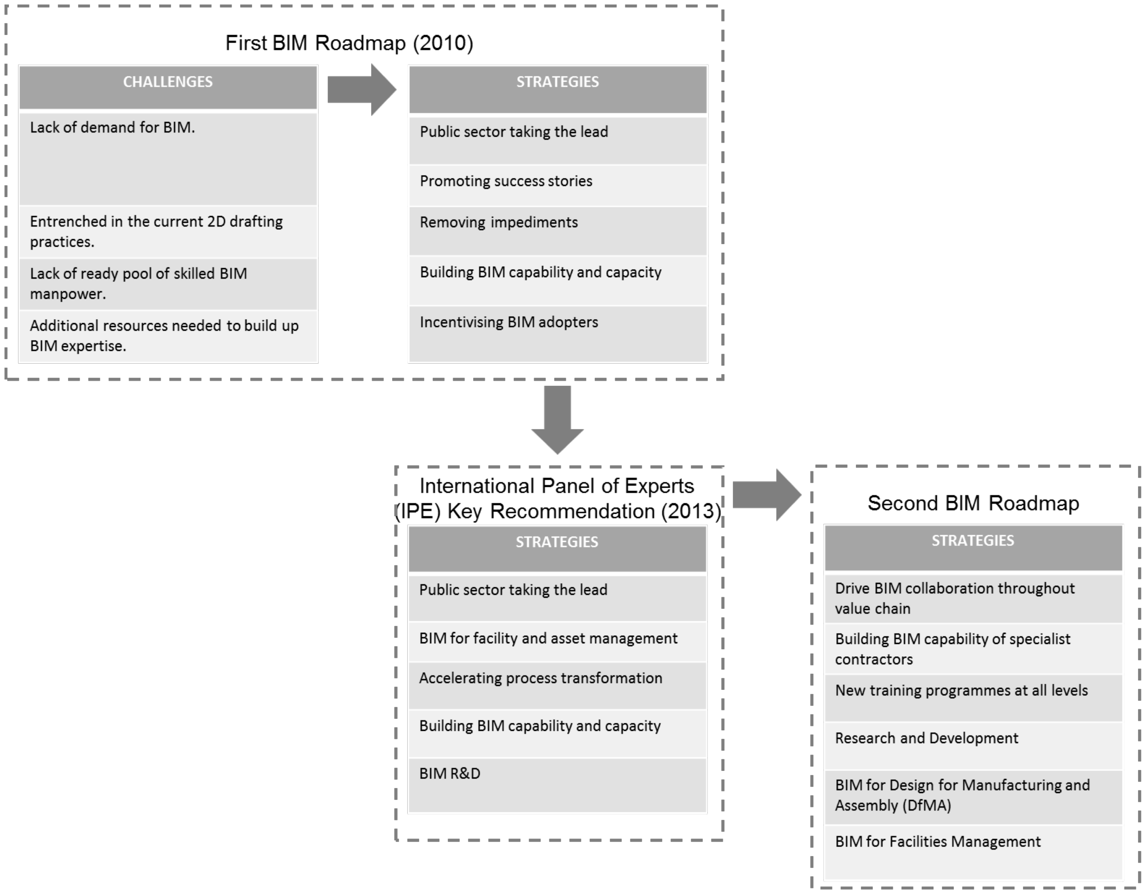

Figure 3: Singapore's BIM Roadmap. Source: Adapted from Lam (2014).

In 2014, the second BIM Roadmap was launched after the International Panel of Experts in BIM proposed a number of key recommendations, which included the public-sector taking the lead, BIM for facility and asset management, accelerating process transformation, building BIM capability and capacity and BIM R&D (Lam, 2014). The report presented a review of the current state of BIM adoption. The developers are detached from the BIM process and lack the know-how to drive the process. The consultants focus too much on e-submission and lack the time to undertake design co-ordination. Main contractors commented on the lack of quality models from consultants. The main contractors are currently not taking advantage of the full potential of BIM to resolve issues with consultants and subcontractors. The specialist subcontractors lack BIM skills. There is a lack of BIM usage for facilities management. It was also highlighted that there is a lack of BIM collaboration among project participants.

Hence, the main focus of the second BIM Roadmap is to drive BIM collaboration throughout the value chain. The funding level from the BCA BIM Fund had been increased from 50 percent to 70 percent for Project Collaboration Scheme. The "Singapore BIM Guide" and "Public Sector BIM Requirement" would be reviewed to include BIM coordination and model handover. Procurement methods and contract conditions would be developed based on BIM.

2. Literature Review: Opportunities and Challenges

The emphasis on national productivity and safety improvement, together with the drive for industry-wide BIM implementation, provides an opportunity for investigating how BIM could be used for improving productivity and safety in the construction industry.

BIM, as a process, allows the exchange of information among the project stakeholders, such as architects, engineers, contractors, consultants and clients. BIM is able to generate and analyse different views, data and information appropriate to various users' needs, which can be used to facilitate decision making and to improve the process of delivering the facility (AGC, 2010). The important feature of BIM is its capability to enable the item to be constructed to be built virtually, prior to building it physically, in order to identify and resolve problems, and simulate and analyze potential impacts (Smith, 2007). BIM can be used for many other purposes in the design and construction process such as visualization, scope clarification, trade coordination, collision detection and avoidance, design validation, construction sequencing planning, plans and logistics, marketing presentations, options analysis, walk-throughs and fly-throughs, virtual mock-ups and sight-line studies (AGC, 2010).

Teo (2014) discussed how BIM could be utilised help to improve productivity and safety in a number of ways. BIM could result in productivity improvement due to reduction in the disruption of the flow of information in the design and construction stages; effective response to changes during the construction stage; improved communication and collaboration among stakeholders in the construction project; informed decision-making; information sharing and interoperability; and fewer changes, less workload and more savings. The application of BIM in construction may improve the performance of onsite operations due to the reduction of manual efforts, time and costs involved (Gong and Caldas, 2011). During the construction phase, BIM contributes to the success of a project by enabling practitioners to effectively control schedule, budget and quality, and to reduce risks (Ku and Mills, 2008). Sacks and Barak (2006) report the reduction of total number of hours spent on three construction projects owing to the use of 3D modelling instead of 2D. Nath *et al*. (2015) found productivity improvements in the precast shop drawing generation due to the use of BIM.

Teo (2014) further argued that BIM could lead to safety improvement because BIM helps practitioners visualise the compatibility of architectural, structural and mechanical and electrical (M&E) design aspects, as well as feasibility of construction of design features or elements. BIM is able to simulate each step of work activities so that construction sequencing and the required safety measures may be identified. BIM also facilitates the communication of any identified safety risks to relevant stakeholders. Zhang *et al*. (2013) developed an automated safety checking platform which is able to inform construction engineers and managers of the various safety measures needed to prevent fall-related accidents before construction starts. The system automatically analyses a building model to detect safety hazards and suggest preventive measures to users. Benjaoran and Bhokha (2010) developed a rule-based system that is able to detect any work-at-height related hazards and propose necessary safety measures. Factors related to building components and activities such as component type, dimensions, placement, working space, activity type, sequence, and materials and equipment are used as input data. These factors are examined to find any work-at-height hazards. Thereafter, the system is able to suggest necessary safety measures including activities or requirements. Choi *et al*. (2014) developed a BIM-based evacuation regulation checking system for high-rise and complex buildings. Their system allows architects, designers and owners to evaluate the design at the design stage to ensure that the design meets the design requirements. Continuous checks are possible due to an automated system and detailed guidelines.

Although BIM has the potential to improve overall construction project performance, it is also widely acknowledged that BIM brings about various challenges in its implementation. Among others, BIM requires collaboration among the project stakeholders. To implement BIM, owners and general contractors must select subcontractors with BIM experience. This changes the contractor selection process, which traditionally focuses on the lowest bidder. Meanwhile, BIM implementation requires a significant up-front investment. Furthermore, construction safety professionals often are involved late in the project development process, which does not allow them to contribute to BIM effectively. Technical challenges are also commonly encountered (Rajendran and Clarke, 2011). For example, adding construction safety elements and temporary systems such as scaffolding, boom lifts, cranes and scissor lifts into BIM can be a challenge.

3. Field Study

3.1 Interviews

The information for the part of the field study reported on this paper was obtained from a series of semi-structured interviews with representatives of twelve firms and institutions in the construction industry in Singapore. Semi-structured, face-to-face interviews were carried out from January to December 2014. The main objective of the interviews was to find out the views of the practitioners in Singapore's construction industry on the current state of BIM, productivity and safety in the industry.

There was a total of 30 interviewees from six contractors, two architectural firms, one cost consultancy firm; and representatives of a professional institution, a trade association, as well as representatives from the government. Selection of the interviewees involved a snowballing sampling technique. The first group of interviewees was identified from reports and articles indicating that they had played a key role in implementing BIM in their projects; or their companies had exceptional productivity and safety performance records.

3.2 Findings: Opportunities and Challenges

The interviews revealed that the firms were utilizing BIM at different levels. Some firms had been using BIM at relatively advanced levels. Some other firms still used BIM at the beginning stage, mainly for meeting the statutory requirements of building plan submissions in BIM format. One firm was still testing the use of BIM internally, to prepare itself for full BIM implementation.

The interviewees acknowledged that BIM brings about many benefits. It helps to visualise, highlight the problems and propose solutions before construction starts. Project stakeholders could view, discuss and analyse different scenarios. BIM is also able to minimise communication and coordination problems among the different disciplines involved in a construction project.

The form of support from the government which had been most popular with the firms was the financial support provided. The majority of the firms of the interviewees had utilised the BIM Fund to the maximum limit. They acknowledged that the funding had been useful and expected that there will continue to be assistance from the BIM Fund in the future.

The interviews gathered that the firms faced a number of challenges in the implementation of BIM, three of the main ones of which are now highlighted. Firstly, BIM implementation requires a multi-disciplinary approach. Specifications in great details from consultants and contractors are required to develop a useful BIM model. For example, to integrate scaffolding specifications with design specifications, information from formwork or scaffolding suppliers is needed. However, many of the parties were concerned with the confidentiality of the information on their projects; hence, it sometimes took a longer time than necessary to share the required information.

Most of the time, an initiative from one of the project stakeholders is able to push the implementation of BIM. For example, one contractor took the initiative to develop an in-house BIM division and train its own personnel in BIM. The contractor developed the BIM models obtained from the consultants further. It also made sure the subcontractors (for the M&E works in this case) to update the BIM models so that the models could be coordinated with the architectural and structural models. It required a great deal of commitment as a significant amount of investment in terms of time, training and equipment is required. Some of the challenges include additional time commitment required for updating the models throughout the duration of the project. For example, subcontractors prefer 2D drawings to 3D and BIM models as they had more experience with the former than the latter. A significant amount of time was spent on modelling and checking as models submitted for submission often are not up to the standard required in the subsequent stages of the project. Hence, they still need to be further developed. In terms of human resources, it was always a challenge getting the people competent in BIM, since there was an acute shortage of these persons. The BIM team in the office needed more support from the site, hence the site team needed to be trained as well. The reluctance of the site personnel to provide this support was mostly due to lack of knowledge, skills and time. As contractors and subcontractors are often under pressure to meet project deadlines, there was no sufficient time for developing the BIM competence required. For similar reasons, there was also no time for continuous and complete updating of the models.

Secondly, in terms of legal framework, there are still uncertainties of the legal responsibilities. For example, a BIM server is expensive. There is also an issue of maintenance costs. Thus, the server will have to be put into the contract for the project. There are also issues of intellectual property from, and ownership of, the BIM developed in earlier stages of the project, as well as responsibility for errors in the BIM. Furthermore, when the project ends, there is a question of who should take ownership of the BIM on the project. Most of the firms interviewed suggested that it would be most appropriate for the client to take ownership of the BIM models.

Some consultants and contractors acknowledged that there is a need to align what the developers want with what the project team can deliver. Many consultants were still not ready to meet the developers' expectations; such as the need to launch the sale of units in the project as soon as possible. Some contractors and consultants also provided the feedback that they were not ready for a full-scale BIM implementation. Hence, some contractors and consultants proposed that BIM should be implemented in stages. There was a need for all project participants to collaborate effectively. All in all, the interviewees suggested that developers should take the lead in the process of developing and using the BIM, but have realistic expectations from the project teams.

Thirdly, there were technical issues. Those which were most commonly encountered by interviewees were: interface issues, the loss of information when transferring the models from one software to another, licenses, bandwidth and security. One technical issue that was commonly encountered by the industry was because BIM models were created using different versions of the popular software. If the models had been prepared using earlier versions of the software, which are no longer available in the market, there will be some productivity loss due to the time spent contacting the manufacturer directly to obtain the particular version of the software before they were able to gain access to the models.

Another example was when one contractor was trying to transfer the BIM models to another party. They were discussing with the BIM vendor on how to transfer the models without losing much information. However, the BIM vendor was unable to resolve the issues. As a result, the other party had to use BIM models which were not the most comprehensive; a considerable amount of time was needed to put in additional information before the BIM models could be used by the other party.

Some other difficulties encountered were because the BIM models were of low level of detail. Hence, a great deal of time and effort was needed to improve the quality of the models so that rule-checking and quantity calculation could be performed.

4. Proposed Intelligent System for Productivity and Safety Improvement

Realising the challenges that the Singapore construction industry faced, an intelligent system has been developed which incorporates both productivity and safety performance, using BIM as the platform. The proposed system is the key deliverable of a research project funded by the

Ministry of Manpower, Singapore. The system, named Intelligent Productivity and Safety System (IPASS), was designed to provide a solution to improve productivity and safety performance by addressing the challenges and creating opportunities for the industry to maximise the benefits of BIM (Figure 4). IPASS enables collaboration among the project stakeholders as they analyse the productivity and safety performance before the start of a project. The system comes with a BIM modelling guide which specifies the method of inputting information in some detail. Thus, it will help to minimise disputes and improve the level of details of the BIM models developed by the consultants and contractors.

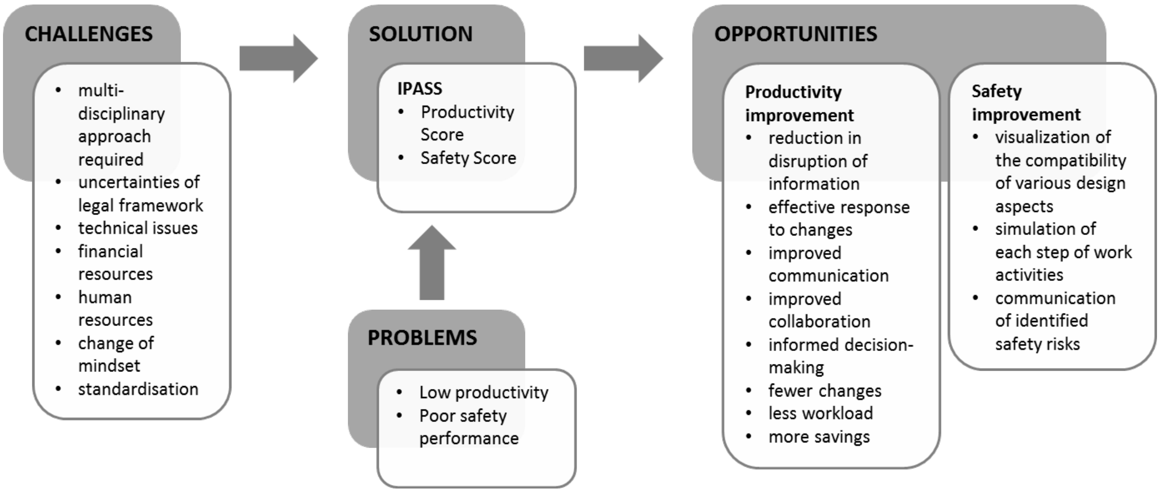

Figure 4. The development of IPASS as one of the solutions which can overcome the problems and challenges faced by the industry and create opportunities.

The system is also able to act as a monitoring tool for productivity and safety performance as the project progresses. IPASS automatically identifies safety hazards and provides solutions to mitigate the identified hazards. IPASS also allows the users to apply different structural and wall systems and see how they affect the buildability score individually or in combination, and to work to achieve the targeted score. Hence, during different stages of a construction project (pre-construction, design and construction stages), IPASS is able to help designers look at and improve the productivity and safety aspect of the design of a building. BIM models generated will help to visualize the different scenarios, enabling continuous productivity and safety monitoring.

The productivity score is computed based on the Buildable Design Score (BD Score) of the BCA's Buildable Score Assessment System (BDAS). The BD Score of a project is made up of three parts: Structural System (maximum 45 points), Wall System (maximum 45 points) and Other Buildable Design Features (maximum 10 points). The maximum productivity score achievable is 100 points. The BDAS was developed by the BCA as a means to measure the potential impact of a building design on the usage of site labour (BCA, 2014). Over the years, BCA has increased progressively the minimum BD score for building plan approval; this is aimed at boosting productivity. Hence, it is necessary for designers to include more productive technologies and standard components in the building design.

The safety score is computed based on the prevention and control of hazards detected in the structural systems and wall systems, and the Construction Safety Audit Scoring System (ConSASS) assessment. ConSASS is a tool to measure the maturity of the WSH system which includes its documentation and implementation, aiming at providing a standardized scoring system for the construction industry (MOM, 2013). ConSASS is aimed to provide an easy comparison between construction sites in term of their effectiveness in managing safety and health risks. ConSASS consists of an audit checklist and a score card. The audit checklist is derived from the Singapore Standards for Occupational Safety and Health Management System (SS506), Code of practice for safety management systems for construction worksites (CP 79) and the Universal Assessment Instrument (UAI) published by the American Industrial Hygiene Association (AIHA). The questions in the checklist are grouped into bands, from Band I to IV, in order to reflect the increasing level of maturity of the elements being audited. The results are tabulated in the score card, which shows the maturity of the different elements in the Occupational Safety and Health Management System (OSHMS).

The maximum safety score that can be achieved based on the prevention and control of hazards is 90 (maximum 45 points for the structural system and maximum 45 points for the wall system). ConSASS assessment is taken into consideration by giving the building a score for each band attained (from Band I to IV). The maximum score that can be achieved through ConSASS assessment is 10, which is when the building under assessment could achieve the highest band (Band IV). The maximum safety score achievable from the prevention and control of hazards as well as ConSASS assessment is 100 points. The full details on the development of the system can be found in other paper/s.

5. Conclusion

The Singapore government is playing an important role in leading the industry construction industry in adopting BIM through the first and second BIM roadmap, launched in 2010 and 2014 respectively. The roadmap put in place a number of strategies necessary for BIM implementation in the industry. However, it would appear that many firms in the construction industry in Singapore have yet to utilise BIM to its maximum potential. There are a lot of opportunities to utilise BIM for more strategic and important tasks than the current application for visualisation and meeting the requirements of building plan submissions.

The paper highlighted three challenges commonly encountered by the local firms. Firstly, successful BIM implementation requires a multi-disciplinary approach, but many players are still not ready for full collaboration since developing a useful BIM model requires sharing of information and specifications in great details. Secondly, there are still uncertainties of the legal responsibilities. The firms were still unclear about maintenance costs and the ownership of the BIM. Thirdly, there are still some important technical issues that have to be solved.

To bring BIM and its application to a higher level, it is essential to address those challenges. BCA had been trying to address some of the challenges. The second BIM Roadmap focuses on this. BIM can be utilised at a more advanced level when the construction industry has addressed the more fundamental issues. Some suggestions include involvement of all project stakeholders (rather than leaving it to the authority); initiatives and drive towards process transformation; and closer collaboration between consultants and contractors so that BIM can be utilised to achieve higher productivity and safer projects in the construction industry.

To address the challenges, an intelligent system has been developed which incorporates both productivity and safety performance, using BIM as the platform. The system, IPASS, was designed to provide solutions for the challenges and create opportunities for the industry to derive greater benefits from BIM. It was developed in line with the second BIM roadmap which emphasises collaboration to achieve higher productivity. IPASS enables collaboration among the project stakeholders as they analyse the productivity and safety performance before the start of a project. The system is also able to act as a monitoring tool for productivity and safety performance as the project progresses.

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What Hinders the BIM Adoption in Singapore: An Empirical Study

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Abstract

Building information modelling (BIM) has been seen as one of the most promising recent developments in the architecture, engineering, and construction (AEC) industry as well as a revolutionary change for managing a project from beginning to end. The Singaporean government has promoted the use of BIM in the AEC industry to help firms improve their productivity. The objectives of this study are to investigate the BIM adoption status and to identify the hindrances to BIM adoption in Singapore. To achieve the objectives, a preliminary questionnaire survey was performed with 34 professionals. A BIM adoption index (BIMAI) was proposed to measure the extent of BIM adoption. The low average BIMAI implied that the BIM adoption in the Singaporean AEC industry was still immature. Consultants were found to have a higher level of BIM adoption than contractors. Additionally, three-dimensional presentation, clash detection, design coordination, and construction system design were found to be the functions that were significantly applied in practice. Furthermore, the statistical analysis results showed that the mean scores of hindrances ranged from 3.79 to 2.65. Nine of the 20 hindrances were statistically significant, and thus were considered as critical hindrances to BIM adoption in the Singaporean AEC industry. "Lack of subcontractors who can use BIM technology", "cost of investment", and "lack of demand for BIM use" were the top three hindrances. This study provides an understanding of the BIM adoption status in Singapore and allows the practitioners to take measures to reduce the critical hindrances.

Keywords: Building information modelling (BIM), hindrances, construction projects, Singapore.

1. Introduction

Building information modelling (BIM) has been seen as one of the most promising recent developments in the architecture, engineering, and construction (AEC) industry (Azhar, 2011). BIM is defined as "a set of interacting policies, processes and technologies generating a methodology to manage the essential building design and project data in digital format throughout the building's lifecycle" (Succar, 2009, pp. 357). This definition highlights BIM's holistic nature, which covers not only software that allows the geometrical modelling and the input of information but also project management-related tools and processes (Bryde et al., 2013). In reality, BIM has been seen as a revolutionary change for managing a project from beginning to end (Chen et al., 2013). It requires the use of information and communication technology (ICT) to simulate the planning, design, construction and operational phases of a building project (Azhar, 2011), in order to provide a safer and more productive environment for users, to assert the minimum impact on environment from its existence, and to be more operationally efficient for the owner throughout the project lifecycle (Arayici and Aouad, 2010).

Application areas of BIM include, but are not limited to site analysis, design option analysis, 3D presentation, design coordination, cost estimating, energy simulation, clash detection, construction system design, schedule simulation, quantity takeoff, site resource management, and offsite fabrication (Azhar, 2011, Bynum et al., 2013, Cao et al., 2014, Eastman et al., 2011, Li et al., 2012, Monteiro et al., 2014). Previous studies have identified a number of benefits that may be brought by BIM adoption. According to a recent study by McGraw Hill Construction (2014) in Australia and New Zealand, the most significant short-term benefits were reduced errors and omissions, enhancement of organization's image as an industry leader, reduced rework, and the most significant long-term benefits were maintained repeat business, reduced project duration and reduced construction cost. In terms of time saving, Autodesk (2008) argued that Revit® Architecture software saved 91% of the time on checking and coordination and 50% on design development, compared with traditional Computer Aided Design (CAD) tools.

In Singapore, the Building and Construction Authority (BCA) and buildingSMART Singapore have been promoting the use of BIM in the construction industry because BIM is identified as a key technology that will enhance productivity and integration across diverse disciplines in the construction value chain. In 2010, BCA initiative the BIM Roadmap with the ambitious target that at least 80% of the construction industry uses BIM by 2015. To achieve this target, one strategy is to introduce the legal provision to mandate BIM-based plan submission (Teo et al., 2015). Since 2013, mandatory BIM electronic submission has been introduced in phases. Thus, it is compulsory for practitioners to submit architectural or engineering plans in the BIM format for regulatory approval.

Despite the efforts from the government and industry, the BIM adoption in Singapore still faces some hindrances and challenges. The objectives of this study are to investigate the BIM adoption status and to identify the hindrances to BIM adoption in the Singaporean construction projects. This study provides an understanding of the status quo of the BIM adoption in Singapore and critical hindrances, which allows the government and practitioners to develop strategies to reduce these hindrances and further promote the use of BIM in the construction industry.

2. Background

2.1 BIM in Singapore

In recent years, the government of Singapore, through the BCA, has highlighted productivity in the construction industry, and initiated a Construction Productivity Roadmap to transform the construction industry and raise its productivity (BCA, 2011b). Because of the potential to enhance construction productivity, driving BIM adoption has been seen as one strategic thrust (Teo et al., 2015). In 2011, a National BIM Steering Committee was set up to provide a governing framework to steer the implementation of the BIM Roadmap (BCA, 2011a), and led the development of the "Singapore BIM Guide" and "BIM Particular Conditions" (BCA, 2013).

To encourage the BIM adoption in Singaporean AEC industry, BCA (2011b) has provide a series of initiatives. For example, BCA and buildingSMART Singapore developed BIM submission templates, a library of design objects and project collaboration guidelines. In 2011, pilot projects with BIM were performed with the public sector clients. Subsequently, BCA issued regulations to make it compulsory for practitioners to submit architectural, structural as well as mechanical and electrical plans for building works for approval in the BIM format (BCA, 2015). Specifically, after 1 July 2013, all architectural plans of new building projects with gross floor area of more than 20,000 m^2 must be submitted in the BIM format; after 1 July 2014, all the engineering plans of new building projects with gross floor area above 20,000 m^2 must be submitted in the BIM format; and after 1 July 2015, all plans of new building projects with gross floor area above 5,000 m^2 must be submitted in BIM format. In addition to the regulations, BCA also set up the BIM Fund, which is aimed to help firms establish BIM collaboration capability by covering the costs for training, consultancy services and purchase of hardware and BIM software (BCA, 2014).

2.2 Hindrances to BIM adoption

Although the benefits of BIM have been recognized within the AEC industry and the technology supporting BIM has grown matured, BIM adoption has been slower than anticipated (Bernstein and Pittman, 2004). Thus, a number of studies have been performed to identify the factors influencing BIM adoption (Cao et al., 2014). Most of these studies have focused on the industry professionals' perceived hindrances to the diffusion of BIM in the industry (Eadie et al., 2013, Howard and Björk, 2008). In Australia, Gu and London (2010) indicated that the lack of experience in BIM due to a limited understanding of the industry needs and technical requirements was a major hindrance to the advancement and adoption of BIM related technologies within the Australian AEC industry. Additionally, Gerrard et al. (2010) found that lack of BIM expertise, lack of awareness and resistance to change were the main barriers to BIM adoption. A more recent study by Alabdulqader et al. (2013) reported that BIM were not well adopted mainly because practitioners perceived the existing CAD system can fulfil the need and BIM was expensive to operate and maintain. Through a literature review, a total of 20 hindrances to BIM adoption were identified, as shown in Table 1.

Table 1: Identification of hindrances to BIM adoption

Code	*Hindrances*	*References*
H01	*Cost of investment*	*(Bernstein et al., 2012, D'Agostino et al., 2007, Eadie et al., 2013, Eastman et al., 2011, Gilligan and Kunz, 2007, Khosrowshahi and Arayici, 2012, Ku and Taiebat, 2011, Tse et al., 2005, Won et al., 2013, Yan and Damian, 2008, Young et al., 2009)*
H02	*Learning curve for BIM technologies*	*(Bernstein et al., 2012, D'Agostino et al., 2007, Demian and Walters, 2013, Eastman et al., 2011, Gilligan and Kunz, 2007, Krygiel et al., 2008, Ku and Taiebat, 2011, Won et al., 2013, Yan and Damian, 2008, Young et al., 2009)*
H03	*Lack of support from senior management*	*(Bernstein et al., 2012, D'Agostino et al., 2007, Gilligan and Kunz, 2007, Won et al., 2013)*
H04	*Design liability issues*	*(Bernstein et al., 2012, D'Agostino et al., 2007, Eastman et al., 2011, Gilligan and Kunz, 2007, Khosrowshahi and Arayici, 2012, Won et al., 2013)*
H05	*Data ownership issues*	*(Azhar, 2011, Becerik-Gerber and Kensek, 2010, D'Agostino et al., 2007, Dossick and Neff, 2010, Eadie et al., 2013, Gu and London, 2010)*
H06	*Poor collaboration among participants*	*(D'Agostino et al., 2007, Eastman et al., 2011, Ku and Taiebat, 2011, Won et al., 2013)*
H07	*Poor interoperability among BIM software*	*(Becerik-Gerber and Kensek, 2010, D'Agostino et al., 2007, Demian and Walters, 2013, Eastman et al., 2011, Grilo and Jardim-Goncalves, 2010, Gu and London, 2010, Ku and Taiebat, 2011, Won et al., 2013, Young et al., 2009)*
H08	*Reluctance to openly share information*	*(Becerik-Gerber and Kensek, 2010, Eadie et al., 2013, Gilligan and Kunz, 2007, Won et al., 2013, Young et al., 2009)*
H09	*Lack of relevant training*	*(Becerik-Gerber and Kensek, 2010, Gu and London, 2010, Khosrowshahi and Arayici, 2012)*
H10	*Unsupportive organizational structure*	*(Eastman et al., 2011, Won et al., 2013)*
H11	*Unsupportive organizational culture*	*(Becerik-Gerber and Kensek, 2010, Eadie et al., 2013, Jensen and Jóhannesson, 2013, Khosrowshahi and Arayici, 2012)*
H12	*Lack of subcontractors who can use BIM technology*	*(Won et al., 2013, Young et al., 2009)*
H13	*Data security issues*	*(D'Agostino et al., 2007, Gu and London, 2010, Won et al., 2013)*
H14	*Lack of relevant expertise and knowledge*	*(Becerik-Gerber and Kensek, 2010, Eadie et al., 2013, Gilligan and Kunz, 2007, Khosrowshahi and Arayici, 2012, Tse et al., 2005, Won et al., 2013, Young et al., 2009)*
H15	*Limitation of current BIM applications*	*(Gilligan and Kunz, 2007, Won et al., 2013, Young et al., 2009)*

H16	*Lack of industry standards*	*(D'Agostino et al., 2007, Eastman et al., 2011, Young et al., 2009)*
H17	*Lack of BIM implementation data in construction phase*	*(Eastman et al., 2011, Won et al., 2013, Young et al., 2009)*
H18	*Perception that current technology is enough*	*(Yan and Damian, 2008)*
H19	*Lack of tangible benefits*	*(Becerik-Gerber and Kensek, 2010, D'Agostino et al., 2007, Gu and London, 2010, Khosrowshahi and Arayici, 2012, Won et al., 2013)*
H20	*Lack of demand for BIM use*	*(Eadie et al., 2013, Khosrowshahi and Arayici, 2012)*

3. Method and Data Presentation

A large research project that attempts to investigate BIM adoption in the AEC industry in Australia, Singapore and China has been implemented. In this study, a preliminary questionnaire survey was performed to investigate the status quo and critical hindrances to BIM adoption in Singapore. The comprehensive literature review supported the development of the questionnaire. In the survey, the respondents were asked to rate the extent of adopting the areas of BIM in their organizations, and the influence of the 20 hindrances on ERM implementation using a five-point scale (1=very low, 2=low, 3=neutral, 4=high, and 5=very high). In addition, they were requested to provide general information, such as their firm type, years of industry experience, designation, and years of BIM experience of their firms. Furthermore, they were asked to provide the number of the projects that their firms had undertaken in the past five years as well as the number of the projects where BIM were adopted.

The population consisted of all the industry practitioners in the Singaporean AEC industry. As there was no sampling frame in this survey, the sample was a non-probability sample. The non-probability sampling can be used to obtain a representative sample (Patton, 2001), and has been recognized as appropriate when the respondents were not randomly drawn from the entire population, but were rather selected based on whether they were willing to participate in the study (Liu et al., 2016, Wilkins, 2011, Zhao et al., 2013).

A total of 130 questionnaires were sent out and 34 completed questionnaires were received, yielding a response rate of 26%, which was acceptable compared with the norm of 20–30% with most questionnaire surveys in the construction industry (Akintoye, 2000, Hwang et al., 2015). In spite of a relatively small sample size, statistical analysis can still be carried out because the central limit theorem holds true when the sample size is greater than 30 (Ott and Longnecker, 2001). The profile of the respondents is shown in Table 2. Out of the 34 respondents, 79% were from contractors while 21% were from consultants, including design firms. In terms of experience, 50% had more than 10 years of industry experience, demonstrating the reliability of the data collected from the survey. In addition, 47% of the respondents had more than two years of experience in BIM. Because the electronic submission of architectural plans began to become mandatory after 1 July 2013, it has been around two years since most firms started to adopt BIM. Thus, it was not surprising that 35% had adopted BIM less than two years. Six firms did not have BIM experience. There may be two reasons for this. First, these firms perform only small projects, for which electronic submission in the BIM format for approval was not mandatory. Second, they outsourced BIM-related tasks to BIM moulders or specialists to satisfy the mandatory requirements from BCA.

Table 2: Profile of respondents and their firms

Organization type	N	%	Industry experience	N	%	BIM experience	N	%
Contractor	27	79%	5-10 years	17	50%	None	6	18%
Consultant	7	21%	11-15 years	11	32%	1- 2 years	12	35%
			16-20 years	4	12%	3-4 years	12	35%
			Over 20 years	2	6%	5 years and more	4	12%

4. Results

4.1 Status quo of BIM adoption

To measure the extent of BIM adoption in firms, a BIM adoption index (BIMAI) is proposed in this study as follows:

BIMAI = No. of projects with BIM adoption / Total no. of projects of a firm × 100%

In this study, the denominator of this equation was the total number of the projects that a firm had undertaken in during the past five years. Thus, the BIMAI of each company surveyed was calculated (see Table 3).

Table 3 shows that the BIMAI of contractors was 26% while that of consultants was 42%. The overall average BIMAI was 30%. These results implied that the BIM adoption in the Singaporean AEC industry was still immature. Consultants, including those BIM specialists and design firms, had a higher level of BIM adoption than contractors. Only three out of the 27 contractors (11%) received BIMAI over 50%

Table 3: Status quo of the BIM adoption in Singapore

BIMAI	Contractor	Consultant	Overall	
			No.	Percentage
0%	5	1	6	18%
10-19%	7	1	8	24%
20-29%	4	0	4	12%
30-39%	4	0	4	12%
40-49%	4	2	6	18%
50-59%	1	1	2	6%
60-69%	2	1	3	9%
90-100%	0	1	1	3%
Total	27	7	34	100%
Mean	26%	42%	30%	

In terms of application areas of BIM, 14 areas were identified from literature review (Azhar, 2011, Bynum et al., 2013, Cao et al., 2014, Eastman et al., 2011, Li et al., 2012, Monteiro et al.,

2014) and presented in the survey. The one-sample t test was used to check whether these areas were significantly applied (see Table 4). Only four areas (three-dimensional presentation, clash detection, design coordination, and construction system design) received mean values above 3 and p-values below 0.05, suggesting that these four areas had been significantly applied in the Singaporean AEC industry. This result was consistent with the low overall BIMAI in Singapore.

Table 4: Application areas of BIM

Application areas	*Description*	*Mean*	*Rank*	*P-value*
Site analysis	*Analyzing project site location*	*2.38*	*9*	*.001**
Analyzing design options	*Exploring and comparing design options based on three-dimensional models*	*3.18*	*5*	*.362*
Three-dimensional presentation	*Three-dimensional presentation of complex structures to nonprofessionals*	*4.26*	*1*	*.000**
Design coordination	*Coordinating design of architectural, structural, as well as mechanical, electrical, and plumbing systems*	*3.65*	*3*	*.002**
Cost estimating	*Project cost estimating during design stage*	*2.76*	*7*	*.274*
Energy simulation	*Analyzing building's energy distribution and consumption*	*1.94*	*13*	*.000**
Other performance simulations	*Analyzing building's other performances such as lighting, acoustics, air flows, and pedestrian circulation*	*2.06*	*12*	*.000**
Clash detection	*Checking conflicts among building systems prior to construction*	*3.85*	*2*	*.000**
Construction system design	*Designing and analyzing the construction of complex building systems in order to increase planning*	*3.41*	*4*	*.021**
Schedule simulation	*Simulating master schedules and construction sequences*	*3.09*	*6*	*.675*
Quantity takeoff	*Quantity takeoff and cost estimation during construction stage*	*2.74*	*8*	*.255*
Site resource management	*Integration with schedules and onsite information to manage the storage and procurement processes of project materials and equipment*	*2.29*	*10*	*.001**
Offsite fabrication	*Generating digitized information to facilitate greater use of prefabricated components*	*2.24*	*11*	*.001**

** The one-sample t test results are significant at the 0.05 level (test value=3).*

4.2 Critical hindrances to BIM adoption

To enhance the level of BIM adoption, critical hindrances should be identified and addressed. The one-sample t test was used to check whether the 20 hindrances had significantly negative influence on BIM adoption in the Singaporean AEC industry (see Table 5). The mean scores of hindrances ranged from 3.79 to 2.65. A total of nine hindrances received mean values above 3 and p-values below 0.05, implying that they were deemed as critical hindrances to BIM adoption.

"Lack of subcontractors who can use BIM technology" received the top rank (mean=3.79), indicating that it was not sufficient to promote BIM adoption in only main contractors. Subcontractors, which were also important participants in construction projects, also have to be involved in the trend of BIM adoption. However, the subcontractors were likely to undertake small projects that did not face mandatory requirements for BIM submission, and thus do not have incentives to adopt BIM.

“Cost of investment” was ranked second (mean=3.74), suggesting the costs associated with BIM were still a great concern of the AEC industry practitioners in Singapore. Although BCA has set up the BIM Fund that may be used to cover the costs for training, consultancy services and purchase of hardware and BIM software (BCA, 2014), there were also specific requirements for the applicants. Thus, some firms may not be eligible for the BIM Fund and have to bear the costs on their own.

Table 5: Critical hindrances to BIM adoption in Singapore

Code	*Mean*	*Rank*	*P-value*	*Code*	*Mean*	*Rank*	*P-value*
H01	*3.74*	*2*	*.000**	*H11*	*3.44*	*9*	*.023**
H02	*3.47*	*8*	*.001**	*H12*	*3.79*	*1*	*.001**
H03	*3.62*	*4*	*.004**	*H13*	*2.65*	*20*	*.032**
H04	*2.79*	*18*	*.269*	*H14*	*3.62*	*4*	*.001**
H05	*3.26*	*11*	*.173*	*H15*	*3.18*	*14*	*.362*
H06	*3.26*	*11*	*.221*	*H16*	*2.79*	*18*	*.228*
H07	*2.79*	*18*	*.228*	*H17*	*3.18*	*14*	*.280*
H08	*2.97*	*16*	*.845*	*H18*	*3.59*	*6*	*.009**
H09	*3.29*	*10*	*.143*	*H19*	*3.59*	*6*	*.006**
H10	*3.21*	*13*	*.214*	*H20*	*3.65*	*3*	*.001**

** The one-sample t test results are significant at the 0.05 level (test value=3).*

“Lack of demand for BIM use” occupied the third position (mean=3.65), implying that the actual demand for BIM in the industry was not as great as the government thought. Indeed, the government recognizes BIM adoption as one of the strategic thrusts that can significantly raise the productivity in the construction industry. Thus, the government should use the potential benefits from BIM to convince industry practitioners that it is really necessary to use BIM to replace two-dimensional CAD.

5. Conclusions and recommendations

Building information modelling (BIM) has been seen as one of the most promising recent developments in the architecture, engineering, and construction (AEC) industry as well as a revolutionary change for managing a project from beginning to end. The Singaporean government has promoted the use of BIM in the AEC industry to help firms improve their productivity. The objectives of this study are to investigate the BIM adoption status and to identify the hindrances to BIM adoption in Singapore. To achieve the objectives, a questionnaire survey was performed with 34 professionals. The low average BIMAI implied that the BIM adoption in the Singaporean AEC industry was still immature. Consultants had a higher level of BIM adoption than contractors. Additionally, three-dimensional presentation, clash detection, design coordination, and construction system design were found to be the functions of BIM that were significantly applied in practice. Furthermore, nine hindrances were recognized as critical hindrances and should attract more attention from the government. “Lack of subcontractors who can use BIM technology”, “cost of investment”, and “lack of demand for BIM use” were the top three hindrances.

There are limitations to the conclusions. First the identification of the hindrances may not be exhaustive with the passage of time. Additionally, the sample size was relatively small in this preliminary survey, so cautions should be warranted when the analysis results are interpreted and generalized. Moreover, the single-source data are very likely to cause common method biases (Jiang and Jiang, 2015, Jiang and Wang, 2014), which is a common limitation of the studies using questionnaire survey (Zhao et al., 2016). Furthermore, the findings of this study are interpreted in the context of Singapore, which may be different from the context of other countries.

Future studies would investigate the interaction mechanisms among the hindrances to BIM adoption, and identify the influence paths comprised by some of these factors. Also, as BIM adoption may involve changes in firms, organizational change theories would be used to interpret the critical hindrances and provide the theoretical rationale behind these interaction mechanisms.

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Improving safety at building construction sites by means of BIM and mobile tools

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Abstract

Building Information Model (BIM) based designs, plans, drawings and other information needed on construction sites can be used more and more by mobile devices as hardware, software and cloud-based data sharing are developing rapidly. As a result, the safety information can also be "mobilized". If compared to the traditional safety documents, the mobile versions provide more efficient workflow and possibility to completely new kind of information contents. However, the most important benefits will likely be, that safety information can be brought closer to the production event, where it can genuinely affect occupational site safety. Additionally, up-to-date safety level information including safety violation statistics can be provided for site management purposes, and this safety data is automatically stored for later analysis and development purposes.

Mobile opportunities have been implemented to safety purposes in limited extent this far. This research aims to clarify the possibilities of useful mobile tools and promising new ways of delivering BIM-based information needed at field. Results are based on an analysis focused on 1) the different types of mobile applications currently available for safety purposes, 2) the most promising new ways of sharing and recording safety related information at site using mobile devices, and 3) the apparent potential of mobility in construction safety management. Data was collected by literature study, experience got by hands-on software testing, and interviewing and discussing with industry representatives in various meetings related to an on-going collaborative research and development project. The goal of the research project is to develop publishing, management and usability of digital building information by web-based solutions and procedures in the construction supply chain.

The identified most promising mobile opportunities for improving the occupational site safety will be tested in a real on-going building construction project. Selection of use cases will be carried out by the involved development project partners, including software vendors, research institutes and industry representatives such as a general contractor, precast fabricator and structural engineering company. Experience will be used to take advantage of BIM and mobile tools more efficiently on construction sites in the future, and to encourage software houses to develop the needed final more suitable applications for the industry.

Keywords: occupational safety, building construction site, mobile information, BIM, mobile safety management

1. Introduction

Building Information Modelling (BIM) is very current topic worldwide. Reasons for increasing BIM implementation are demands from governments/building authorities, demand from big conscious client organizations, competitors' good experience in BIM as a tool to support and intensify the design and construction processes, the emergence of common national BIM guidelines to standardize the main principles and procedures in projects, the general global digitalization in construction industry, and simply the identified business opportunities related to BIM. The current fast construction digitalization is highlighted e.g. in a summary of BIM adoption around the world published by Construction Management magazine (CIOB 2015). Examples of reported safety related uses of BIM in building construction sector are BIM-based 3D site layout and fall prevention planning, and BIM-based workflow visualization and analyses including hazard identification (Sulankivi 2014). In a survey conducted by McGraw Hill Construction in US (2013), a large percentage (43%) of the firms that use BIM reported that BIM use has a positive impact on safety.

In the construction industry, ICT systems were designed for stationary office use, but have been pushed out to the production environment, which have resulted in that construction management teams are tied up inside the site offices at their desktop computers a large part of their working hours (Löfgren 2007). According to previous research, construction management personnel have a clear need to use digital information while at field, not in the site office only (Lemmetty 2013). Now, after mobile technology has become an essential part of our everyday life, it's rolling into professional use as well, improving e.g. the access to construction documentation and other production information for site staff. Löfgren (2007) describes how Skanska, one of the largest building companies in the world, become among the first ones interested in mobile ICT as a result of identifying problems related to the overwhelming quantity and poor quality of information in the field in a US construction project 2005. The collaborative effort between a software developer and the production management team in the project resulted in improved understanding of the limitations of existing technology and the generation of new tools that were more useful to the construction site environment. Good experience in mobile ICT got in Skanska US led rapidly to a global development initiative involving e.g. Sweden, UK, Norway and Finland. Focus was first on the management of drawings and specifications used on construction sites, but soon mobile tools and procedures started to be developed to replace existing administrative on-site work processes as well. Also according to Fender & Wolfley (2014) portable electronic devices such as tablets and smartphones can be useful for safety professionals, and the right apps can improve efficiency and tablets can pay for themselves quickly.

As a result of rapid development of hardware, software and cloud-based data sharing, also BIM-based designs and other new kind of information needed on construction sites can be used more and more by mobile devices. However, mobile opportunities have been implemented to safety purposes in a limited extent this far. This research aims to clarify the possibilities of further digitalization by identifying useful mobile tools and promising new ways of delivering BIM-based plans and other information needed at field. Several current mobile hardware and software can serve construction project management as a whole, including safety, but this paper introduces new mobile opportunities from the specific viewpoint of occupational site safety, the final target being to bring relevant safety information closer and more easily available in the production events and site management procedures, where it is needed to conduct the construction work safely.

2. Research method

Results are based on an on-going collaborative research and development project, which main goal is to develop publishing, management and usability of digital building information by web-based solutions and procedures. Results presented in this paper aim to promote safety management from the same information sharing aspects as construction production management as a whole is being developed in the research project.

Potential new technology and exploitation possibilities have been analysed based on information got by literature study, surveying available mobile applications intended or suitable for building construction industry, studying and testing the features of these applications, discussing about the needs and expectations of e.g. site staff with the research project partners in various meetings, and by individual interviews. Beside research organizations, industry representatives such as a general contractor and a precast concrete manufacturer, engineering companies, as well as software developers providing and developing both BIM-based and mobile applications for construction industry are involved in the research and development project. Based on the collected information, this analysis considers practical safety information needs at field, possibilities of the newest mobile or BIM-based software, as well as the found leading edge mobile work flow and procedures.

Selected most promising new mobile opportunities for improving the occupational site safety will be studied in more detailed level and tested in a real on-going construction project. If a suitable tool or a prototype for a specific need is not available for testing, research organizations will demonstrate the needs to software house representatives to encourage them to develop the needed final applications for market.

3. Results

3.1 Mobile technology for site safety

After surveying available web-based/cloud-based mobile applications intended or suitable for building construction industry, those including some kind of safety related features were analysed in more detailed level and 4 different kind of categories of applications identified. These different types of mobile safety related applications are presented in Table 1 together with few examples of real tools of each type.

Table 1: Examples of different types of mobile safety related applications.

Types	*Examples of existing mobile tools*
1: Construction project management applications including safety related tools	*Trimble ProjectSight, Autodesk 360 Field, bim+ Connect, Aconex, Procore construction management software, PlanGrid*
2: Safety auditing or safety level inspection/measurement/rating apps	*iAudit, iOSHA Process Safety Management Auditing, Trimble Inspector, Kotopro TR-mittaus, T3, InstaAudit*
3: Applications for a single specific purpose	*Dakota's EHS Pocket Guide, ChemAlert, iTriange, Clinometer HD, SoundMeter, DMD Panorama, Tekla Field3D, Safety Coach*
4: Applications meant for a specific construction phase or work	*Daily Reports (e.g. for concrete work), Concrete calculator, Fall PtD, Raksamittari PRO*

The first type, *construction project management applications including safety related features*, are comprehensive project management or collaboration solutions typically aiming to connect the office to the field, as described by Trimble (Lavine 2015), as well as distributing/sharing up-to-date project documentation and information regardless of time and physical location of the user. At site office or headquarters these solutions can be used by PC using a web browser as the user interface. At field, mobile device such as iPad or a mobile phone is usually used together with the corresponding mobile application installed to the device. That's why they are usually tied to a specific operating system such as Windows, Android or iOS, but some applications are available for several operating systems. However, when a browser is the interface in the mobile device also, the application is available to all devices with internet connectivity regardless of the operating system.

The second type of applications are developed for systematic and effective *mobile site safety auditing or safety level inspection/measurement/rating*. As a result of cultural differences in safety regulations and inspection procedures, these are typically country-specific applications. For example, "Kotopro TR-mittaus", "T3" and "Insta Audit" are based on a Finnish method to calculate the weekly safety level, serving the Finnish building construction sector only. In turn there is e.g. an US application called "iOSHA Process Safety Management Auditing" based on US regulations. On the other hand, there could be some good ideas related to the mobile application or the original auditing process, which might be useful to be transferred from one country (and application) to another.

The third type of applications are developed for *a single specific purpose* such as issue management, browsing H&S regulations, checking employee qualifications, searching chemical data or medical information, measuring site conditions, as well as viewing 3D building information models. Issue management applications included in this group can typically be used for many different purposes and even in different industries and could thus be called "general issue management solutions". The fourth type, applications meant for a *specific construction phase or work*, include mobile tools for flooring or concrete pouring, for example, and include some safety related features just for these specific work tasks.

If considering all different available mobile applications, one typical common feature is the possibility to use them off-line. This is important at building construction site, where internet connection can't be guaranteed all the time. The main principle is that e.g. recording issues and other work at field can be conducted off-line, and uploaded to the cloud-based project database when possible. Another common feature is, that the applications typically indicate if there is updates available to the project data stored into tablet, but the user decides if updates are downloaded instantly or later using better internet connection or to avoid disturbance for the work task going on at the moment, for instance.

3.2 Exploitation of Mobile devices and Safety data on site

Exploitation of mobile devices is relatively new phenomenon in construction sites. According to interviews performed in a Finnish construction company, at the moment the biggest issue concerning mobilization is the implementation of the new procedures into production. However, more and more applications are being released and software houses are constantly developing more user friendly applications, in order to help the implementation into construction sites. This on-going research project is encouraging software houses into development by evaluating mobile applications together with construction companies.

Similar to organizations in other industries construction and engineering organizations are leveraging mobile and wireless solutions to address the need for greater collaboration among a highly mobile and distributed workforce (Krebs 2009). Many mobile tools have also been tested for different kind of safety related purposes already, including sharing project designs and plans, recording and documenting safety observations, browsing safety data and guidelines, and various safety related measurements and calculations. Summary of found different kind of uses for mobile tools in context of safety management is presented in table 2, and the use cases are visualized by practical examples of possible utilization.

By the interviews carried out in the Finnish construction company, this research aimed to determine the utilization rate and user experience of mobile devices. One of the main findings was, that a safety level inspection application is considered the most valuable applications concerning occupational safety in the company at the moment. Production management personnel stated that it genuinely provides effective tool to audit safety level, and the additional features such as action assignment and automatic follow-ups were appreciated highly/evaluated useful. The possibility to assign task or notification to the responsible person by email straight from the application is not only saving time but making production management more efficient. Previously this whole procedure been conducted using pen and paper, and it must have been transferred to digital format after the inspection. As a result of using a mobile device, the inspection and reporting is completed once during the inspection tour, which saves time significantly. Mobile devices can be used also to take photos and attach them to the inspection report, making the documentation and positioning more accurate. At the moment, general contractors use mobile tools more than their sub-contractors/special contractors. As a result, there is still need to deliver information by e-mail to most of the subs, but in the future they will be provided an access to a web-based system to e.g. record safety notices and to get notifications of issues assigned to them. On the whole, the goal is to make safety observations available to all workers at the site, not only to the production management personnel.

Table 2: Safety related use cases of mobile applications.

Use case	***Short description or practical example of possible use***
1. Project and Safety document sharing	*Documents needed at field are carried along digitally in a mobile device or accessed on-line by web.*
2. Viewing BIM-based construction and safety plans	*Reviewing e.g. 3D fall protection plan with help of BIM viewer application.*
3. Safety Notices Management	*Recording notices at field digitally by mobile tools and putting an issue to someone's responsible and following corrective actions. Collecting, filtering and analysing up-to-date safety data is also possible, helping to decrease specific safety violations and develop safety management procedures.*
4. TR Safety level measurement (weekly observed safety level at the site, a Finnish method)	*Conducting mobile TR-safety level inspection and filing safety observations digitally, as well as calculating the weekly safety level rating automatically by the tool.*
5. Other safety inspections	*Ready-made digital checklists and forms, and filling out those digitally once while the inspection. Inspection forms may be for safety inspection process or checking cranes, for instance. Electronic time stamping registering visit entry and departure may also be included.*
6. Browsing Safety and security regulations and guidelines, and accessing safety and health sites	*Browsing OSHA-regulations, best practices, or fire protection standards at site. Browsing information on personal safety equipment requirements for a specific work*
7. Getting information and help without delay in case of illness, accident, or other H&S related situation	*E.g. iTriange: By entering the symptoms, one gets information about likely causes and a proposal for the treatment/action. By entering name of a drug/medicine, provides basic information and warnings related to the substance, and the location of the nearest first aid centre. (Professional Safety 2014)*
8. Accessing chemical safety data	*Information for chemical safety management by accessing chemicals database by mobile application. E.g. ChemAlert provides access to over 100 000 chemicals, and includes e.g. hazards classifications, recommended personal protective equipment and first aid information.*
9. Photos and Panoramic photos (360 degrees)	*Cameras can be used for documenting worksite conditions and helping safety personnel to identify safety hazards. Panoramic photos can be used for e.g. incident investigations and safety inspections, and created by help of specific applications such as DMD Panorama (Professional Safety 2014).*
10. Measuring safety of the working conditions	*Measuring angles of slopes to evaluate safety (e.g. Clinometer HD), or measuring sound level dB (e.g. SoundMeter) to determine whether a more precise measurement using more accurate device is necessary. Or measuring thermal conditions (e.g. OSHA Heat Safety Tool). (Professional Safety 2014).*
11. H & S related calculations	*E.g. iPad apps available for conventional safety management calculations (ready-made calculation formulas included in apps such as HSE Buddy).*

One of the first purposes of mobile tablet computers was to support more efficient access and viewing of 2D building designs and other construction documents at field, and at the same way, the traditional safety documents can be viewed digitally using tablets. However, designs and construction plans are used more and more by viewing BIM-based 3D models with tablets at field. As a natural step forward, BIM-based safety plans such as 3D fall protection plans can be viewed as part of construction documentation in the future. Figure 1 demonstrates how BIM-based safety plans could be viewed using e.g. iPad. Model viewing tools are already available for tablet computers, but BIM-based safety plans such as fall protection plans are not common in real construction projects yet. According to Krebs (2009), while BIM solutions were not designed with mobile applications in mind per se, mobilizing BIM applications significantly enhances not only their value but also the strategic value of mobile solutions to construction and engineering operations.

Figure 1: Structural 3D model including safety railing viewed in iPad using mobile application Tekla Field 3D.

3.3 Impact and benefits of the new technology

Summary of found and potential benefits of the new mobile technology are presented in table 3. Many of these listed safety related benefits may likewise be achieved in the quality assurance and management, for example, but information collected, recorded or analysed would just differ from the ones presented as examples in the context of safety management.

Table 3: Benefits of mobile technology in safety management.

Benefit	*Examples*
1. Time savings, and at the individual level easier to deal with issues/work assignments on one's own schedule	*Safety observations and notices are recorded and documented at once while inspection. Mobile application may also automate calculations related to safety auditing. Meeting minutes are made once during the meeting.*
2. Improved productivity	*Beside time savings, faster access to up-to-date project and safety related information improves productivity, as documents needed at field are carried along digitally in a mobile device or accessed on-line by web.*
3. More systematic, transparent and traceable process	*All concerned parties can see who and when created a safety notice or other record, who is responsible for correcting actions, how urgent it is to correct the issue, and a notification of fulfilling the task.*
4. Better information quality	*Easier to manage the project information timeliness with help of a cloud-based system. Easier access to e.g. safety regulations to consider safety more carefully in a specific construction phase or work task. More accurate documentation of safety issues, since information structure/content is standardized by digital forms in app and e.g. photos can be attached to any issue.*
5. Faster resolution of problems and faster access to first aid information	*Faster access to safety information and guidelines e.g. in a case of injury. After an accident, the history data of issue management may help find the reasons at the background of it. Additionally, faster resolution of any occurring issue in a project decreases also safety hazards.*
6. Automated reporting, filtering and summary concerning site status	*A list can be produced e.g. of all safety notices recorded at one building site, or of all which one specific firm is responsible for. Summary of the most common safety violence types at the specific construction site can also be automatically filtered from a cloud-based database, to tell which issues should be addressed and corrected.*

The most obvious benefits are 1) *time saving in resource use* and 2) *improved productivity*. According to a survey conducted by VDC Research, investments in mobile and wireless solutions provide real and measurable benefits, improvements in worker productivity being 30.1% (Krebs 2009). For example, in case of safety inspection, there isn't need to make written notes first and then make documenting as an additional task after getting to the office. Experience shows, that this speeds up the safety inspection process significantly (Lemmetty 2013).

In a tablet computer pilot construction project described by Löfgren (2007), the users experienced improvements in their own personal productivity when equipped with updated project information on tablet computers. Also to solve arisen on-site problems and critical construction issues there is a need for quick access to necessary information. Previously production management personnel used to run back and forth between the construction site and their computers inside the site office, leading to inefficient use of managerial resources. With issues resolved quickly and returned to the field accurately, field staff was able to continue to work unhindered. Additionally, meeting notes can be taken directly with the electronic pen on the tablet computer. Using the built-in tablet computer text recognition tool, the notes can be translated into an ordinary data text document when the meeting is over, which directly can be distributed via e-mail to project participants. (Löfgren 2007)

At site level, mobile cloud-based tools enable *more systematic, transparent and traceable safety issue management process*. Various players of the building project get better opportunity to inform others about their safety concerns, and all parties concerned get notification about the issue, as well as how and when it was solved. E.g. various subcontractors get better opportunity to plan their own tasks, since they will be notified if problems affecting their work occur at site, as well as when the issue is solved. At the end of the project there are less unclear issues.

Better information quality: Distribution speed, information quality and understanding of production issues communicated to involved actors can be enhanced (Löfgren 2007). Mobile tools provides faster creation of records once it is identified at field, and understanding of occurred issues is easier if text descriptions are supplemented with attached photos, for instance. Also information quality is better in manner of timeliness: If compared to the traditional way of carrying along blueprints, there is faster access to safety related up-to-date information, since drawings, 3D models and other documents can be updated to the mobile device for viewing whenever, provided that there is just Internet connection. Site staff does not need to go to view their computers inside the site office to get the information needed. In the other words, relevant safety information can be brought closer to the production event, where it can genuinely affect occupational site safety.

Faster resolution of problems and faster access to first aid information: In case of injury or accident, various mobile applications provide faster access to first aid information and help making documentation for later analyses. In the future, mobile information delivery provides possibility to completely new kind of information contents as well, since information is available in the web and can be combined automatically with the information, which origin is in totally different place or different parties of a building project.

Automated reporting, filtering and summary concerning site status: Beside direct benefits, the indirect benefits of mobile tools may actually be even more significant. If information on e.g. safety issues is systematically recorded, resulting project-specific database makes it possibility to automatically summarize, filter and analyse current safety hazards at site, as well as identify development needs in the longer term. Additionally, based on occurred safety issues on site, automated alarms become possible, such as issues to take care of today, issues to take care of in a coming week, and actions that are overdue. Such features are included e.g. in Trimble's "ProjectSight" application, when PC and web-browser is used as interface to project data recorded at site. The "Project dashboard" shows the summary of realized safety on the specific site, and by help of this automated safety issue analyses, the site manager can monitor what kind of safety violations have occurred most. Other automated features include possibility to filter safety notices in various ways such as "All" or "Pending me", for instance.

As a result of cultural differences in the traditional construction procedures, there are differences in the most appropriate or useful use cases of mobile tools in various countries. Löfgren (2007) describes that while supervising teams in the U.S. appreciated the tablet computer in their first pilots as a tool for handling and updating digital drawings, in Sweden that had a very limited application area due to a completely different way of administrating the blueprint update process. The tablet computer project in Sweden was leaning more towards enabling more effective on-site administration of construction activities through mobile on-demand access to existing business information systems and construction project administration tools to e.g. fill out field work report forms online. Cultural differences make also localization of the mobile applications necessary, since the interface of the tools should be as easy to use as possible and guide the user to common systematic workflows including e.g. using a relevant record type for a specific issue and filling the related information in a same way each time. These requirements can't be fulfilled, if terms are in foreign language and thus not clear to the users.

4. Discussion

Exploitation and effective use of mobile applications require features which are appropriate for construction and safety management procedures at field. As a result of national differences in traditional processes, this will most likely lead to localizations of the most promising tools. On the other hand, it's possible, that as a result of implementation of new genius mobile tools, the more effective working procedures are adopted and spread around the world deceasing cultural differences in construction processes. However, the traditional processes should not be digitalized as such, but at the same time with the mobilization it should be considered, if the process itself could be simplified as is the target in the Lean construction. Current web-based application stores provide very efficient selling and delivery network of mobile applications already now, but the internationalization of workflows would further increase their markets, and speed up development of the digitalization in construction industry on the whole.

In case of construction site´s mobilization, it´s important to take into consideration also risks related to mobile devices in general. Mobile devices and digitalization rise up concern about data security and reliability of mobile information. Further research concerning risk management of mobile applications at construction sites is definitely needed. It is also clear that mobile device itself can cause near miss situations or accidents by occupying personnel's focus in a dangerous working environment.

The Internet of Things (IoT) development of computer technology will bring whole new kind of possibilities to combine information for improving occupational site safety management. For example, Jiang et al (2013), identifies possibility to add new monitoring devices such as smoke sensor to the web-based safety management system. IoT development enables variety of data to be analysed and reported. By utilizing IoT and computer technology for example individual wellbeing of site staff can be monitored and analysed in order to support occupational safety and health.

5. Conclusions

Utilization of mobile tools is increasing rapidly on construction sites, and so do availability of mobile applications and cloud-based solutions meant for construction industry. Found mobile tools including some kind of safety related features were categorized in this research into 4 types: *Construction project management applications including safety related tools, Safety auditing or safety level inspection / measurement/rating applications, Applications for a single specific safety related purpose*, and *Applications meant for a specific construction phase or work*. These has been tested for various purposes in different countries, and especially mobilization of BIM and e.g. issue management seems significantly increase the value of mobile devices in the future.

The most obvious benefits resulting from mobile tools are time savings in resource use, and other productivity improvements at personal, site or company level. Achievable benefits include also more systematic, transparent and traceable issue management process, for instance, and better information quality e.g. in terms of timeliness. Faster resolution of problems and access to e.g. first aid information may become a lifesaver for an individual. However, the indirect benefits of automated reporting, filtering and summary concerning site status may be even more significant from the view point of improving site safety. If e.g. safety issues are systematically recorded, resulting project-specific database makes it possible to automatically analyse current safety hazards at site, as well as identify development needs in the long term. Additionally, based on occurred safety issues on site, automated alarms become possible, such as issues to take care of today, leading to more effective hazard prevention proactively. When sub-contractors also begin to use more tablet computers and the mobile applications, the general contractors and the building projects as a whole start to gain more benefits from these tools in terms of efficiency. That's because the same information doesn't need to be provided in many different ways for the various project parties anymore. Mobilizing BIM own remarkable potential to enhance their value, but also the value of mobile solutions to construction and engineering operations.

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Visualization of building models and sensor data using open 3D platforms

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Abstract

Modern facilities management in digital systems requires user-friendly tools for visualization and decision making, and improved data. To help achieve this, 3D models can operate as a platform for integrating sensor data and other documentation for a building. If 3D models are not readily available for a specific building, measuring methods can be applied. In this article, a prototype of a building model with a sensor data visualization system is presented using an open source 3D platform. The prototype is utilized to visualize 3D models produced by terrestrial laser scanning, thermal camera images, and sensor data. Several development directions are identified for such systems.

Keywords: indoor air quality, building model, laser scanning, maintenance, visualization

1. Introduction

In building information modeling (BIM), the information representing different disciplines in the field of construction (architecture, engineering, etc.) are integrated into a three dimensional (3D) digital model. With the help of BIM, it is possible to detect collisions and conflicts in an early stage of design (Azhar, 2011) and, for example, improve scheduling in the construction phase (Tulke et al., 2008).

However, the construction and planning only represent a small fragment of the total life cycle of a building. Contemporary buildings contain a multitude of different technical systems that need to be managed during the operational life of the building. The increasing complexity of the buildings is putting pressure on the traditional methods of facilities management, as stated by Ahn and Cha (2014). Several authors have suggested that a BIM-based solution has to be applied for facilities management (Becerik-Gerber et al., 2012; Ahn and Cha, 2014). By aggregating facilities management data into a BIM model, the data management issues caused by missing or non-synchronous documentation can be solved (Ahn and Cha, 2014).

Sick building syndrome exists in Finnish public buildings (Audit Committee of the Parliament of Finland, 2013), as in so many other countries globally. Complicated building structures and growing needs for better indoor air quality increase the need to monitor, adjust, and supervise building parameters properly and illustrate data visually in a compact form (Hietsalo et al., 2014). More sensors and wireless networks are needed to fulfill those requirements. In particular, there is a demand for better control of relative humidity (RH), dew point calculations, CO_2 sensors and total volatile organic compound (TVOC) sensors to assure healthy indoor air. The absolute amount of water vapor in indoor air can be determined by combining data on RH and temperature. The difference between the amount of water vapor in indoor and outdoor air is a good indicator of the efficiency of building ventilation. In a similar manner, the pressure difference between the building interior and exterior is a good indicator of a properly operating ventilation system: If the ventilation system is correctly adjusted, the pressure difference should be low to prevent any unintentional air flows, and so forth. For monitoring the building envelope, continuous measuring is important, as the amount of moisture can, for example, vary significantly during a single day. As a result, one time measurements become unreliable. Sensors can also be integrated into building structures. By measuring the moisture of building structures, it is possible to monitor, for instance, the drying of a concrete structure after repair work. By combining the data from indoor condition measurements and structural measurements, there is the potential to estimate the risk of mold growth.

If BIM-based facilities management methods are to be applied in these cases, measuring and modeling becomes essential. On this point, Tang et al. (2010) provide an overview of the automated as-built BIM reconstruction problem and some of the partial solutions. This reconstruction can be performed manually, by viewing a point cloud in a computer-aided design (CAD) suite and building the model (Mill et al., 2013). A similar approach can be found in building modeling using terrestrial laser scanning (TLS), as presented by Arayici et al. (2007)

for example. In most cases, however, the modeling is too laborious. While the project may be carried out without the comprehensive model, many of the benefits of BIM are not attained.

For both manual and semi-automatic BIM reconstruction, laser scanning can be used as a measuring method. In measuring the built environment, it is usually applied as TLS, with the instrument being mounted on a tripod. In laser scanning, the laser pulse travel time or phase difference is used to calculate distances relative to the scanner position. By combining data from the scanning angle and impact of atmospheric reflection caused to the speed of light on the time data, 3-dimensional locations of the scanned points can be identified. If the scanner positions are known, several scans can be combined to create a larger point cloud of the built and natural environment (Virtanen et al., 2014c; Lehtola et al., 2014; Kankare et al., 2013). The high point density and fast acquisition speed make laser scanning an efficient method for documenting complex building surfaces (Virtanen et al., 2015), rapid prototyping (Virtanen et al., 2014a), and detecting structural deformations in buildings with great accuracy (Virtanen et al., 2014b). On this point, Chee Wei et al. (2010) present the workflow for utilizing terrestrial laser scanning from a cultural heritage documentation project. The documentation of the chosen artifact is conducted with a laser scanner. Scanning targets are used for both registering the scans and geo-referencing the project. In addition, digital images are taken with the integrated camera system of the scanner to obtain RGB values for the scanned points (Chee Wei et al., 2010).

Mobile laser scanning (MLS) has generated a large amount of interest for measuring and modeling urban environments. In particular, it is suited for measuring in outdoor environments, producing models of e.g. building facades. Typically, MLS systems are mounted on regular cars, but there have been implementations of MLS on a cart or an all-terrain vehicle (ATV). One such example of a MLS system is the ROAMER system, developed at the Finnish Geodetic Institute (Kukko et al., 2007). The essential components of a MLS system are a laser scanner, GPS receiver, inertial measuring unit (IMU), and data recording system. The GPS and IMU are jointly used for the accurate localization of the MLS systems (Kukko et al., 2007).

In addition to laser scanning, image-based measuring methods (digital photogrammetry) can be applied for precise 3D documentation (Virtanen et al., 2012; Kurkela et al., 2012). Different types of images (panoramic image mosaics, image databases, sensor images, and multispectral photographs) are employed to produce information from the environment.

Another significant source of data concerning buildings are sensors. Several types of sensors can be installed in a building to measure a variety of parameters (such as CO_2, temperature, and amount of light). In this field, one of the research directions is wireless sensor networks (WNS) that can be applied in construction and building maintenance. As the “health” of a building is dependent on a large group of factors, different sensors are required to follow a group of parameters. To produce comprehensive data, these sensors have to be scattered across all parts of the building and also installed inside the structures. WNS can help reduce the amount of cabling needed for such installations and thus help reduce costs. When using sensor data for decision making in construction, data visualization becomes a central task. A large amount of data must be presented, preferably dynamically, so that it can be seen in near real time

(Hammoudeh et al., 2015). If this data is to be utilized in decision making with the 3D building models, they have to be visualized together. This both simplifies the interpretation of data and enables the detection of correlations (Motamedi et al., 2014). It is possible to identify temporal correlations from the sensor data, e.g. the impact of microbiological activity on the CO_2 concentration. It is also possible to search for long term trends and thus try to identify potential problems before they emerge and become acute. In current planning and maintenance systems, buildings are mostly studied as individual entities. This reduces the overall efficiency that could be reached by looking at interactions not only within a single building but between buildings. Networking the buildings and analyzing their data, energy, and resource flows is the key to unlocking the full potential of these networked, smart buildings. The resulting Internet of Buildings can share resources and thus optimize the use of energy and services, to maximize the efficiency when using renewable natural resources. For buildings in this networked ecosystem, new business models can be created, thus improving the conditions of the building owner as both a consumer and provider of services (Lukin, 2015).

The four mentioned aspects are combined in the future digital models used for building upkeep and maintenance (Figure 1). Firstly, a digital 3D model operates as a platform for information and forms the starting point for all building maintenance activities. Secondly, all data concerning the building is aggregated on top of this model, the individual data sets being bound to respective model components. Thirdly, the sensor data from the building is integrated into the same model and visualized. And finally, the model has to operate in a networked system, enabling the integration of several buildings or other online resources. In addition, if the proposed solution is to be applied to the current building stock, for which no BIMs exist, the starting data for the model has to be generated using the existing 3D measuring techniques.

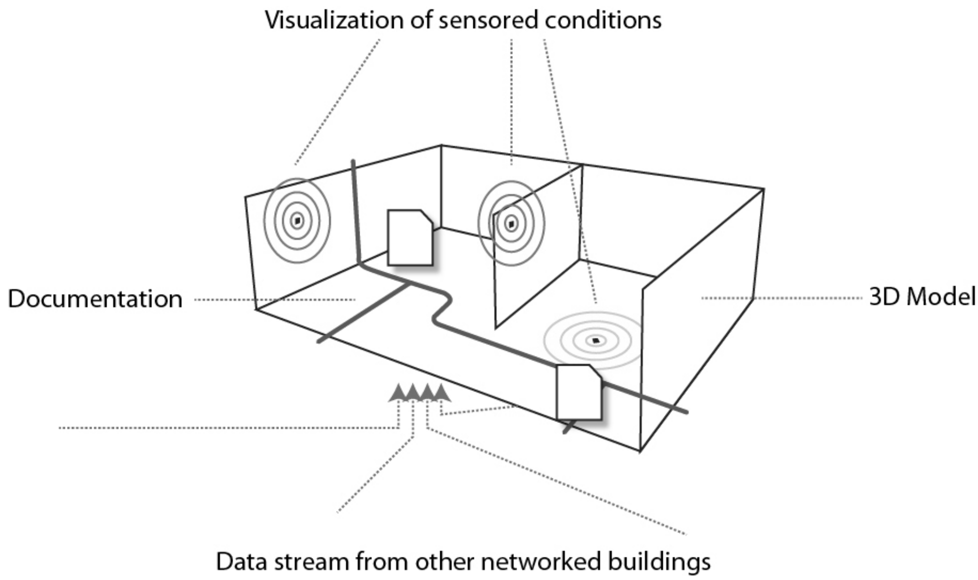

Figure 1: The aspects of future digital models used for building upkeep and maintenance

Thus, this paper presents a 3D visualization method as a tool for analyzing and viewing 3D building models with additional sensor data. 3D measuring techniques are utilized to produce models that depict the building as it is in use. The visualization results focus on indoor air quality measurements. This solution will provide information for monitoring the status of the indoor environment of the building. The goal of the system is to improve indoor air quality and reduce the cost of unnecessary renovations.

To proof the system, various sensor data will be combined with a 3D model. Data from imaging sensors, such as a thermal camera, and individual sensors, such as temperature, moisture, and carbon dioxide, is used as the test data set. Moreover, an open 3D application development platform is utilized to visualize the building models. A user interface is then developed to facilitate the study of time series. The resulting model can then be used to study the state of the building and its indoor air quality. Based on this prototype, the aim is to outline future development directions. To take the whole operational life of the building into account, models have to include, as much as possible, all information concerning the use and upkeep of a building.

2. Materials and methods

2.1 Measuring methods for indoor environments

The open source 3D Internet application platform was used to host the building models created and operate the developed applications. The resulting virtual scene is defined in a TXML file, following the XML syntax. Each object in the scene is defined, with the object geometry being stored in an external file, accessible over an http connection (realXtend, 2015; Alatalo, 2011).

To obtain indoor measurement data from one of the test sites, the test utilized the Faro Focus 3D terrestrial laser scanner and Matterport Pro 3D Camera. Faro Focus 3D is a conventional TLS instrument with an integrated camera designed to obtain texture images that can be used to colorize the point cloud in later processing (Faro, 2015). The distance measurement accuracy of the instrument is ±2 mm at a distance of 25 m (Chow et al., 2012). Faro Scene software was utilized to process and co-register the TLS scans. Matterport is a commercial solution for measuring indoor environments based on depth camera technology (Matterport, 2015). The device is used to acquire a set of panoramic depth images from the environment, with each image covering a full 360° field of view. The 3D reconstruction process is performed automatically with cloud computing. After the user has uploaded the measured data, an optimized alignment of the 3D captures is solved, and a textured mesh model created (Bell et al., 2013).

Four different model reconstruction methods were employed: three dimensional models were created from the TLS point cloud using AutoCAD 2016 and Geomagic Design X. In addition, the automated generation of a mesh model was performed from the TLS point cloud by using Geomagic Studio 11. For the Matterport data, the automatic online service of Matterport was used to obtain the mesh models. After the modeling, game engine compatible models were created in Blender for use as game engine equivalents for the visualization.

2.2 Sensor networks

Data from the 720 indoor air quality measuring system (720, 2015) was employed in the experiment. The sensors were installed in two rooms of the test building. The data consisted of the hourly averages of the CO_2 concentration, relative humidity, temperature, and TVOC concentration. In total, the time series contained some 1030 readings, spanning a time period of 43 days. A small application was also written on the platform to visualize the data.

2.3 Online 3D building maintenance model

To assemble an online 3D representation of all data available from the building, a data model was utilized that divided the data into both individual spaces and data types. In the resulting model, each single entity of data (e.g. a Flir image or a 3D indoor model) was given two identifiers, a room code and a data type. The data types are provided in Table 1. The full set of metadata defined for objects is given in Table 2.

Table 1: Data types

Name	*Description*
2D CAD	*Two dimensional CAD drawing*
3D CAD	*Three dimensional CAD model*
Mesh	*Triangulated 3D mesh*
FLIR	*Thermal image*
Picture	*Image*
Point cloud	*Three dimensional point cloud*
Document	*Text document*
Other	*Other than above types*

Table 2: Object metadata

Attribute	*Description*
Data type	*Data type (listed in Table 1.)*
Data source	*Description of source (e.g. measuring instrument used)*
Room identifier	*Unique identifier of room in building (e.g. room number)*
Building identifier	*Identifier of building (e.g. address or name)*
URL	*Path of the full data (e.g. on intranet server)*
Additional information	*Any additional descriptions of data set*

As the chosen game engine-based system was unable to represent all object types, game engine equivalents were created for all objects. These equivalents were created by producing mesh models of the reduced polygon counts for all 3D objects and textured planes for the 2D objects. After this, the location of the actual data was input to the metadata of the object in TXML. Thereafter, an application was developed that allows the user to select individual spaces of the building, to choose the displayed objects according to data types, and to study the values of the sensor time series.

3. Results

By using the methods described, a virtual scene depicting two rooms of the test building was created. The orientation of these data sets was resolved manually, and the metadata was input for the objects. The resulting scene was hosted using a realXtend server. In the tests, a local machine was used to run the server and access the scene. In the scene, different measuring data sets are displayed in the same virtual 3D space.

In the scene, a user can filter the displayed object according to the data structure described, fetching data sets of a certain class from each room individually. The counts of objects available on the server for each type are displayed. In addition, there are tools to hide all data sets or isolate an individual data set for study. The values obtained by the 720 sensors are displayed next to each room. To enable functionality, a user interface is provided for jumping backwards and forwards in the time series. Accordingly, Figure 2 illustrates the system displaying Matterport mesh models for both rooms, the sensor data for both rooms, and a set of thermal images for the other room. As shown, the user can move freely in the virtual 3D space. Figure 3 also demonstrates a preview of a thermal image being shown inside a mesh model.

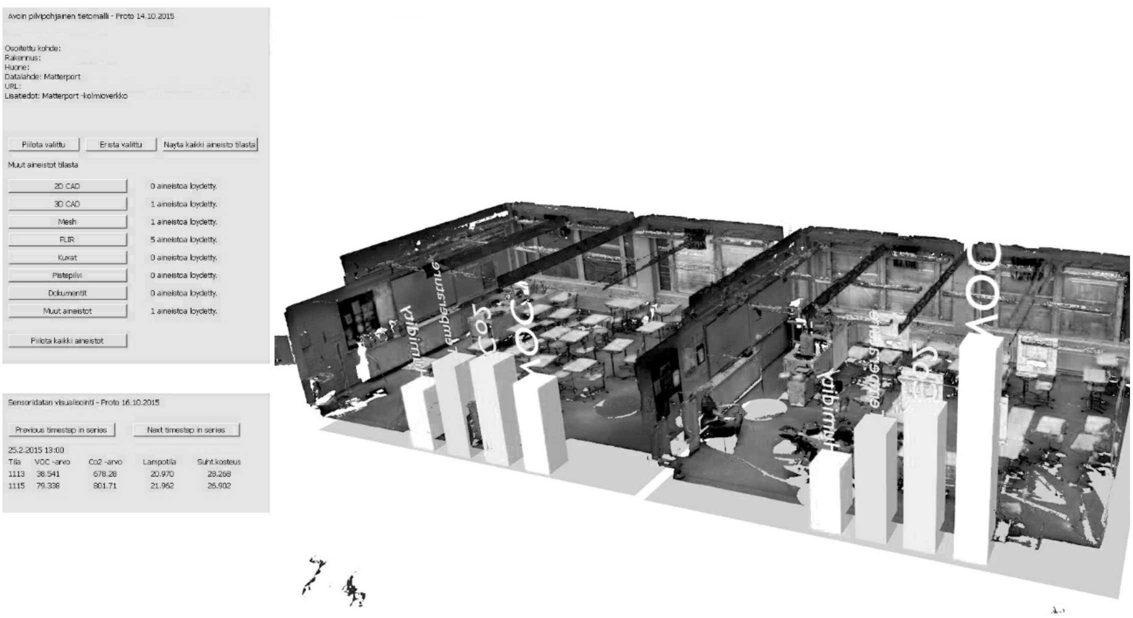

Figure 2: System in use, displaying some data for both rooms

Figure 3: Studying an individual thermal image in the data set

4. Discussion

The presented setup is able to display objects of different types in a virtual 3D space and also sort them according to the metadata. There are a number of advantages that can be found in the proposed system. Firstly, the concept of using game engine equivalents is essential for the development of computationally light applications that operate over the Internet. As there are already browser-based systems that utilize the same architecture (Meshmoon, 2015), the possibility of developing fully browser-based tools remains. A simplified, game engine-optimized model can, in these systems, be used to depict a larger, more complex model. In this way, the user can preview the model relatively quickly and then download the full model later, using the existing tools of the industry (e.g. point cloud processing software or full-featured CAD) to study and process the actual model. Secondly, the usage of game engine equivalents enables the utilization of existing game engines for application development. This is already being conducted in several cases where, for example, Unity (Unity, 2015) is used to display building models. Thirdly, by leveraging the typical features of game engines, the system is able to represent both 2D and 3D data along with dynamic and static data in the same environment.

However, as the system is still a very early prototype, it has a number of apparent shortcomings. Firstly, the amount of automation in the content production is very low. Content building methods more familiar to the game development industry than construction have to be applied for making game engine equivalents of the 3D models. As such, the system is unable to directly support model formats commonly used in construction (e.g. DWG or IFC). Secondly, the orientation of the data sets with respect to each other has to be solved manually, if the data sets are in a different coordinate system. For example, Matterport mesh models had to be manually moved to match the coordinate system of the TLS campaign. Finally, there are no automated tools for adding new objects to the scene; the user must use the tools offered by the platform. These shortcomings render the current system unfeasible for immediate wider adaption.

Comparing the presented prototype to the aspects of future digital models employed for building upkeep and maintenance as presented in the introduction, it is possible to identify several development directions for the system. The future development roadmap is summarized in Table 3. The main development directions are the increase in the applicability of the system to large models, the inclusion of the entire building life cycle, and finally the support for sensor networks. With these development directions, the integration of geometric, sensor, and maintenance data becomes an important research focus.

Table 3: Future development directions

	Large, detailed models	*Building Life Cycle*	*Network of smart buildings*
Application	*Renovation* *Existing building stock* *Modeling of large complexes*	*Life cycle simulation* *Building maintenance* *Comparison with as-built data, identification of deviations*	*Multi-building systems* *Prediction models, alerts*
Data integration	*Integration of geometric, sensor, and planning data*		
Platform development	*Support for large data sets* *Segmentation, Optimization*	*IFC models* *Integration to planning systems* *Model change detection & updating*	*Interfaces* *Data visualization*
Data sources	*Big Data* *Open Data* *Measuring methods*	*Facilities management* *Building planning*	*Internet of Buildings* *Dense sensor networks*

5. Conclusions

Smart management of existing buildings requires new tools that integrate data from several sources and enable the study of networks of buildings. Based on the literature, the four features of future models used for building upkeep and maintenance were identified: the use of a virtual model as a starting point for operations, the aggregation of data on top of the model, the integration of sensor data to the model, and the building of an Internet technology-based networked system for maintaining and accessing the model.

In the presented experiment, data from 3D measuring techniques and imaging was used to build a prototype of such a model, consisting of two rooms in a larger facility. To achieve this, virtual world technology was used as a platform for the prototype. A simple application was then developed to facilitate the study of the models and other data. As such, the system was able to visualize the data. However, the low degree of automation in constructing the model prevents the immediate adoption of the proposed system.

Future development directions include the increase of automation in the content building of the presented system, the utilization of browser-based technologies, and the pilot use of the system to better identify development needs. With measuring techniques such as MLS, a 3D time series can be created for identifying geometric changes in the environment. 3D application platforms based on client-server architecture are well-suited for prototyping these models and visualizing data from the various sensors together with the 3D models.

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BIM-supported Life Cycle Analysis: A Case Study

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Abstract

Building Information Modelling (BIM) as emerging technology, bears promise to enhance the process-integration in the AEC industry and thereby enable life-cycle optimization of built environment. BIM model should serve as a joint knowledge database for the interdisciplinary planning team, offering thereby significant potentials for analysis and optimization of the over-all energy- and resources efficiency already in the early design stages; however these potentials remain largely still unexplored.

This paper explores the potentials of BIM as support tool for life-cycle assessment (LCA) and structural analysis in the early design stages on a case study of a timber-structure housing block. The timber-based structure and wooden façade promise higher eco-efficiency in terms of CO2 saving, however in order to support the decision making process towards such more sustainable construction, a decision making process towards optimisation of the structure based on life cycle and structural analysis is needed in the design stage.

Upon initial creation of BIM architectural model in Archicad, we carried out a comparative life cycle analysis study for assessment of the environmental impacts of the construction materials. The automated process using BuildingOne Tools with direct access to BIM model linking the eco-indicators to the specific materials and building elements and assessing overall eco-efficiency was compared to the "manual" data handling and LCA-calculation using Exel Software.

The varying needs concerning the Level of Development (Level of Development is the degree to which the element's geometry and attached information has been thought through) and semantical differences in the modelling procedures of the part-taking disciplines (architecture and engineering) were identified as main reasons for the defects of the building models.

Further on, lack of standards for parameterization of intelligent, digital building products in terms of LCA, that would unify property definitions used by eco-inventories or environmental product footprints and BIM libraries represents difficulty for the automation of life-cycle assessment. zIn order to improve BIM based life-cycle analysis, not only interoperability of the software has to be improved, as well as re-design of the design process and enhancement of individual capabilities.

Keywords: BIM, LCA, Optimization, Structural Analysis

1. Introduction

The achievement of sustainable built environment is based on energy and resources efficient construction. Thereby the design stage is of crucial importance (Azhar et al, 2011), since the impact of decisions made in this stage has the largest impact on the life cycle performance, at a very low cost. Simultaneously, the early design stage is critical in terms of decision-making and knowledge management, since the level of design-information is low, the design-knowledge is mostly implicit and difficult to grasp or communicate, which makes decision-making process extremely difficult. Simple, easy to handle tools for the prediction of future building performance that would enhance the decision support in the early design-stages are lacking. Thereby, design-oriented methods for prediction, simulation and optimization enabling decision making support in the choice of most balanced solution in terms of environmental performance and resources efficiency are needed.

Buildings run through various life cycle stages – design, construction and operation, where in each phase data is exchanged among team members, in order to document the current state of the building. The information exchange occurs on several levels – face to face communication, analogue, drawings or planning documents, digital or CAD planning documents - along proprietary or open data standards (interfaces) in various software platforms. There by knowledge transfer and loss represents the greatest challenge, partly due to the fragmented nature of AEC industry and silo-thinking, and partly to the lack of efficient means and methods for data exchange and transfer.

Building Information Modelling (BIM) as emerging technology, bears promise to enhance the process-integration in the AEC industry and thereby enable life-cycle optimization of the built environment (Fellows and Liu 2010). BIM, as defined by National Building Information Model Standard Project Committee (buildingSmart, 2015) is a digital representation of physical and functional characteristics of a facility. Various 3D, intelligent, data-rich building information models can be exchanged within the project team and ideally throughout the life cycle of a facility (Smith and Tardif, 2009). BIM acts thereby as an integrated platform for team members to share and exchange project information in the phases of design, construction and operation (Eastmann et al, 2011) thus serving as planning documentation as well as for data management; supporting decision-making process. In order to enable smooth data exchange and transfer without data-losses, open standards and interfaces are needed, such as IFC - Industry Foundation Classes (buildingSmart, 2015).

Further on, BIM as a parametric, data-rich model enables follow up analysis such as structural analysis, thermal or lightning simulation, assessment of environmental and economic impacts through life cycle assessment, life cycle costing etc. (Diao et al, 2011). However, in order to employ such follow up analysis in the early design stages, and make it a standardised procedure within design process as decision support instrument, ease of use, user-friendliness and high level of automation in data exchange between various tools is needed.

Using a case study of timber-structure housing block, we will explore the potentials of BIM as knowledge platform for life cycle optimization in the early design stages. Thereby we will apply the BIM modelling methods for the creation of architectural model, and carry out follow up analysis involving life cycle assessment and structural analysis, thus enabling design-optimization in the early design-stages. Thereby we will evaluate the employed software tools as well as the work-flows, and outline the potentials and deficits.

2. Related Work

Potentials of BIM-use for life cycle analysis in the design stage has been of increasing interest in the research community. Especially interesting is so called BIM to BEM approach – transfer of building information models to building energy modelling for follow up thermal simulation. Model exchange in this area has been especially troublesome, since commercial BEM software such as Energy Plus or similar do not support IFC interface, but a proprietary gbxML interface, which makes the transfer particularly troublesome. Researchers such as O'Donell at al (2014) propose a workflow for BIM to BEM based on IFC interface, proposing so called BIM Model View Interface, allowing semi-automated model exchange. Schlueter and Theselling (2009) develop a proprietary tool for energy performance analysis in design stage for Autodesk Revit software platform. Azhar et al. (2013) undertake a thorough analysis of BIM fitness for sustainability assessment using LEED rating analysis, establishing a procedural framework between the environmental analysis that can be carried out using BIM model, and LEED credit requirements, however they conclude that the automation of the workflow is not possible, due to the lack of LEED features integrated in the software.

3. Research Design

Upon initial creation of BIM architectural model in Archicad 19 BIM-Software platform, we carried out a comparative study of life cycle assessment of the environmental impacts of the construction materials. The semi-automated process using BuildingOne Database with direct access to BIM model linking the parameters of eco-indicators to the specific materials and building elements and assessing of overall eco-efficiency was compared to the "manual" data- and parameter handling and LCA-calculation using MS Excel. The obstacles in the semi-automated process will be identified as well as the difficulties in the manual process.

In the further step the primary loadbearing structure from the architectural model was transferred to the structural analysis software package via .ifc interface, in order to optimise the load bearing structure. Thereby data-transfer was tested in terms of data-losses and model coherence from architectural to structural model.

The Case Study consists of following steps:

1. Step: Creation of BIM model for a specific case – exploration of densification potentials of supermarket sites

2. Step: BIM for LCA – comparative study of a) semi-automated LCA using BuildingOne Database and b) manual LCA using Excel sheet (not automated)
3. Step: Work flow analysis of Transfer of BIM model to Structural Analysis via IFC interface

3.1 Methods and Tools

For the creation of Architectural Model, Archicad 19 was used, as certified software for both .ifc import and export. The model was created in the Level of Development 300 (BIMforum, 2013). Thereby the building elements are defined as load bearing and not-loadbearing (walls, columns and slabs). The building elements are defined as multilayer-building elements, in order to be allow latter parameterization of material and elements through parameters such as area, eco-indicators, etc. of the building elements, needed for the LCA.

Life Cycle Analysis was carried out applying the IBO (Austrian Building and Ecology Institute) OI3 Index (2013) methodology. The OI3 Index is generally based on assessment three of indicators – Global Warming Potential - GWP, Primary Energy Indicator- PEI and Acidification Potential (AP) for the construction-materials of a building. The single materials are bundled into the multi-layer building elements (e.g. exterior wall). The methodology finally proposes an assessment of a single, synthetic indicator as weighted sum of the three sub-indicators, which is benchmarked with the proposed grading system, finally obtaining a level of certification within the IBO-Index system. The methodology proposes several scenarios regarding (spatial) system limits, ranging from inclusion of building envelop only, to inclusion of complete building systems. We have opted for so called BG1 scenario, where complete thermal building envelope and interior slabs only are included in the assessment (interior walls excluded). The data-base used for the attribution of eco-indicators is also IBO Catalogue of Elements.

BuildingOne (2015) is a database originally created for the management of room-data sheets, enabling quantity survey, cost calculation and estimation. It offers bi-directional data exchange between the database and BIM software, such as Achicad 19 or Revit, and the data synchronisation. Through compilation of own queries customised calculation can be carried out, and exported into MS Office Platform (Excel). Since quantities (parameters) can be user-defined, the follow up calculation it terms of LCA can be carried out using customised queries and scripts.

Structural Analysis of primary loadbearing structure (timber) is carried out using Dlubal REFM software, for the Finite Elements Analysis. RFEM provides deformations, internal and support forces as well as soil contact stresses. Add-on modules facilitate the data input by creating structures as well as connections automatically and perform further analyses and designs. Since there is no direct, proprietary interface between Archicad and Dlubal REFM; the data is transferred using IFC interface. The model in Archicad is crated in such way, that building elements are differentiated in load bearing and not-loadbearing elements, only loadbearing elements are transferred in the Structural Analysis Software, for the simplification of the analysis-process.

4. Case Study

4.1 Architectural Model

In the year 2025 a population of almost two million people is being expected in the city of Vienna, which means that about 11.000 new apartments will be needed each year. As building land reserves are rapidly decreasing, new concepts for supporting densification are required. Numerous supermarkets within highly urbanized neighborhoods and their related vast parking spaces represent huge building land consumers, promoting urban sprawl as a result.

In this case study, a densification-concept is developed through proposing a timber housing block on the parcel and above one of such supermarkets in Vienna, in order to improve the overall ecological efficiency of the site (expressed in kg of CO_2/Occupant). Thereby the design is carried out using BIM planning method, exploring the potentials of BIM for follow up analysis such as life cycle assessment for compilation of eco-efficiency and structural analysis for feasibility and optimization of the load-bearing system.

The model is as mentioned in the chapter 3.1 modelled in Archicad 19 BIM software (Figure 1), as open-platform BIM software, enabling data-transfer using .ifc interface (open standard). Projects are temporary constructs, characterized through high level of uncertainty, e.g. unknown planners and software-constellations. In such setting, open interfaces are needed for smooth data transfer and project progress.

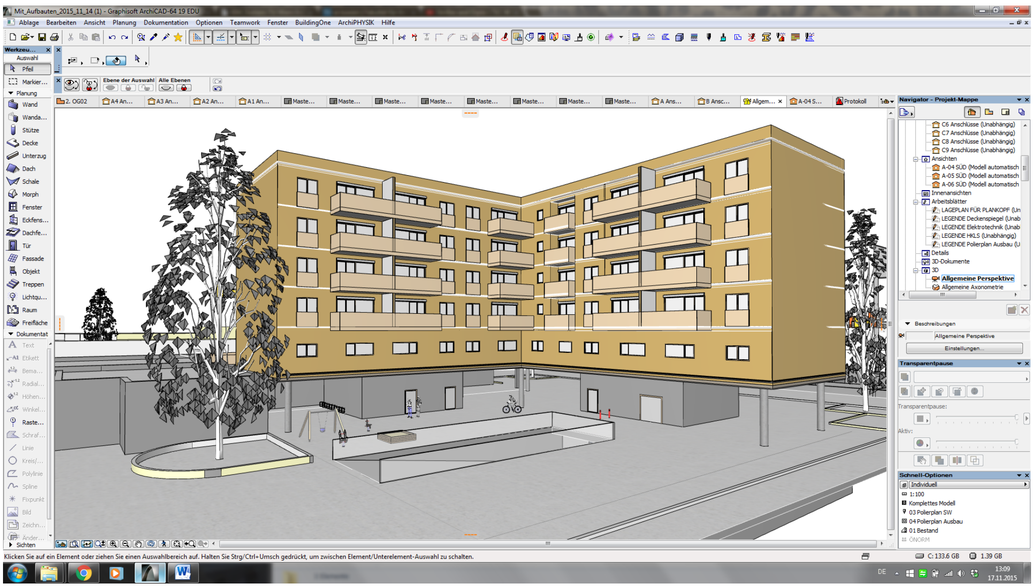

Figure 1: Architectural Model

All of the building elements regarding the building envelope (outer façade walls, roof, bottom slab) as well as the interior slabs were modelled as multi-layer elements (Figure 2), in order to be able to carry out the latter LCA according to OI3 Index, with system limit BG1.

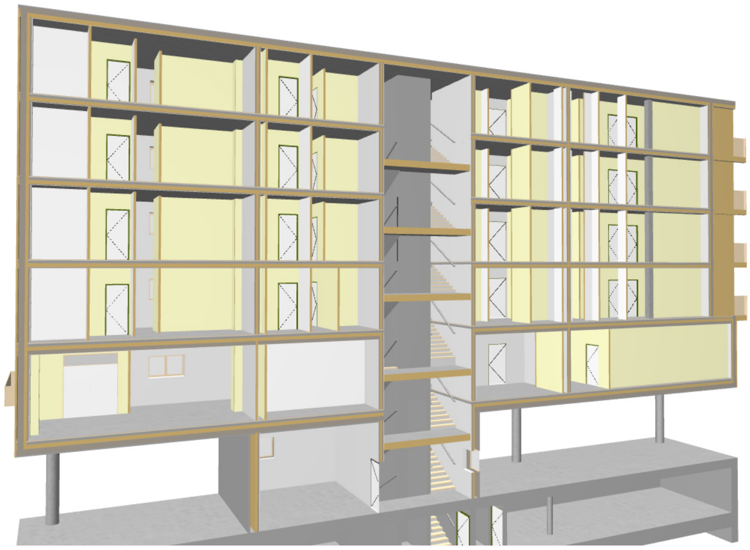

Figure 2: LOD – Multi-Layer Elements

Since eco-indicator data is difficult to obtain for specific materials, as first step the layers were defined in descriptively in .xls using the eco-indicators. Only after this the multi-layer elements were modelled and parameterised in Archicad – Model (Figure 3).

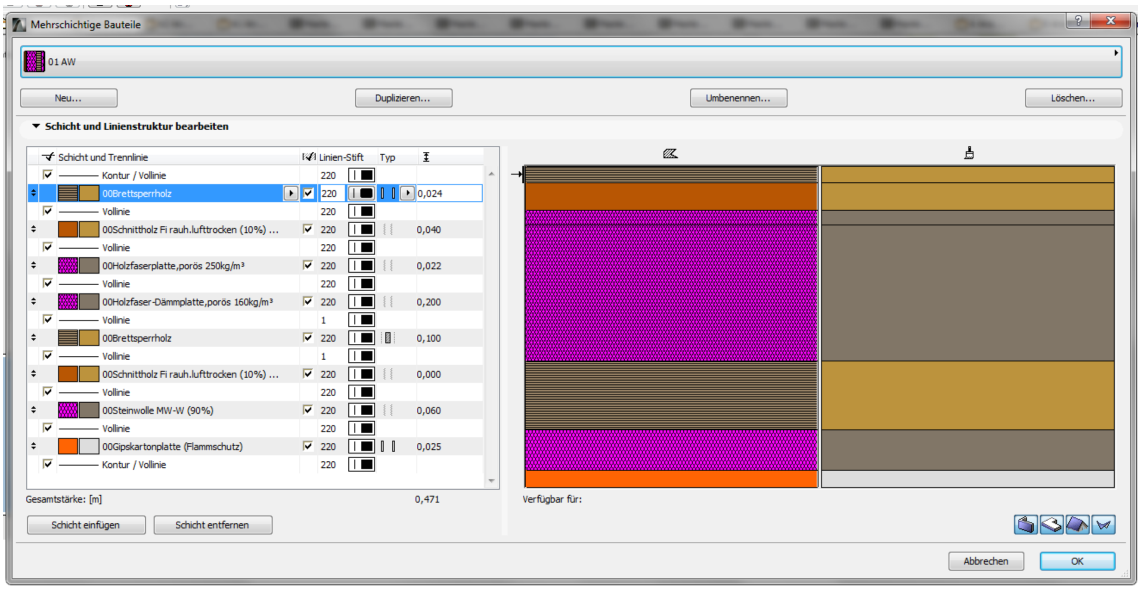

Figure 3: Multi-Layer elements – Parameterisation in Archicad

4.2 Life Cycle Assessment – A Comparative Study

After defining the multi-layer elements, two ways of carrying out the LCA were tested. In the first step the BuildingOne Database was tested, using BuildingOne plug-in in the Archicad. Initially a configuration was carried out, which we defined which building elements and properties should be exported to the database. To make this process easier, we created a layer combination called "OI3" in Archicad, which includes the building components relevant for the OI3-Index. Through this configuration, later mistakes, which can appear through synchronisation of wrong building components were avoided. Afterwards the multi-layer elements together with relevant parameters such as area, volume, layer (material) etc. were exported in the BuildingOne (Figure 4). In BuildingOne the elements were further parameterised through eco-indicators, which was carried out manually. However, due to the direct connection with the BIM model, all of the model-changes are synchronised with the database. For the calculation of the each OI3 Index indicator (GWP, PEI or AP) customised queries have to be compiled, as well as for the final calculation, which requires know-how and experience in the work with databases, which normally the designers and architects do not have. Finally the eco-efficiency report from the database can be exported in .xls for further processing.

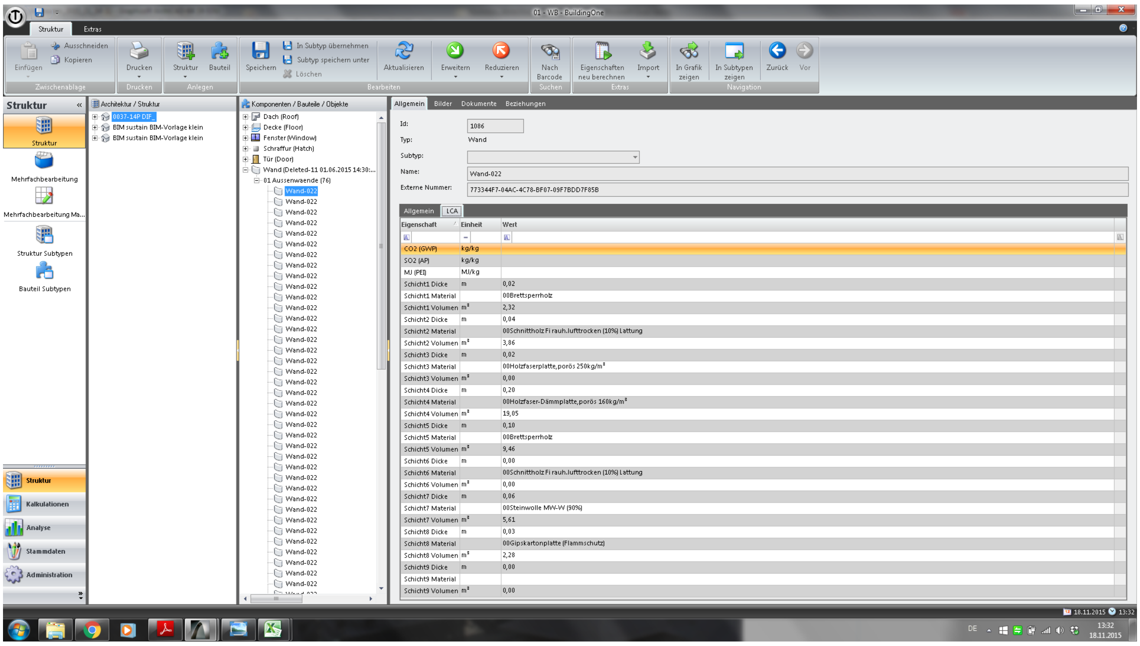

Figure 4: Data Management in BuildingOne

For comparison, the manual handling of data was carried out directly in .xls, where the originally compiled list of building elements and related eco-indicators was manually processed by adding the parameters such as areas and weight for final calculation of OI3 Index (sum of the parameters). The manual processing was easy and fast for handling, however due to the lack of automated synchronisation, prone to errors due to model-changes, such as areas, which had to be adapted manually. Figure 5 shows the comparative study, and advantages and disadvantages of both processes.

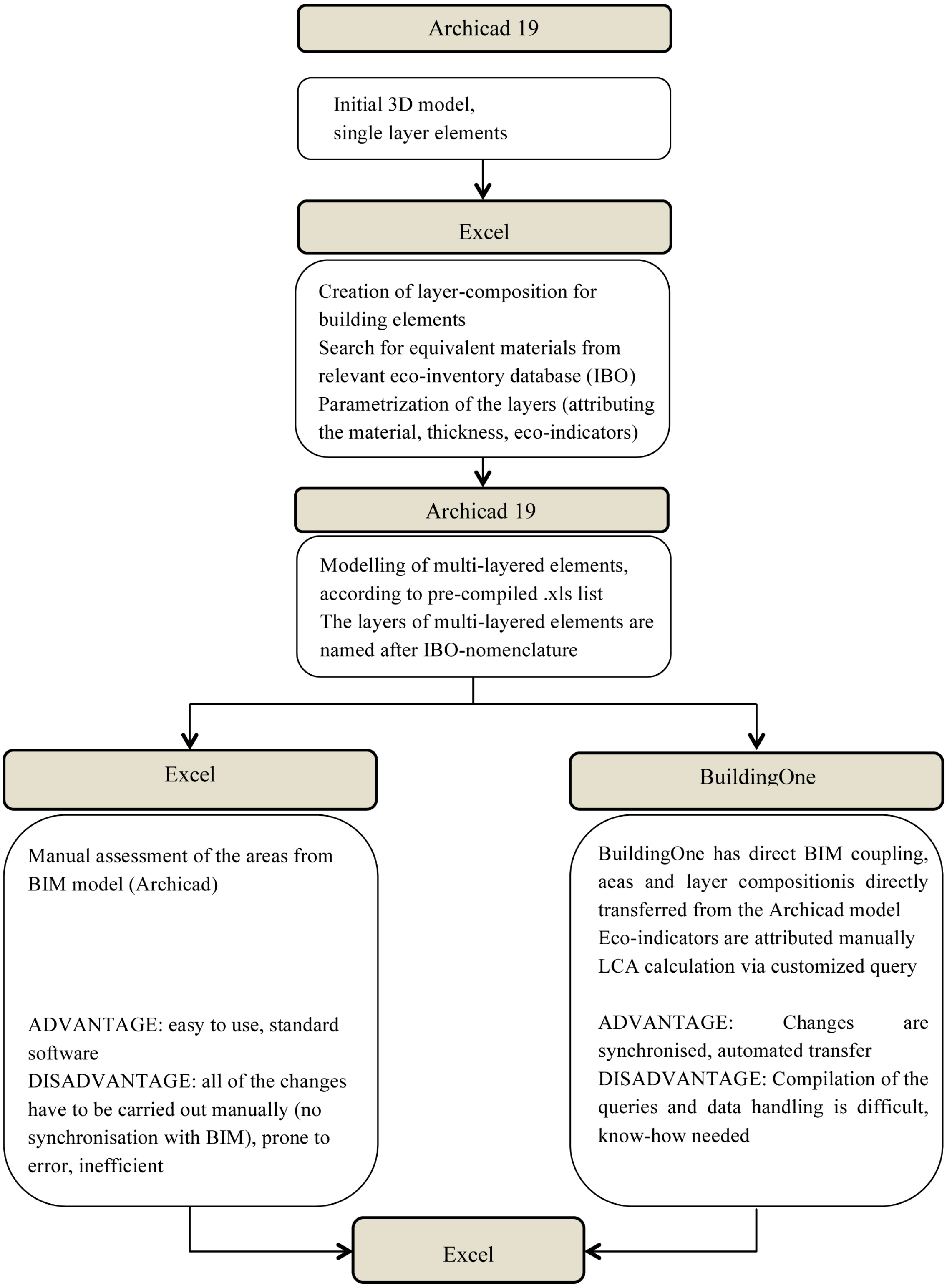

Figure 5: Comparative Study: LCA using BuildingOne and MS Excel

4.3 Structural Analysis

The primary focus of this study was to prove the data exchange efficiency between architecture (Archicad 19) and structural design and analysis (Dlubal REFM) modelling. The data and model exchange process still required model-repairs after the import in the structural analysis, despite the fact that the architect was instructed by the engineer about the required model-quality for the transfer. The work-flow analysis is presented in Figure 6.

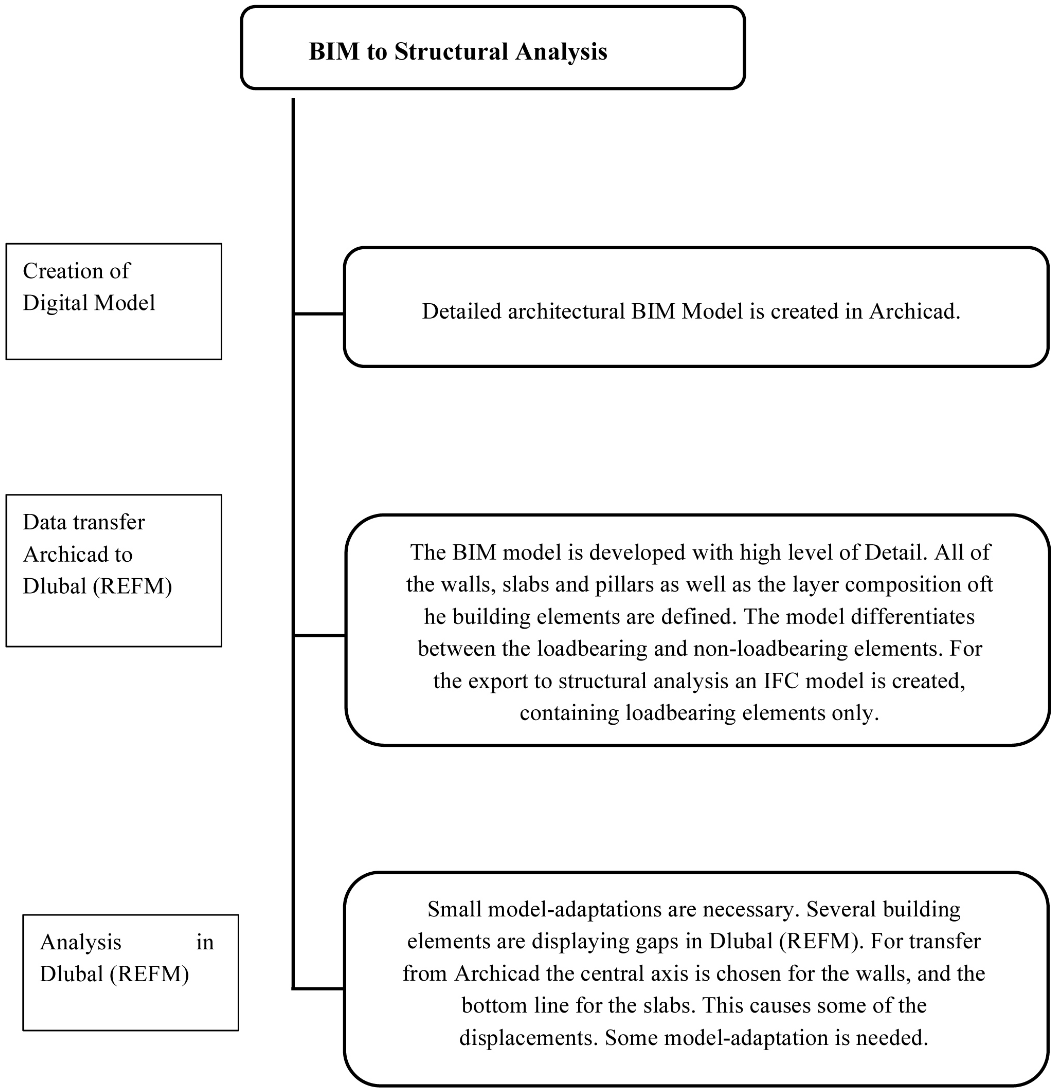

Figure 6: Structural Model before repair (slabs and walls intersecting)

In order to solve the lacking of geometrical intersection of various elements or of the wrong interpretations of geometry after export, model-repair had to be undertaken as shown in Figure 7.

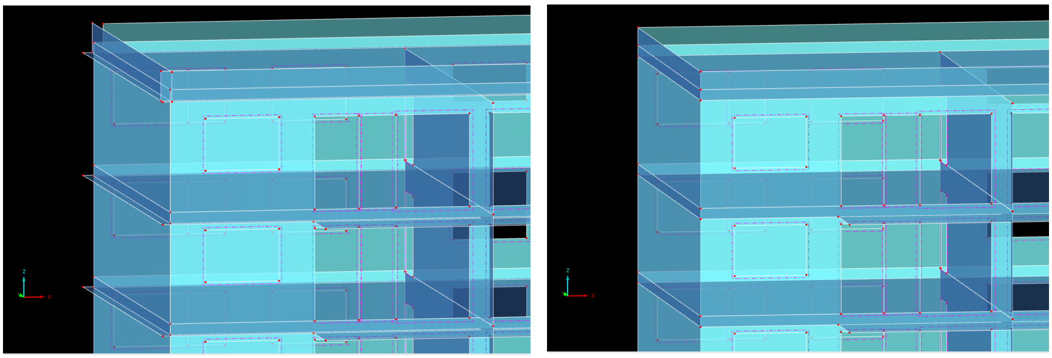

Figure 7: Structural Model before (Left) and after (right) repair (slabs and walls intersecting)

A development of a method for the discretization of geometry is here required, to bridge the semantical differences and varying needs in the modelling of architecture and structural engineering (e.g. slab-to-slab column in architecture; continuous column in structural engineering). The automation-procedures for model repairing and bi-directional exchange should be developed, in order to enable more effective interdisciplinary BIM supported design process.

5. Discussion

Despite of the intensive efforts of bodies such as buildingSmart (2015) or Austrian Standardisation Institute (ÖNORM A6241-2, 2015) to support interoperability through unification of building objects and their attributes (buildingSmart Data Dictionary – bSDD, 2015) there are large differences between the BIM data and the eco-inventories. Databases contain diverging descriptions (nomenclature) of building elements or materials, which again disables process-automation. Further on, manual parameterisation (attributing of eco-indicators) of materials of either multi-layer or single-layer elements in BIM model itself is not possible at the current moment (in Archicad 19). The elements contain some eco-indicator data already, however this data does not correspond to the Austrian LCA-Standard, nor are the system limits known (black-box problem), thereby the provided data is not valid for a sound LCA assessement.

BuildingOne has proved as potentially very useful tool. Due to the fact that its original purpose was cost accounting and area management and not LCA, some difficulties were encountered along the line of discussion above - some of the identical walls have a different identification number (attributed according to the position). A query for grouping of the elements must be compiled. A lot of effort is needed to customise the database, so if using such a tool, designers need skills and enhancement of capabilities.

As further general problem the Level of Development can be identified. The question remains in which Level of Development the model should be modelled for each life-cycle stage and for which specific purpose. The LOD 300 is defined by BIMforum (2013) as:

” The Model Element is graphically represented within the Model as a specific system, object or assembly in terms of quantity, size, shape, location, and orientation. Non-graphic information may also be attached to the Model Element. “

The problem encountered in the conducted case study, was that the various disciplines needed various detailing and data-richness of the model (e.g. LCA very detailed model, structural analysis very basic model), but in the same design-stage. This poses challenges on the designer. Thereby, an integrated process is needed where partaking disciplines can discuss model-needs for their specific purposes from the beginning, thus establishing project-related conventions, instead of relying on standards, which do not reflect the specific needs of the project. For example, if architect had not been working with structural engineer from the beginning of the process in the case study, it would not have been possible to provide a proper model. There by experience as well as interdisciplinary collaboration are two crucial factors for BIM supported analysis.

Further difficulty for LCA in general, however using BIM software in particular, is that the required Level of Development is often too high for such early design stage - all of the layers of the building elements have to be defined in order to attribute the eco-indicators, and carry out the follow up analysis. Often this cannot be done, because of the many unknown design-parameters in such an early design stage.

6. Conclusions

In this paper we have explored the potentials of BIM as joint knowledge base for the follow up life cycle assessment and structural analysis in the early design stage. Thereby various software tools were employed and workflows were analysed in terms of efficiency of data transfer and management, data-losses and ease of use. The comparative LCA-study has demonstrated that data-handling with standard software is easy, however prone to errors due to the numerous changes in the design which have to be adapted manually – the semi-automated process using BuildingOne database is more reliable in terms of change management, however requires skills and competencies of designers, which they normally do not have. Model-transfer to structural analysis required small model adaptations due to semantical differences in geometry, despite the interdisciplinary collaboration and coordination between the architect and engineer in terms of modelling.

We can conclude that integrated planning approach is necessary, where all of the members of design team work together from the beginning of the process, in order to discuss the specific Level of Detail as well as of Development needed for the follow up analysis. Standardisation process for creation of international reference libraries for digital products and materials has to be more intensified on transdisciplinary level, in order to enable the life cycle analysis of built environment.

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An Evaluation of BIM Opportunities in Design Phase of Donor-Funded Projects

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Abstract

The construction projects in developing countries have been negatively influenced by communication gaps and lack of interoperability in design and construction processes. BIMs appeared as an enablers of interoperability, but today the implementation of Building Information Modelling as an information management paradigm that spans over the projects' entire life-cycle provide unique opportunities for facilitation of the processes in all phases of the construction lifecycle. In order to explore the full potential of the implementation of the Building Information Modelling as an information management strategy, opportunity analyses covering different phases of the life-cycle is required. This paper focuses on providing an opportunity analysis to explore the opportunities provided by the BIM to facilitate collaboration and coordination in the design phase of construction projects.

Keywords: BIM, Opportunity, Design, Donor, Projects

1. Introduction

The construction projects in developing countries have been negatively influenced by communication gaps and lack of interoperability in design and construction processes. Some countries who are under economic and political pressures frequently face difficulties in completing the large projects. In a few of them such as Palestine (i.e. West Bank & Gaza Strip) government projects are funded by donor organizations due to county's difficult economic situation. Donor-funded construction is a rarely observed economical model for the construction industry and neither its processes nor the difficulties and opportunities contained in the model has been in the focus of built environment research. On the other hand, Palestine appears as a nice case which contains many cases of donor-funded projects. Key projects in Palestine depend on aid from donor countries and organizations. The bodies and organizations that offer grants to the construction industry in Palestine are the World Bank (WB), the Islamic Development Bank (IDB), the United Nations Relief and Work Agency (UNRWA), the U.S. Agency for International Development (USAID), United Nations Development Program (UNDP), the European Union (EU), German and Japanese institutions, Welfare Association and World Vision (Abdulhadi, 1994). The construction industry in Palestine is one of the key industries and is the main force motivating the Palestinian National Economy. The industry can be viewed as an advancement enabler for achieving nationwide goals in modern society In the country, the problems in construction projects are not only caused by the lack of technical skills and financial resources but also as a result of inadequate coordination, integration, communication and control of project activities.

The paper focuses on providing a review of opportunities provided by the use of Building Information Modelling in the design phase of donor-funded projects. The review provided in this paper is based on outputs of authors' previous research on i.) opportunities provided by the implementation of Building Information Modelling in several phases of the construction life cycle and ii.) exploring and mapping the processes of donor-funded construction projects. The latter effort was unique in terms of depicting and formalizing the processes of donor funded projects and also in terms of discussing how the processes in donor-funded projects can be facilitated by better communication and coordination between all stakeholders. The paper will summarize the results of this latter effort together with providing information on the opportunities provided by the utilization of Building Information Models. The paper starts by summarizing the construction industry in Palestine, including different contract types and actors. The 3rd section introduces the concept of process-based construction management. The 4th section discusses coordination problems in donor funded projects. The 5th section focuses on the details of the processes in the design phase of the donor-funded projects. The 6th section discusses the opportunities provided with BIMs in donor funded projects. The paper finalizes with a summary and conclusion section.

2. Overview of the Industry

The projects in the construction industry have a significantly high rate of business failure, and collapse and bankruptcy. The projects in the industry has been significantly affected by economic, environmental and political cycles due to many uncertainties resulting from many players of multiple disciplines who are brought together at various stages throughout a single project (Enshassi et al., 2006). Palestine construction industry is not an exception to this. The industry is complex and influenced by factors which may cause weakness including changing economy, closures, mismanagement of projects and the lack of skills and technology (Enshassi & Abu Rass, 2008). Elbeltagi (2006) indicates that the construction projects in Palestine can be classified into four major categories as:

- *Residential Housing Construction* which includes single-family houses, multi-family dwellings, high-rise apartments.
- *Institutional and Commercial Building Construction* which encompasses a great variety of project types and sizes, such as schools, hospitals, sports stadiums, retail chain stores and large shopping centres.
- *Specialized Industrial Construction* such as oil refineries, steel mills, chemical processing plants and coal-fired or nuclear power plants.
- *Infrastructure and Heavy Construction* which includes projects such as highways, mass transit systems, tunnels, bridges, pipelines.

Different types of enterprises take part in the construction industry of Palestine, according to PCU (2003) these can be classified as,

- *Donor (International Financing) Enterprise* which appeared as a result of general economic situation and financial failures that prevented the completion of the projects.
- *Public Enterprise which* covers governmental institutions that owns or manages public projects.
- *Private Enterprise*

In construction projects, three main actors are present as (Elbeltagi, 2006):

- *Owner (Client)* can be a public or a private entity and is the body who funds the project as result of the donation received.
- *Designer* is the design professional, this group includes architects, engineers, and design consultants.
- *Contractor (The Construction Professional)* is the party who undertakes the responsibility of construction from the owner (Bockrath, 2000).

A Contract can be defined as an agreement between two or more parties that creates for each party a duty to do something (e.g., to provide goods/ a service at a certain price and according to a specified schedule for one party and to pay for the service provided for the other) (Owen, 2003). Construction contracts in the country can be classified into the following types as; General (Traditional) Method "Unit Price" Contracts, Cost Plus Contracts, Design-Build Contracts, Turnkey Contracts, Management-Oriented Contracts, Construction by Daily Labor Contracts, Target Estimate Contracts, Guaranteed Maximum Price Contracts, Construction Management Contracts, Lump Sum Contracts, (BOT) Build–Operate–Transfer Contracts, and Special Contracts. The selection of the contract type in Palestine depends on several factors such as government agency type, project type, and sponsor identity. Sometimes the local agencies are even enforced to use the contract template of the sponsor organization’s country.

Based on the result of interviews that were conducted during this research, 4 different types of contracting methods were found to be actively in use as

- General (traditional) contract Method “Unit Price” Contracts
- “Special Contract Method” Contracts
- “Construction by Daily Labor” Contracts
- “Turnkey” Contracts

In addition, there are 2 more types that are in use which are the Lump Sum and (BOT) Build–Operate–Transfer Contracts but they are used less frequently.

3. Process Based Construction Management

Process Based Construction Management can be defined as the management of the activities in construction projects based on well-established processes which are formalized by process protocols, frameworks and models. A Process Protocol is a tool and methodology for formalizing the process in the construction industry. The formalization of the processes serves for better understanding of the flow of events and interactions between the parties, finally resulting in better coordination during the design and construction stages. The approach has its roots in systems engineering and total quality management, where each molecular level component of a business (i.e. a process) is identified in detail. This identification includes the identification of the activities (i.e. the atomic level business components), actors that take part in this process, the input and outputs of the process, and identification of the relations between different processes, between super and sub processes. U.K. and U.S institutions are the leading research bodies in this field. The U.K. Construction Industry Process Protocol is a well-known protocol and is based on a recognized process model. Process Protocol Website (2013) defines this protocol as *“a common set of definitions, documentations and procedures that provides the basis to allow a wide range of organizations involved in a construction project to work together seamlessly”*. In the model, construction processes are grouped in 4 main stages as pre-project, pre-construction, construction and post-construction. Then this stages are divided into ten phases. Also, the participants within the Process Protocol are organized into activity zones. As stated in Wu (2004), the major benefits of Process Protocol are:

- The archiving and retrieval of project information
- Rapid communications
- Effective co-ordination
- The visualization of client’s requirements
- The visualization of structural and spatial requirements

There are also process frameworks based on technology re-engineered processes, a key example of these is the framework presented in BIM Execution Planning Guide. This study outlines the re-engineered processes based on the use of specific information management approach known as Building Information Modeling (BIMPEPG, 2013). Identifying the process models helps in identification of deficiencies in process along with risks associated with these deficiencies. On the other hand process maps provides a clear understanding of processes, their sequence, and their relations with other process. This in turn provides a foundational framework for identifying the opportunities related to each process. Following a review of the coordination related problems in the industry remainder of the paper will present a process map of design-phase activities in donor funded projects and discuss the opportunities provided by the BIMs in these type of projects.

4. Coordination Problems in Processes

Mohd Noor (2011) mentioned that 90% of all problems on site are due to late or inadequate information. Late information can cause thousands of dollar of losses in design and construction phases. In this research the identification of coordination related problems in donor-funded projects is accomplished by semi-structured interviews that were conducted with twenty experts including i.) engineers who work in government or NGO (non-governmental organizations) or at private engineering offices, ii.) contractors , and iii.) project managers. The interviewees were selected based on their experience in construction projects, In addition, they were working in different institutions and each have key positions in the government, in the contracting companies or at engineering offices. The interview process took over a period of two months. Open-ended questions most of which were prepared prior to the interview were used mainly as the interview instrument, and some emerging questions were asked spontaneously during the interview. Once the interview is concluded, the researchers analyzed the responses. The problems that were identified through literature review and problems appeared as the result of the interviews were grouped together, in six main groups, which are problems related to construction information, management, legal, financial dimensions, and included design phase problems and technical problems.

The construction information related problems were appeared in the form of problems related to the coordination due to; i.) lack of operational information such as change orders, ii.) unclear or contradictory information which is not comprehensive enough, iii.) incomplete drawings and documents, and iv.) problems in scheduling. The interviewees indicated that there exists gaps between the implementation of the drawings on site and the requirements in the specifications due to misinterpretation of drawings. Management problems are related with planning, controlling and so on. Unclear task specifications, problems in planning stage, and unpredictable changes in the project scope and requirements were identified as the key problems. The legal problems identified were i.)weakness in the harmonization of laws, and ii.)ambiguities such as legal disputes that emerge during the construction phase, iii.) changes that occur in government regulations and laws during the construction of the building. The financial problems were related to poor cost management and quantity surveying practices, and to the lack of cash flow management systems. The design phase problems include conflicts between consultants and design engineers, and uncoordinated (structural, mechanical, electrical) design. Finally, the technical problems were related to lack of technical support for the project, team and lack of human resources with required technical skills. Problems appeared as a result of rushed bidding process, and the use of obsolete technology in planning and construction stage were also reported during the interviews.

5. An Overview on the Design Phase Processes of Donor-Funded Projects

The Building Construction process in Palestine is initiated by the owner organization. The owner organization first indicates a requirement for a building to the responsible body of government, such as Ministry of Education, Ministry of Public Works and Housing. Then the government agency elaborates on this project idea, conducts a feasibility study and start to look for the financial authority that would support the project. As a result of the economic situation in Palestine, most of the projects depend on grants from donor countries or organizations. Once a donor is found and the support request for proposed project is approved by the donor the pre-design phase concludes. The donor organization then starts the transfer of the funds for the project through the Ministry of Finance. Most of coordination problems observed start in this phase, due to misinterpretation of clients' needs and due to problems in feasibility studies.

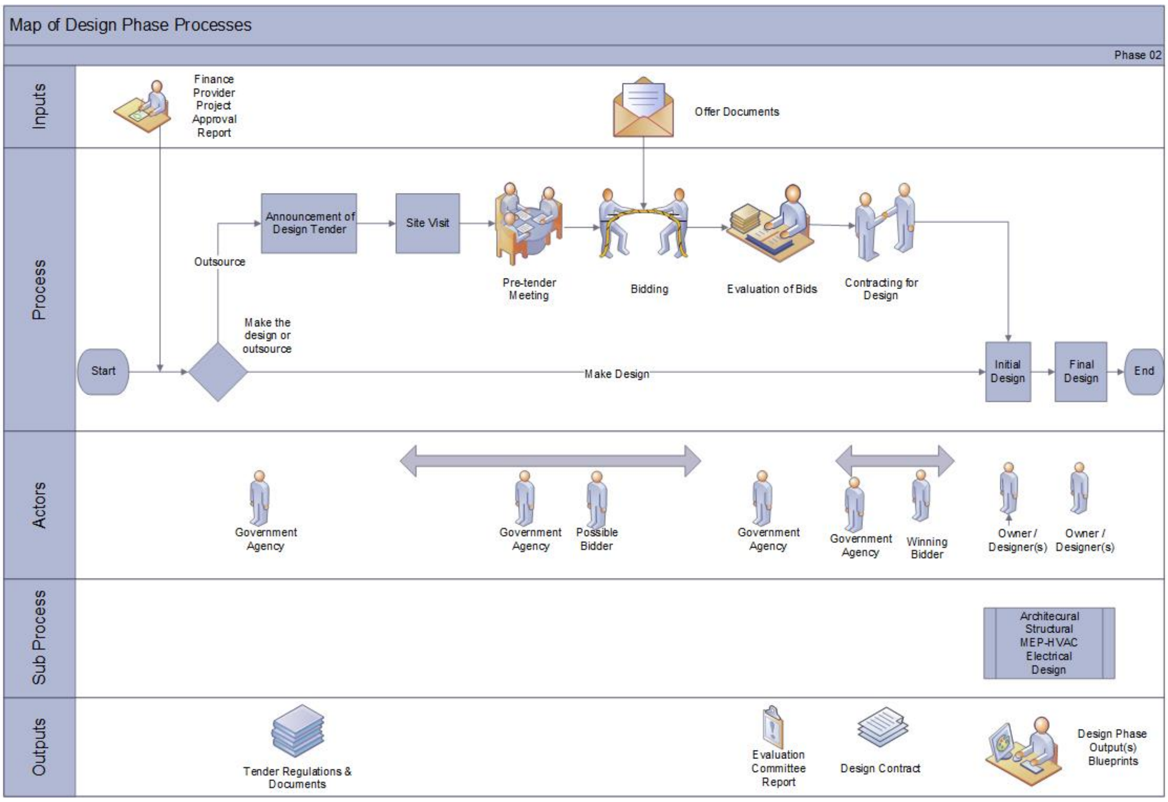

Figure 1. Design Phase Processes of Donor-Funded Projects

The following phase of the projects is the design phase. The process map for the design phase is shown in Figure 1. Once the government arranges the financing of the project at the pre-design phase there are two routes to follow. In the first one the Design and Supervision Department prepares the design, and the construction tender documents based on the client specifications, the conditions of the client and the budget allocated for the project. On the other route the design is delegated to a design consultant as a result of a bidding process. In this option the tender-for-design is announced in local newspapers in order to reach sufficient number of bidders. This is followed by a visit to the site, and an initial meeting to respond to the information requests of the possible bidders before the tender is opened. Once the tender is opened and finalized, the evaluation of the bids is conducted by the Evaluation Committee of the Government Agency. A design development contract is signed with the winning bidder. The winner prepares design documents, and the documents required for the construction tender (including detailed design, BOQs and so on).

6. Opportunities provided by BIM for Design Phase Processes

The implementation of Building Information Modelling as an information management strategy covering the projects' whole lifecycle and as a design management approach would facilitate design processes by enhancing communication, collaboration and coordination between the stakeholders. The opportunity analysis presented here is prepared by narrowing down the coordination related problems identified in the earlier phase of the research based on the design phase processes presented in previous section. The opportunities provided can be grouped into 4 categories as provision of consistent information, provision of comprehensive information, nD capabilities of BIM and process facilitation through the implementation of BIM methodology, which are presented in Table 1. BIMs contain detailed and comprehensive information about the building elements, their materials and material properties, elements' current state, their relations with other elements. The information residing in the BIM is always consistent in terms of 3D geometry of building elements and their semantic attributes. Views (i.e. subsets) can be generated from the model on demand or periodically and blueprints can be automatically derived from the model. Thus there will not be any inconsistencies between the digital model and the shop drawings. Finally, BIM methodology (BIM as an information management methodology) will help the facilitation of different processes in the lifecycle of the building. Below presents an overview on how the coordination problems mention in Table 1. can be eliminated by using the BIMs.

Table 1. Opportunities provided by BIM in Design Phase Processes of Donor-Funded Projects

Causes of Coordination Related Problems	**Opportunities Provided by BIM**
Unclear or contradictory information which is not comprehensive enough	-Provision of Comprehensive Information
Incomplete drawings and documents	-Provision of Consistent Information
Problems in scheduling.	-nD Capabilities of BIM
Unclear task specifications	-nD Capabilities of BIM
Poor cost management and quantity surveying practices	-nD Capabilities of BIM
Conflicts between consultants and design engineers	-Provision of Consistent Information
Uncoordinated (structural, mechanical, electrical) design	- Process facilitation through implementation of BIM Methodology
Lack of technical support for the project	-Process facilitation through implementation of BIM Methodology
Lack of human resources with required technical skills.	-Process facilitation through implementation of BIM Methodology
Legal disputes that emerge during the construction phase	-Dispute resolution through implementation of BIM Methodology

Provision of comprehensive information: BIMs provide comprehensive information about all building elements including, geometric and semantic properties, their materials, to-be-built dates, and relationships between them. The information provided by BIM will help in removing the unclarified information representation and flows which occur during the construction processes.

nD Capabilities of BIM: The use of BIMs will help in increasing efficiency in scheduling with the help of 4D scheduling simulations, will facilitate processes by eliminating problems occur due to lack of clarity in design communication. The information contained in BIMs will help in building up better design workflows and better specification of design and construction related tasks. The semantic information contained in BIMs will facilitate the process of quantity take-offs The implementation of automatic calculation of quantities will produce efficient inputs for the bidding phase in a timely manner. This in turn will be the first step for the better cost management practices.

Provision of consistent information: The BIMs contain 3D information with associated semantics where 2D drawings can be derived from it. During the construction of the BIM tools such as clash detection are used to prevent inconsistencies in the model. Thus the derived 2D models, and blueprints would eventually be components of complete and consistent design documentation. Thus the incompleteness in design documentation would be provided by the use of the BIMs. The BIM-derived shop drawings and design documents would contain detailed information about each building element together with details regarding the construction and assembly of the element, which in turn would be very helpful in preventing the conflicts between the consultants and designer which emerge in not well documented construction processes.

Process facilitation and dispute resolution through implementation of BIM Methodology: BIM methodology can be defined as an information management methodology that spans over the projects entire life cycle and focuses on management of the construction project based on the information derived from the BIMs. Building Information Modelling methodology proposes the use of design collaboration tools and software which would facilitate the coordination in the design process between architects, structural, electrical and mechanical engineers. The implementation of Building Information Modeling methodology will help in getting technical support in collaborative workspaces. The implementation of Building Information Modelling methodology requires highly skilled workforce on BIM related technologies and this generates the need for BIM training. An important impact of the training is development of a highly skilled workforce which in turn can be utilized in future projects. As indicated in Koc and Skaik (2014) the information derived from the BIM will be helpful in supporting the claims of the parties. In addition, BIM can also be helpful in dispute resolution through efficient representation of building elements that are related with the dispute. Furthermore, the 4D representation of the dispute event will contribute to the resolution efforts, as it will help the parties in evaluating the problem in focus in more detail.

7. Conclusions

The paper presented a structured review of opportunities provided by the use of Building Information Modelling in the design phase of donor-funded projects. The opportunities provided by the use of BIMs facilitate i.) design phase processes and ii.) processes which are dependent on design phase processes. The opportunities arise by the use of BIMs as shared information models and the implementation of Building Information Modeling as an information management methodology in the design phase. The BIMs provides comprehensive and consistent information which in turn enables better collaboration, communication and coordination of the design phase activities. The information contained in the BIMs are more reliable than conventional CAD models as BIMs contain agreed 3D geometries and semantic information, where sub models and other graphical representations (such as 2D) can be generated automatically. On the other had the implementation of Building Information Modelling as an information management method will also contribute to increase the skill levels of the employees, while providing a them a more efficient working environment.

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BIM in LCA/LCEA Analysis: Comparative analysis of Multi-family House and Single-family

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Abstract

The use of Building Information Modelling (BIM) in the Architectural, Engineering, and Construction (AEC) industry has increased lately due to the awareness of this methodology's potential to improve the performance and efficiency of projects and reduce errors. Similarly, there is a growing concern with energy consumption and environmental impact of buildings. If BIM is integrated with other methodologies that assess the environmental impact of buildings and its energy consumption, such as Life Cycle Assessment (LCA) and Life Cycle Energy Analysis (LCEA), it is possible to achieve higher levels of sustainability of the urban environment.

This paper (i) identifies which information LCA tools require and how to incorporate it in BIM objects, (ii) determine how that information can be incorporated in the BIM model, and (iii) perform an energy and environmental analysis of two different buildings and compare the results obtained in order to understand the impacts of designer's choices on the building's performance. The authors not only identify which information is required for an automatic LCA analysis of BIM-based projects, but also assess which phases and materials contribute the most for the environmental impact of buildings.

Keywords BIM; LCA; LCEA; multi-family house; single-family house

1. Introduction

The building sector accounts for 40% of energy consumption and 36% of carbon dioxide (CO2) emissions in Europe, with a similar scenario in the United States (Commission 2015). As the building sector is the main contributor of greenhouse gas (GHS) emissions and a huge consumer of raw materials, it is extremely important to develop adequate legislation for construction, in order to achieve the Kyoto emission targets. In the case of EU, the goal is to achieve a 20% energy efficiency target, 20% share of energy from renewable sources until 2020, and reduce greenhouse gas emissions by 80-95% by 2050, compared to the levels of 1990 (Commission 2012).

If methodologies such as Life Cycle Assessment (LCA) and Life Cycle Energy Analysis (LCEA) are employed in the Architectural, Engineering, and Construction industry (AEC) the EU will more likely achieve these targets. The LCA methodology predicts how a building will perform during its lifespan, considering its entire life-cycle (environmentally focused) (ISO 2010). LCEA assesses the energy consumption of the whole project (energy efficiency focused), considering: (i) embodied energy, which is the amount of energy due to the process of production, construction, transportation, and possible renovations; (ii) operating energy, which is the amount of energy used to maintain the indoor air quality (IAQ) and thermal conditions of the inside environment through heating and cooling, as well as lighting and operating appliance; and (iii) demolition energy of the building, which is the energy required to demolish the building and dispose of the material (Cabeza et al. 2014). As the operating energy is responsible for about 80-90% of total energy consumption and environmental impact (EI) of a standard building during its lifecycle, it becomes crucial to choose the solutions that will enhance the energy performance of the building from the very first phase of the project (Asdrubali et al. 2013). This must be taken into account when we are performing an LCA or LCEA of a project, in order to achieve a sustainable construction.

Nonetheless, in order to fully use the potential of methodologies such as the ones described above in the AEC industry, an integrated approach capable of supporting all life cycle phases and gathering and processing a high volume of information is needed. Building Information Modelling (BIM) might be the solution for that problem. BIM is a methodology that enhances the collaborative aspect amongst all different fields of expertise throughout the project design and enables a more efficient management of a building's operation cost (Costa and Grilo 2015). The potential of BIM in the field of energy simulation and building performance has also been recognized lately, with applications ranging from photovoltaic (PV) simulation, waste management, energy rehabilitation of existing buildings, etc. (Ahn et al. 2014; Cheng and Ma 2013; Gupta et al. 2014).

Despite the growing amount of published papers in the last years regarding BIM synergies with energy and building performance (Hiyama et al. 2014; Marzouk and Abdelaty 2014; Woo and Menassa 2014), so far, the literature in BIM-LCA only analyses the theoretical advantages of this integration (Antón and Díaz 2014; Díaz and Antön 2014), with only three papers having a more empirical approach (Basbagill et al. 2013; Jalaei and Jrade 2014; Jrade and Abdulla 2012). Identifying this need for additional BIM-LCA discussion, the current paper focuses the integration between BIM and LCA/LCEA tools, and reports an energy and environmental analysis of two different buildings and compares the results. The rest of the paper is structured as follows: section 2 describes the methodology used; section 3 identifies the required information for BIM-based LCA/LCEA; section 4 presents a pilot case study conducted to test existing tools for energy analysis and environmental performance of buildings, and in section 5 conclusions are presented.

2. Methodology

As mentioned above, the aim of this paper is to briefly discuss the integration of LCA/LCEA with BIM methodology and conduct an LCA study resorting to a pilot case study. As a result of this BIM and LCA/LCEA integration, this paper contributes to: (i) the efficient use of LCA and simulation methods in design processes, (ii) promotion of performance-based methods within designers, contractors, and providers of facility maintenance and energy services, and (iii) the improvement of product information management throughout the construction life cycle.

The first part of this paper describes the LCA and LCEA methodology and what type of generic information should be included in the BIM model. In this sense, the authors initially search for existing standards in the field of LCA and then identify the key information required to conduct an LCA study, and that should be included in the LCA databases.

In the last part of this paper, an LCA/LCEA is conducted using BIM-based software, using the pilot case study method. Two different solutions representing the residential buildings are analysed and compared: a single-family building and a multi-family building. Revit software is used to create the BIM models, while Revit Energy Analysis tool is used to conduct the energy analysis and Tally tool to perform the LCA study of the above mentioned solutions.

The results of the Revit Energy Analysis are based on the geometry and materials of the BIM model and automatically consider some predefined options based on ASHRAE standards (e.g. Occupancy Schedules and number of people living in the dwellings). The authors only specify the Analysis mode ("building elements"), the HVAC system ("Residential 14 SEER/8.3 HSPF Split Packaged Heat Pump"), the location ("Lisbon, Portugal"), and the building type ("single" or "multi-family"). The obtained results are then imported to Tally in order to consider the environmental impact of operation phase, and the impact assessment method used is TRACI 2.1.

3. BIM and LCA/LCEA tools Integration

3.1. Definition of LCA/LCEA

According to AIA (Bayer et al. 2010), the LCA methodology have almost 50 years, when researchers demonstrated their concerns over the resources depletion and energy waste, searching for new ways of sustainable lifestyle (Adalberth 1997; Bekker 1982; Sharma et al. 2011). LCA's potential started to be noticed only in 1997 with the International Organisation for Standardisation (ISO) publishing a set of standards promoting the adoption of LCA method and presenting a framework for conducting an LCA analysis, with four phases (ISO 2010):

- The scope of an LCA: depends on the subject and the intended use of the study,
- The life cycle inventory analysis phase (LCI phase): consisting of the inventory of input/output, involving collection of the data necessary to meet the goals of the defined study,
- The life cycle impact assessment phase (LCIA): provides additional information to help assess a product system's LCI results,
- Life cycle interpretation: the results of an LCI and/or an LCIA are discussed as a basis for conclusions, recommendations, and decision-making in accordance with the goal and scope definition.

Although LCA method has been used in a variety of sectors for a long time, it was studied only in the last decade in the AEC sector (Antón and Díaz 2014; Buyle et al. 2013; Díaz and Antön 2014; Jrade and Abdulla 2012). As LCA is a very consistent tool to evaluate environmental impacts, the AEC industry is increasingly incorporating this method and suitable product selection into decision making processes in order to optimise the whole construction process (Asdrubali et al. 2013).

In addition to the LCA method, there are other methods that assess the environmental impacts of constructions, such as Life Cycle Energy Analysis (LCEA) and Life Cycle Cost Analysis (LCCA). Unlike the LCA methodology, LCEA is more focused on the energy inputs of a building during its life cycle, including the embodied energy, operating energy, and demolition energy (Cabeza et al. 2014), and the sum of all the energy consumed in the building is the life cycle energy (Ramesh et al. 2010). Designers that resort to LCEA are able to identify the phases that have the highest energy demands, having the possibility to make more appropriate material choices. LCEA can also quantify GHG emissions through the primary energy of the building by multiplying it by a factor. However, LCA tools provide more precise results (Ramesh et al. 2010), as in this methodology, the product's environmental impact is assessed from the beginning of the analysis.

In order to successfully design a sustainable building with better performance, the designer not only should use BIM, as it is a methodology that has the ability to analyse different scenarios faster than the traditional methodologies, but also take into account a great diversity of different simulations, such as (Krygiel and Nies 2008): (i) Building orientation, (ii) Building massing, (iii) Daylighting, (iv) Water harvesting, (v) Energy modelling, (vi) Renewable energy, and (vii) Materials. As such, the designer must be aware which type of information fed into the BIM model will have a greater impact on the results of the LCA analysis.

3.2. Information required for LCA/LCEA tools

One source for LCA/LCEA tools databases is the Environmental Product Declaration (EPD), legislated and harmonised with the EN 15942:2011. EPDs have the purpose of facilitating the communication of a product's environmental performance for business-to-business (B2B) (Standards 2011). LCA can use generic, average, or specific data (Silvestre et al. 2015), with EPDs fitting in the last category. Specific data is the data collected at the manufacturer's plant. However, the product's impacts can differ from other similar products (Silvestre et al. 2015). This is easily explained, as for the same products different manufacture processes can be used. If a manufacturer intends to develop an EPD of a product, the following information must be provided (Standards 2011): (i) General information of the product; (ii) Parameters describing the environmental impacts of the product; (iii) Parameters describing the resource use and primary energy use of the product; (iv) Parameters describing the resource use, secondary materials and fuels, and use of water of the product; (v) Information regarding waste categories of the product; (vi) Output flows of the product; (vii) Additional technical information; (viii) Additional information on release of dangerous substances to indoor air, soil, and water during the use phase.

In order for BIM-based tools to perform an automatic or semi-automatic LCA of a project, BIM objects must therefore contain the information described above. If manufacturers include that information in BIM objects, there will be no need to connect to specific LCA databases, promoting the open access to environmental information, as most LCA databases are paid. Also, it will be much faster and simpler to execute an LCA study in this situation, as designers will not need to learn how to work with additional tools. However, there are some data that designers should add in the BIM objects that are site-specific (e.g. energy and water used, site location, transportation from factory to site, etc.). In order to include the required data in BIM-based objects, manufacturers and designers can resort to parametric modelling, which allows to incorporate the information regarding different specialities in a single object, as well as defining parametric relations and constraints (Lee et al. 2006). International guides for a BIM object library should be used in this process, such as NATSPEC BIM Object/Element Matrix and NBS BIM Object Standard.

4. Pilot Case Study: multi-family house vs single-family house

The purpose of this pilot case study was to understand the effect of designer's choices in the environmental impact of the building and to compare the energy consumption and environmental impact of a multi-family house with a single-family house, according to Figure 1. As such, the authors used Autodesk Revit to develop the BIM model, Revit Energy Analysis for energy simulation, and Tally for environmental assessment of the projects, as explained in Section 2.

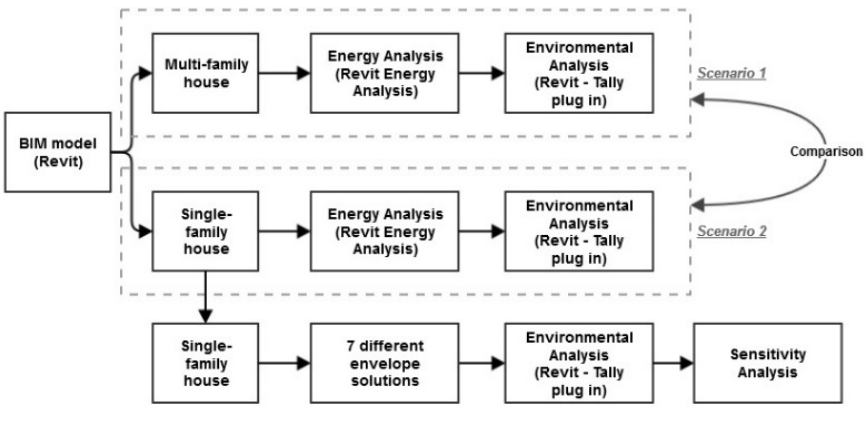


Figure 1 – Pilot Case Study methodology

The initial step was to model two simple buildings in Revit (Figure 2 and Figure 3), both with same envelope solutions, in order to guarantee that the results obtained are independent of material choices. After the development of both BIM models, the authors used the Revit Energy Analysis option to simulate the energy consumption (Table 1) and Tally plug-in to perform the LCA of these projects (Table 2), assuming a 60-year lifetime. Unfortunately, Tally plug-in did not recognise the chosen materials in Revit, only the construction solution, as this tool only works with GaBi's database. Extra work was therefore required in order to select the corresponding materials in Tally's database. This could compromise the accuracy of the expected results, as the tool users can select only the available materials. Nonetheless, as the purpose of this paper is to compare two scenarios with the same materials solutions, this software limitation will not jeopardise the expected results (both in Revit and Tally).

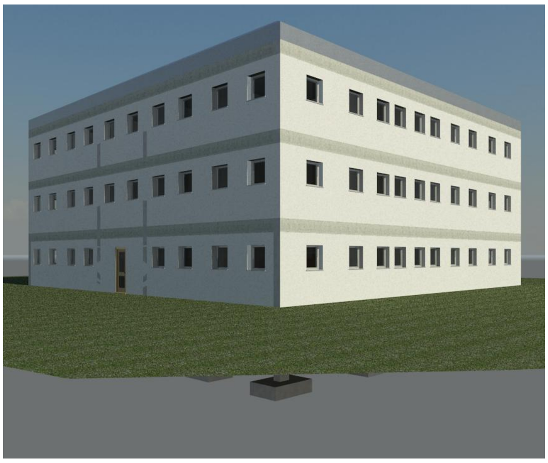


Figure 2 - 3 floor multi-family house (3D view)

Figure 3 - single-family house (3D view)

The second step of this Pilot Case Study was to analyse the environmental impacts due to materials selection, by examining the results of seven different envelope solutions (Figure 1). Unlike the first step, in which the authors' objective was to compare the energy and environmental analysis of different types of buildings, in this step the authors seek to understand the impact of designer's choices of materials, using a single scenario (single-family house).

Table 1 - Revit Energy Analysis results (multi-family house vs single-family house)

	Multi-family house	**Single-family house**	**Units**
Area	1,120.00	100.00	m2
Electricity Use	88.00	90.00	kWh/m2/year
LC Electricity Use	2,956,800.00	270,000.00	kWh
	270.0	24.7	kWh/day
PV low efficiency	46,514.00	11,243.00	kWh/year
PV medium efficiency	93,029.00	22,487.00	kWh/year
PV high efficiency	139,543.00	33,730.00	kWh/year

Table 2 – Tally results (multi-family house vs single-family house)

	Row Labels	Sum of Acidification Potential Total (kgSO2eq)	Sum of Eutrophication Potential Total (kgNeq)	Sum of Global Warming Potential Total (kgCO2eq)	Sum of Ozone Depletion Potential Total (CFC-11eq)	Sum of Smog Formation Potential Total (kgO3eq)	Sum of Primary Energy Demand Total (MJ)	Sum of Non-renewable Energy Demand Total (MJ)	Sum of Renewable Energy Demand Total (MJ)
Multi-family house	End of Life	75	41	174960	0.00	2550	575515	569443	6046
	Maintenance and Replacement	3114	366	319574	0.01	17084	3840682	3309445	531238
	Manufacturing	5364	468	1285760	0.10	48229	10458306	9612019	846288
	Operations	12200	630	2635708	0.00	142650	59812579	36338720	23473859
	Total	**20754**	**1506**	**4416001**	**0.12**	**210514**	**74687083**	**49829627**	**24857430**
Single-family house	End of Life	-2	4	39813	0.00	149	42730	41394	1329
	Maintenance and Replacement	282	34	26429	0.00	1457	339942	291080	48862
	Manufacturing	567	49	192020	0.02	5358	1033348	940644	92704
	Operations	1100	57	222181	0.00	13750	5201615	3060519	2141097
	Total	**1948**	**143**	**480442**	**0.03**	**20715**	**6617635**	**4333636**	**2283992**

As it is possible to observe from Table 2, Tally provided six different Environmental Impact categories: Acidification Potential, which causes fish mortality, forest decline, and the deterioration of building materials; Eutrophication Potential, which can cause an undesirable shift in species composition; Global Warming Potential, which causes an increase of the greenhouse effect; Ozone Depletion Potential, which leads to higher levels of UVB ultraviolet rays; Smog Formation Potential, which leads to respiratory issues and damage to ecosystems; and Primary Energy Demand, which measures the total amount of primary energy extracted (non-renewable plus renewable resources). In general, the environmental impacts from the multi-family house are about 10 times higher than the single-family house, being almost proportional to the area of the building.

The Global Warming Potential (GWP) is one of the most relevant impacts, and in both cases it is mostly due to operational energy consumption. However, for the single-family house the weight of the operational phase is lower than for the case of the multi-family house. On the other hand, the manufacturing processes contribute more to the GWP of the single-family house than the GWP of the multi-family house. So, we might argue that there is an economy of scale in terms of manufacturing (as an example we can refer that there are several construction elements, such as foundations, roof, etc., that are not proportional to the number of floors) but in terms of operational energy consumption the same logic does not apply, as the multi-family house has higher relative energy consumption (what might be related to the relevant energy consumption of the common/social spaces).

It is also important to understand which kind of materials have higher environmental impact, and if these materials represent a considerable portion of the building's mass. Table 3 and Figure 4 display the environmental impact of all materials used in the single-family house, throughout the different project phases. For this purpose, it is meaningless to display both scenarios (multi-family house and single-family house), as our real concern is only to analyse the environmental impacts due to materials selection, not to compare the two scenarios.

Table 3 - Tally (single-family house material's EI)

	Building Phases	Sum of Acidification Potential Total (kgSO2eq)	Sum of Eutrophication Potential Total (kgNeq)	Sum of Global Warming Potential Total (kgCO2eq)	Sum of Ozone Depletion Potential Total (CFC-11eq)	Sum of Smog Formation Potential Total (kgO3eq)	Sum of Primary Energy Demand Total (MJ)	Sum of Non-renewable Energy Demand Total (MJ)	Sum of Renewable Energy Demand Total (MJ)
Single-family house	**End of Life**	**-2**	**4**	**39813**	**0.00**	**149**	**42730**	**41394**	**1329**
	03 - Concrete	17	2	3676	0.00	304	61060	58499	2561
	04 - Masonry	4	1	792	0.00	65	13189	12642	547
	05 - Metals	-19	0	-3730	0.00	-200	-39564	-39987	423
	07 - Thermal and Moisture Protection	-5	0	39061	0.00	-40	12243	10165	2072
	08 - Openings and Glazing	-1	1	-518	0.00	-28	-12902	-8244	-4658
	09 - Finishes	3	0	532	0.00	48	8704	8320	384
	Maintenance and Replacement	**282**	**34**	**26429**	**0.00**	**1457**	**339942**	**291080**	**48862**
	03 - Concrete	0	0	0	0.00	0	0	0	0
	04 - Masonry	5	0	654	0.00	29	7244	6854	391
	05 - Metals	235	31	16334	0.00	990	246946	211625	35321
	07 - Thermal and Moisture Protection	2	0	180	0.00	7	1088	770	318
	08 - Openings and Glazing	10	1	1943	0.00	120	35210	23277	11933
	09 - Finishes	30	1	7318	0.00	312	49453	48554	899
	Manufacturing	**567**	**49**	**192020**	**0.02**	**5358**	**1033348**	**940644**	**92704**
	03 - Concrete	181	7	40938	0.00	2402	290957	277781	13177
	04 - Masonry	19	1	11139	0.00	295	138240	130311	7928
	05 - Metals	283	33	25320	0.00	1725	364925	324893	40031
	07 - Thermal and Moisture Protection	53	7	105754	0.02	544	158259	143472	14787
	08 - Openings and Glazing	12	1	2455	0.00	147	47947	31358	16589
	09 - Finishes	19	1	6413	0.00	246	33021	32828	192
	Operations	**1100**	**57**	**222181**	**0.00**	**13750**	**5201615**	**3060519**	**2141097**
	Grand Total	**1948**	**143**	**480442**	**0.02**	**20715**	**6617635**	**4333636**	**2283992**

As expected, concrete was the material with the highest mass percentage of the building, having a relatively low environmental impact/mass ratio (except in the manufacturing process). On the other hand, metal-based materials and insulation materials have a very high environmental impact/mass ratio, particularly on GWP, Acidification Potential, and Eutrophication Potential, despite their low representativeness in the total mass of the building. If designers are aiming for sustainable solutions, the selection of insulation material and its thickness is an extremely important aspect for the environmental impact of a building. It is relevant to mention that the higher the insulation thickness, the less thermal loss, leading to a decrease of operational energy consumption. So, for a sustainable solution to be reached, it would be advisable to perform a multi-objective optimisation of both (environmental vs energy consumption).

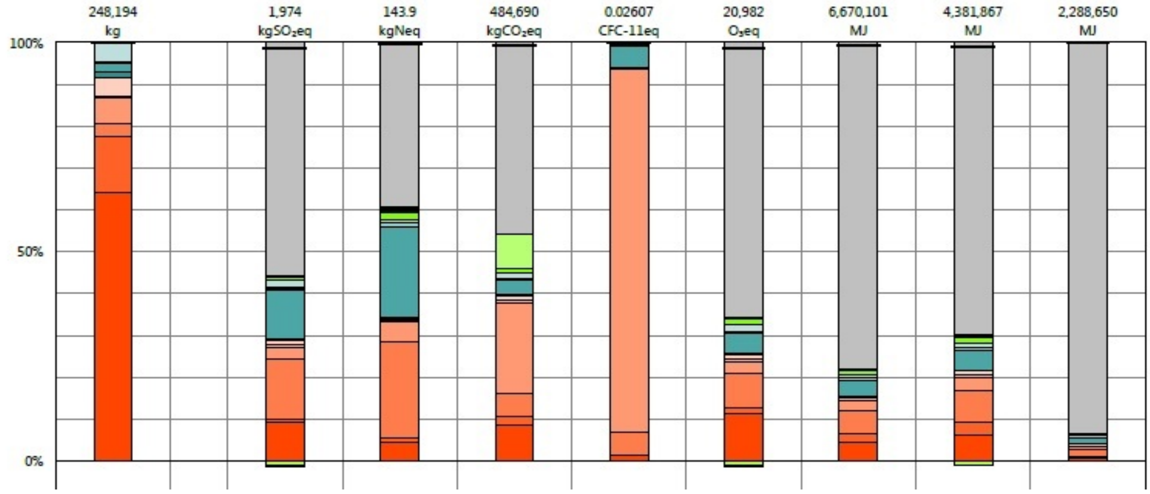


Figure 4 - Tally (single-family house material's EI)

However, in order to demonstrate how the designer's choices can profoundly affect a building's environmental impact, the authors decided to use the scenario of a single-family house and select different Revit and Tally solutions for the envelope. As observed in Figure 5, the original option (studied earlier) is one of the best sustainable solutions for most environmental impact categories. Also, wood-based solutions (option 3 and option 5) are the ones in which renewable resources can suppress most of the required Primary Energy Demand. Interestingly though, these two solutions also seem to be amongst the least environmentally friendly solutions (option 3 – wood roof: 1st in Acidification Potential, 1st in Eutrophication Potential, and 1st in Primary Energy Demand; and option 5 – timber floor: 2nd in Eutrophication Potential and 2nd in Global Warming Potential). However, if we examine Figure 6, we can conclude that most of those environmental impacts result from the End of Life potential use (recycling/reuse/recovery) of wood-based solutions, assuming that these materials are still in good condition. They are also the only ones with a positive energy return at the end of life (through burning processes). Regarding Smog Formation Potential, Acidification Potential, and demand from non-renewable resources, option 6 (full concrete envelope) comes as the least environmentally friendly solution.

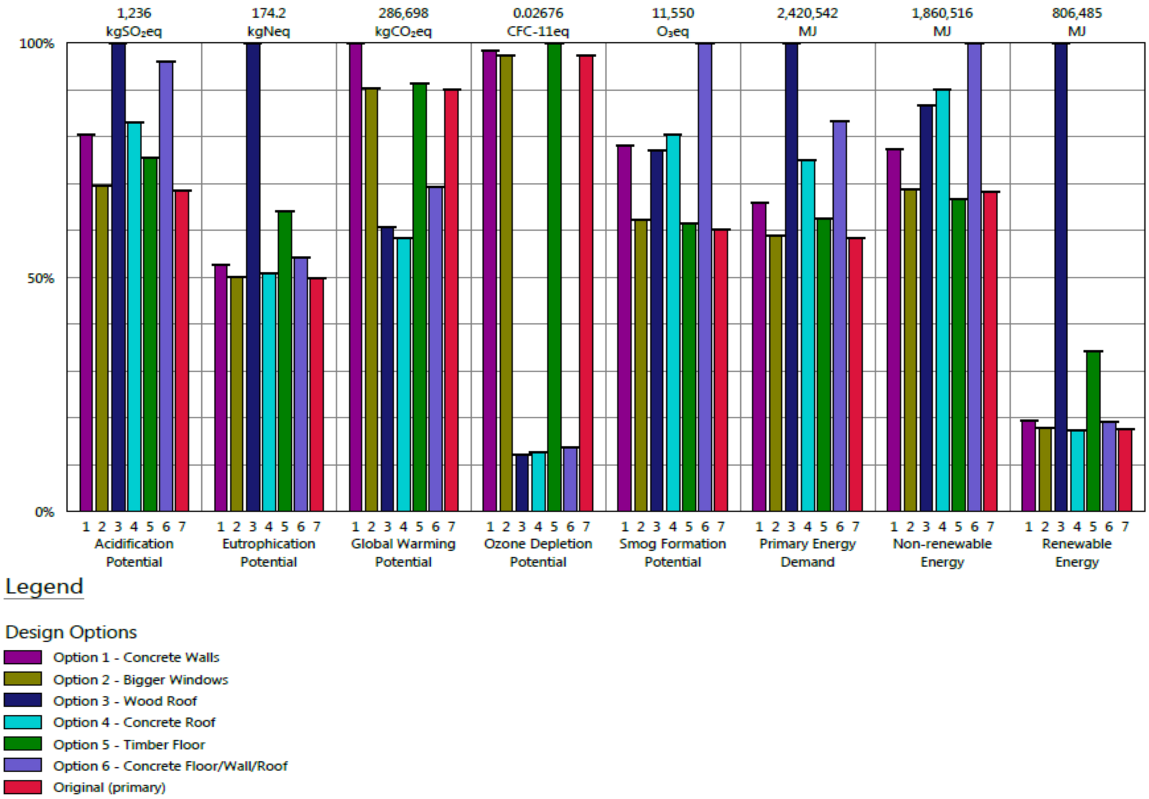
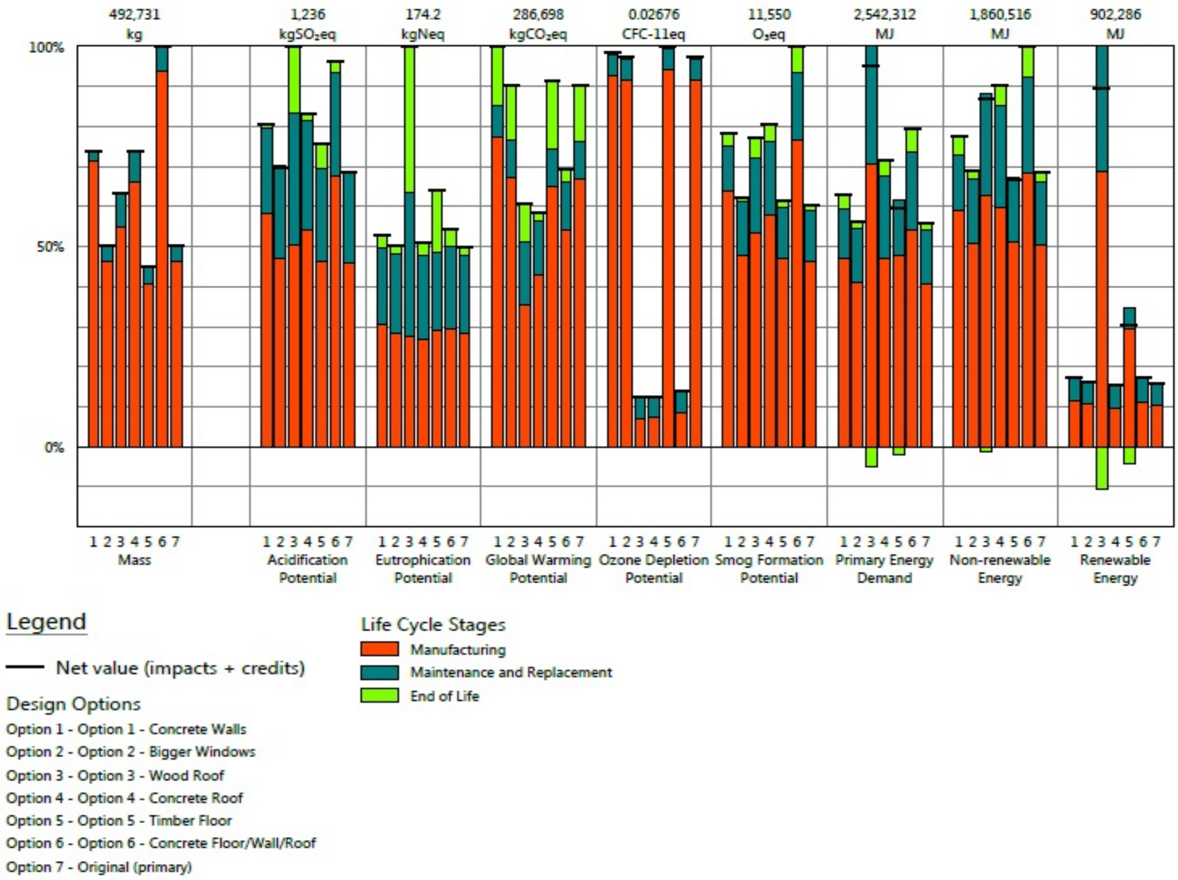


Figure 5 - Tally LCA analysis of single-family house (7 different options)



5. Conclusions

The first purpose of this paper was achieved through the analysis of existing ISOs and ENs, in which EPDs were identified as one of the main sources for LCA's databases. As such, in order to develop a BIM-based LCA automatic simulation tool, BIM-based objects must contain some crucial information that is requested by EPDs (see Section 2). The LCA plug-in used in this article, in spite of identifying Revit elements present in the project, did not recognise the object's information, as it works with GaBi's databases. This means that all information used by this tool must be manually added by the user after designing the architecture and type of solutions in the Revit. The second goal was achieved by performing Revit Energy Analysis, in order to obtain the expected energy consumption of both multi-family house and single-family house, and then by performing an LCA by using Tally. As mentioned above, the authors had to manually add the energy consumption of the selected scenario (provided by Revit Energy Analysis) with the purpose of obtaining results due to Operational phase, and also manually add the materials chosen to be used in the construction of the building, from a pre-defined list.

Despite the innovative environmental approach of Tally plug-in, designers will be greatly limited by existing options. However, the designers must also bear in mind that Tally plug-in represents only a quick and approximate analysis of a building's environmental impact. The authors initially assessed that both multi-family house and single-family house had a similar energy consumption (kWh/m^2), with multi-family house having about 10 times greater area, higher energy consumption, and greater environmental impact in most categories. The authors concluded that there was a positive correlation (in most cases) between energy consumption and environmental impact of buildings. Lastly, after the analysis of several envelope solutions for the single-family house scenario, the authors identified some effects due to the designer's material choices. Wood-based solutions are those in which renewable resources can potentially suppress most of the required Primary Energy Demand. Wood-based solutions are also those with higher End of Life potential use, leading to greater environmental impacts due to recycling/reuse/recovery processes. Option 6 (full concrete envelope) is one of the worst solutions, being on top of Smog Formation Potential, Acidification Potential, and demand from non-renewable resources. This is explained by the concrete's manufacturing environmental impact, which is very high compared with other materials.

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Benchmarking the Thermal Performance of GUtech's EcoHaus by Dynamic Modelling

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Abstract

The Sultanate of Oman is facing rapid population growth, fast urbanization and a steeply increasing energy demand. A major load is the cooling energy necessary for the ever-growing number of single-family houses in the hot and humid climate. In order to develop solutions to this pressing issue, the German University of Technology in Oman (GUtech) has designed and built a net-zero-energy residential building, the EcoHaus. The objective of this study is, to benchmark the thermal behaviour – and in conclusion the cooling energy demand – of the EcoHaus against the cases of buildings built according to the building regulations as well as according to the standard building practice.

The calculations are based on a dynamic model, which reflects the geometry of the EcoHaus and uses approved methods of heat transfer. The model is implemented in a MATLAB® simulation code, which is used to calculate summer- and winter scenarios. The most interesting results are summarised and discussed. These are the stand alone behaviour of the house, the energy balance of the inner air volume and the temporal cooling load as well as the cooling energy demand in the summer scenario.

The study shows that the EcoHaus achieves major energy savings in comparison with the chosen cases, which is founded in the (passive) design strategies. Furthermore, it was found that the house can keep the air temperature stable over a long period of time. The benefits in comfort conditions are significant and surmount the conditions in a standard house, although the energy demand is lowered.

Keywords: Benchmarking, Net-zero-energy building, Building simulation, Hot climate, Oman

1. Introduction

The Sultanate of Oman is facing a rapid urbanization with half the housing stock built within the last decade (Al-Awadhi 2007; Asif, Sharma et al. 2015). With view of the demographic situation and the current land distribution policies, this trend is likely to continue. About half the population is under the age of 30 years (Department of Economic and Social Affairs of the United Nations 2015) and every citizen is eligible for a plot of 600 m. at the age of 21 years; a trend that accelerates the urban growth and energy demand. The predominant house design is based on the building typology of the free-standing single-family house, and the predominant construction method is a reinforced concrete frame with a single-layered infill of concrete hollow blocks without further insulation on walls, roof, or windows. This standard low-cost design solutions and construction methods neither address the climatic conditions, such as the very high temperatures (up to 45 °C) and high humidity (up to 90 %) in summer (Dorvlo and Ampratwum 1998), nor do they link to the cultural traditions, in which a high degree of privacy in the house is required. The result of the first is high energy consumption for cooling buildings to reach comfortable interior conditions. With depleting availability of fossil fuel resources within the country and decreasing income generated from exporting these resources, the high subsidies for electricity consumption are questioned. The need for better solutions is obvious, and there are first initiatives to address this problem.

In 2011, The Research Council of the Sultanate of Oman (TRC 2015) gave grants to five universities in the country to design, build, operate, and monitor a net-zero-energy residential building on their campus. The project of the German University of Technology in Oman (GUtech), the EcoHaus, was completed in 2014. It is recognized as a successful contribution through national and regional awards for its concept, design, construction, and also the involvement of students.

While data of the actual performance of the house still being logged, this paper presents a dynamic model, which is used to simulate the assumed performance. With this, a benchmarking of the EcoHaus as an as-built case is undertaken against two other cases, the case of a building according to the building regulation requirements as well as the case of the actually used standard construction system. Not many such studies are undertaken in hot climates, especially not in the region. One example is the 'Baytna'-project in Qatar, in which two identical villas are built adjacent to each other - one built to usual standards and the other to "Passivhaus” standards - to allow for a comparison of their performances. The results of this benchmarking, however, are not published yet (Quatar Foundation 2015). Ochoa and Capeluto investigated the effect of an implementation of active- (e.g. blinds, lighting control and forced night ventilation), passive- (e.g. fixed shading, low-emissivity glass, or natural night ventilation) and a combination of both strategies in an office building in Haifa, Israel (Ochoa and Capeluto 2008). They found an energy saving potential of around 50-55 % in comparison with the actual building and stated a necessity to include energy saving strategies in early stages of the design process.

2. Model

The benchmarking is based on a dynamic model of the EcoHaus reflecting the geometry and the heat transfer properties of the basic building components. In this modelling approach, the house is divided in two parts, the envelope and the inner volume. The inner volume is divided in the solid volume that stands for all inner walls and other thermal masses within the building, and the air volume. The air volume temperature is the command variable of the model. Figure 2.1 shows the floor plans of the EcoHaus, where the parts of the envelope and of the solid volume can be distinguished: the inner surface of the envelope that is in heat exchange with both, the solid volume and the air volume, and the outer surface that is in heat exchange with the environment. For both surfaces, heat transfer by convection as well as by radiation is considered, while the heat conduction in the wall is solved according to the Binder-Schmidt-method. The envelope is discretized in circumference to picture the irradiation in dependence of the sun position. The same pattern is implemented for the roof as well as for the windows, where in addition the sun light transmission is considered.

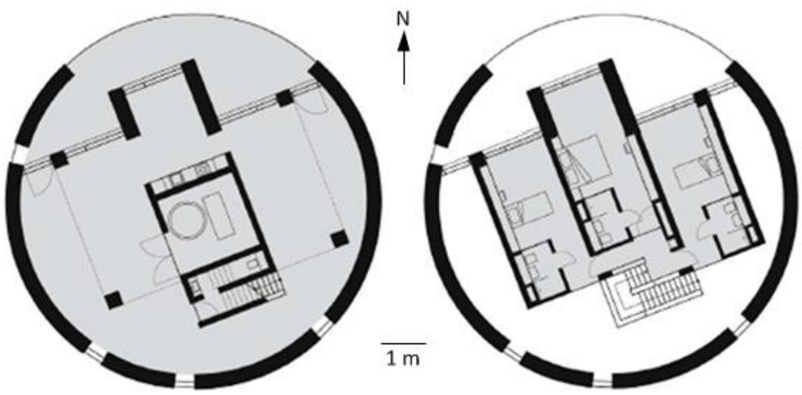

Figure 2.1: Floor plans of the EcoHaus

The model is implemented in a MATLAB® simulation, which is discretized in sufficiently small time steps. Due to this dynamic approach, the model can perform beyond estimations, which includes static temperature conditions and a steady state temperature profile in the wall. In the approach presented in this work, the thermal capacity of the wall and the dullness of heat transfer effects get considered in a sufficient way.

The most important input parameters for the simulation are the weather data and the material data for all reflected house parts. As weather data, including the hourly sun position, direct and diffuse sun radiation and environmental temperature, periodic input signals are used. The necessary values for the materials are the heat conduction coefficients, the density, the heat capacity and the minor geometrical information like the wall thickness.

The equations for different kinds of parts are simulated in modules. A superordinate code compounds the modules in a specific way for the EcoHaus geometry. The details of the model set-up will be presented in another publication. The focus of this study is on benchmarking the EcoHaus.

3. Case study

3.1 Material properties

The objective of this study is to benchmark the EcoHaus's performance in terms of energy consumption and indoor comfort conditions against common building types in Oman. In the comparison, the building material and material quality is changed for the outer walls, the roof and the windows – hence the envelope – according to these building types. The major geometry stays the same due to the code architecture of the superordinate simulation code.

To define the cases, information about the material properties has to be collected from different sources and a quantity for the differences between the envelopes in each case is needed. In architecture and civil engineering, the use of the U-value to quantify the heat transfer properties of a wall is usual. This value is quite useful to have a direct comparison of different structures. The static heat flow can be calculated in dependents on the air temperature on both sides and with an assumed steady state temperature profile in the wall. It therefore not only pictures the material properties, but the convection coefficient on the surface as well. As the simulation is transient, however, the convection coefficient changes with each time step and the thermal properties of the wall are pictured by the conduction coefficients (and heat capacities) of the wall only, which are fixed material properties. To gain a quantity capable of comparison of the heat transfer properties in the transient approach, the U*-value is introduced in equation (1). With this, the heat flow can be calculated in dependents on the surface temperatures of the wall. For a multi-layer wall it is given by

$$U^* = \frac{1}{\frac{\delta_1}{\lambda_1} + \frac{\delta_2}{\lambda_2} + \cdots + \frac{\delta_n}{\lambda_n}} \quad (1)$$

with δ as the layer thickness and λ as the certain heat conduction coefficient. The U-value is

$$U = \frac{1}{\frac{1}{\alpha_I} + \frac{1}{U^*} + \frac{1}{\alpha_O}} \quad (2)$$

with α_I as the heat transmission coefficient on the inside boundary and α_O on the outside. With this distinction, the cases are defined as following.

Case 1 "as built" is the EcoHaus in the actually build condition. The wall is made of an outer layer of light-weight concrete blocks with pumice as aggregate. The core layer is perlite as loose insulation infill and the inside layer is made by compressed earth blocks produced by the university's team on campus. The windows are constructed as curtain walls with air-tight joints to the walls and gaskets, frames of UPVC with thermal breakers, and an argon-filled double glazing. The outer surface is equipped with a sun protective coating, which influences the radiation properties. The roof is a multi-layered construction with a loadbearing structure of reinforced concrete slab, an EPS insulation layer and a cover of sand and white cement tiles (Figure 3.1). The thermal material properties are taken from tables.

Case 2 “regulations” is a building according to the thermal performance requirements set in the Muscat Building Regulations from 1992 (Muscat Municipality 1992), which are still valid today. This document sets U-values to be U = 0.741 W/m.K for external walls and U = 0.57 W/m.K for the roof. However, no material specifications are made. To gain representative material data, an U-Value calculator conforming to the German norm DIN 4108 (DIN Deutsches Institut für Normung 2014) is used in an exemplary temperature setting. A suitable material configuration in accordance with the regulations is set concluding a support structure and an insulation layer. The properties from these materials are used for the simulation. The windows are not clearly specified in the regulations and therefore the same window properties as in the EcoHaus are used.

Figure 3.1: as built case - energy-efficient construction method of the GUtech EcoHaus

Figure 3.2: practice case – standard construction method for villas in Muscat

Case 3 “practice” is a building according to the standard building practice in Muscat, which for reasons of low-costs and non-enforcement of the above mentioned regulations, can be considered the standard. Here, the material specifications are assumed based on observation at the many construction sites in Muscat (see Figure 3.2). Houses are structurally based on a reinforced concrete frame of columns, beams and solid concrete slabs. The infills are made with a single layer of concrete hollow blocks, joined with cement mortar and rendered with a cement plaster on both sides. The blocks are partly built in semi-industrial plants and partly in “backyard factories”. Therefore, an even standard regarding their material properties cannot be assumed. However, it is reasonable to use data from industrial product catalogues and material property tables (Bobran and Bobran-Wittfoht 2008; Thomas Armstrong Ltd 2015). The commonly installed windows are single panes in aluminium frames. The heat conduction resistance of the pane is negligible against the convection on the surface. For the windows, a sun protective coating is assumed. Even though the standard construction system disregards the issue of thermal bridges and air leakages, this disadvantage is not further reflected in the model.

An overview of the resulting U*-Values for all cases is given in Table 1.

Table 1: U-values in W/m²K for house parts*

Case \ House part	*Wall*	*Windows*	*Roof*
Case 1 "as built"	*0.14*	*2.07*	*0.15*
Case 2 "regulations"	*0.85*	*2.07*	*0.62*
Case 3 "practice"	*1.83*	*25.00*	*5.48*

3.2 Defining weather input data

For the analysis of the case study, periodic weather data in dependence on typical daily data in summer and winter season is created. Figure 3.3 shows the data exemplarily for 10 days in the summer. T_environment is the environment temperature, E_direct the direct sun radiance and E_diffuse the diffuse sun radiance. The temperature development is full periodic over 24 hours, while the radiance is half periodic during day time. The respective sun course is taken from (Hoffmann 2015), while the weather data is created in dependence on data from the company "Weather Analytics" (Weather Analytics LCC 2013).

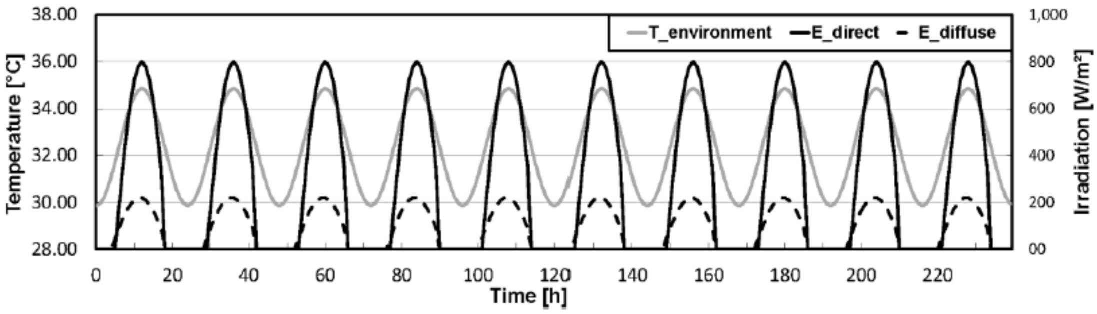

Figure 3.3: Weather data for the summer scenario

The environmental temperature for the summer scenario is between 30 °C and 35 °C. For the winter scenario, the same input signal is used with temperatures between 19 °C and 25 °C.

3.3 Examination

In a first step, the behaviour of the house is investigated without any cooling. This setting is called "stand-alone". To allow all examined temperatures to settle at a constant average value, 40 day periods are simulated. For the summer scenario an inner volume start temperature of 30°C is chosen, for the winter scenario it is 24 °C. The stand-alone setting is suitable to show the dullness (phase shift) and the relation of amplitudes between the air volume- and environment temperature. The air volume energy balance for this setting is analysed in detail afterwards to get a closer view on the temperature development and rate the envelope part's contribution. The balance is

$$c_{P,A} \cdot V_A \cdot \rho_A \cdot \frac{dT_A}{dt} = \dot{Q}_{Wall} + \dot{Q}_{Window,North} + \dot{Q}_{Window,South} + \dot{Q}_{Roof} + \dot{Q}_{Solid} \quad (3)$$

With $c_{P,A}$ as the heat capacity of the air, V_A as the volume of the air, ρ_A as the density of the air, T_A as the air temperature and with the heat fluxes on the right side. The respective index shows, which part of the house the air volume interacts with. In the analysis, the development during the 40 days of each flux will be examined.

Afterwards, the most interesting and significant value to compare the cases – the cooling load in the summer case – is examined. To implement this setting, the indoor temperature is limited at a certain comfort condition, but it can fall below this limit. This behaviour pictures the control of a simple air conditioning. Here, 24 °C and 20 °C are chosen as comfort conditions.

4. Discussion

4.1 Stand-alone temperature development

Figure 4.1 shows the temperature development for all three cases in the summer scenario with the air volume temperature of the as built case, the regulations case and the practice case. The environmental temperature is shown for comparison.

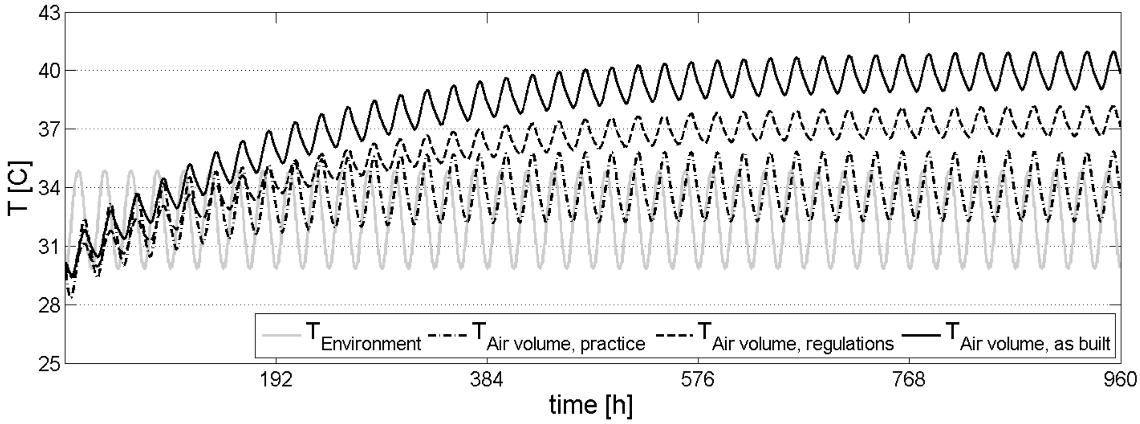

Figure 4.1: Air volume temperatures for summer scenario, stand-alone setting

The average air volume temperature settles above the environmental temperature in all cases, while the average temperature is maximal for the as built case. The relation of the amplitudes differs from the relations of the average temperatures. The regulations case shows the smallest amplitude, although the average temperature is in the middle of the three cases. The amplitudes of all simulated temperatures are significantly lower than the amplitude of the environmental temperature. The phase of the air volume temperature post-pulses approximately 5 hours behind the environmental temperature with nearly no differences in all cases. This phase shift is due to the high thermal mass with low thermal conductivities. The house's behaviour is the same for the winter scenario (Figure 4.2), but at a different temperature scale. The phase shift varies a bit and now post-pulses 2.5 to 4 hours behind the environmental temperature with a minor spreading. The air volume temperature is influenced by heat exchange with the inner surface of the envelope parts and with the solid volume. To see the relations between these flows, they are examined in Figure 4.3 to Figure 4.6 according to equation (3).

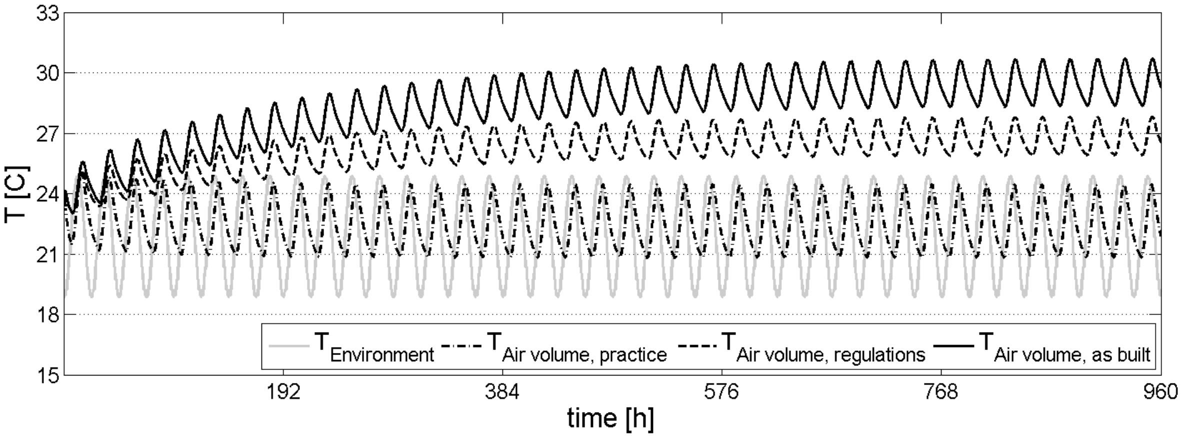

Figure 4.2: Air volume temperatures for winter scenario, stand-alone setting

4.2 Air volume energy balance

The contribution of the respective inner surface in the air volume energy balance is a result of the air volume temperature and the surface temperature. This one is influenced by heat that conducts through the wall and radiation that is transmitted through the windows. The radiation heats the inner walls and the solid volume, but not the ceiling. Heat conduction occurs for the wall, the roof and the windows.

The convective flow from the north side window to the air volume is drawn in Figure 4.3 for the practice case. The large area with the high heat conduction coefficient is not exposed to direct sun light due to the orientation and the air volume temperature is above the environment temperature. Therefore, this window mostly acts as a heat sink with amplitude up to -1400 W. The south side windows show a similar behaviour with minor amplitude of up to -300 W (Figure 4.4). These windows are exposed to direct sunlight only for a few hours a day.

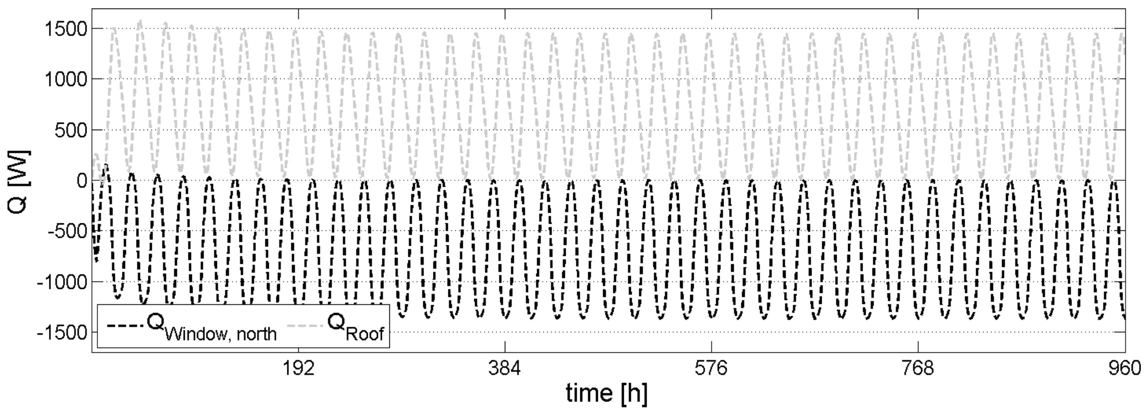

Figure 4.3: Heat fluxes in air volume energy balance for summer scenario, practice case, part 1

The heat flux through the roof is drawn in Figure 4.3. It is phase shifted by approximately 10 hours in relation to the window flux and the amplitude reaches the same order of magnitude – around 1500 W. Due to the constant sun exposition of the outer surface during the day and the resulting heat conduction, the heat flux is positive.

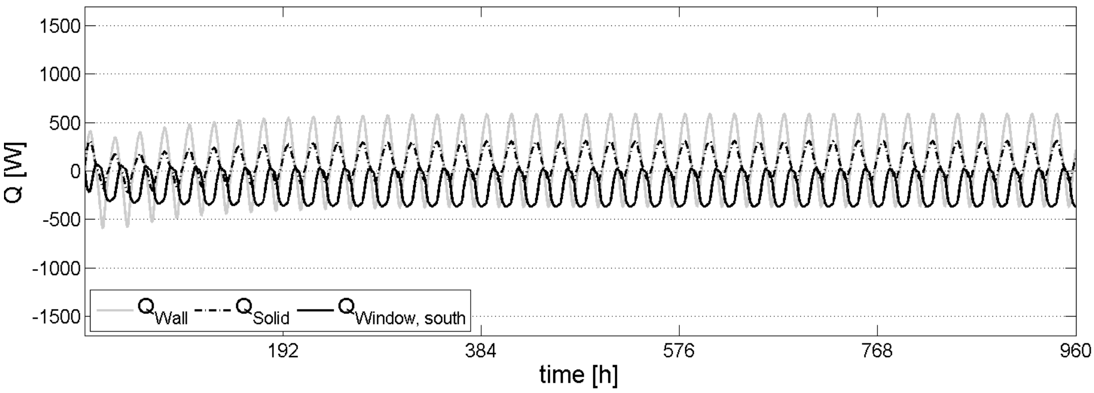

Figure 4.4: Heat fluxes in air volume energy balance for summer scenario, practice case, part 2

The heat exchange with the solid volume (Figure 4.4) is mostly positive at around 1/3 of the north side window- and roof flux amplitude. The solid volume is heated only by the transmitted radiation. As the phase is the same for the solid volume and the wall (between the roof and the windows flux), the transmitted radiation influence on the wall flux must be dominant against the conduction in the wall, although the outer surface of the wall is exposed to the sun several hours a day. This is due to the very high insulation.

For the regulations and as built case (Figure 4.5 and Figure 4.6, please notice different scale than in Figure 4.4), the phase correlations are generally the same. The roof and north side window fluxes are significantly lower and in the order of the other fluxes. This is in accord with Table 1, since the U*-values are in another order of magnitude. In general, the air volume temperature above the environment temperature in all cases is an indicator for the dominance of the transmitted irradiation against the convection.

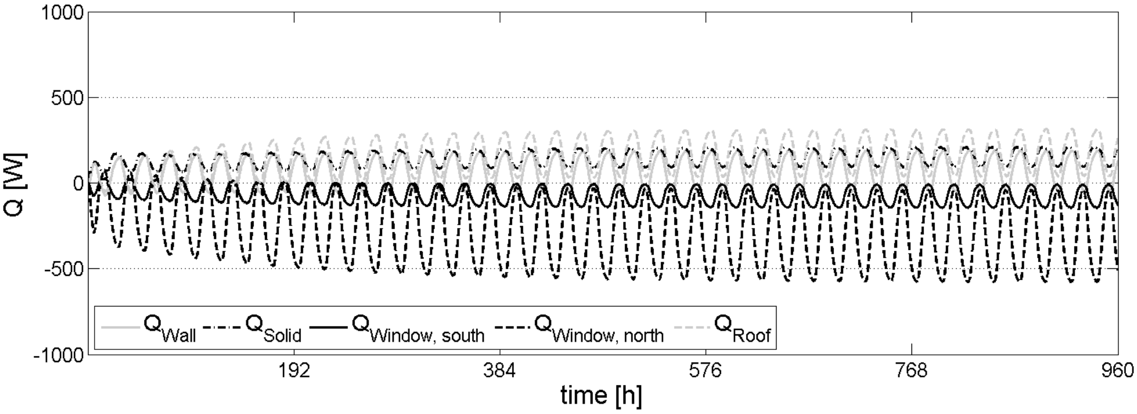

Figure 4.5: Heat fluxes in air volume energy balance for summer scenario, regulations case

The reason for the amplitude correlation in the temperature development (Figure 4.1) is in the phase shift of 10 hours between window and roof flux, which is nearly half a period. Due to this, effacement occurs and the amplitude of the temperature gets lowered. The higher conduction ability of the roof allows the heat during the day to escape better.

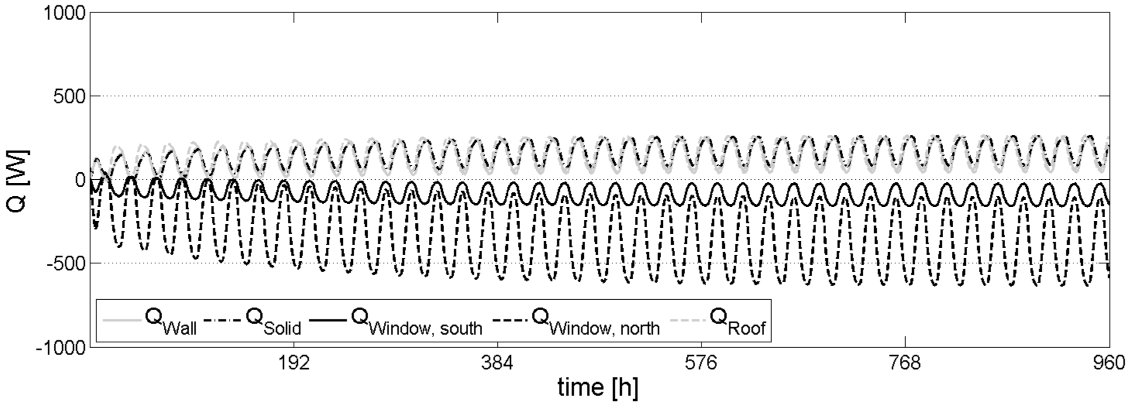

Figure 4.6: Heat fluxes in air volume energy balance for summer scenario, as built case

Overall, the house isolation holds the energy that is yielded by the radiation, from conducting to the cooler environment. The air volume is “decoupled” from the environment. This leads to a high dullness of the average settle temperature. Due to the different sun exposition of the parts, the contribution in the energy balance is not always in the relation indicated by the U*-values. Just these results get visible by the time dynamic modeling approach exclusively.

4.3 Cooling load

By the analysis of the cooling load and accordingly the summarised cooling energy demand for the 40 day period, the advantages of the EcoHaus can be quantified. Figure 4.7 pictures the load over the time for the summer scenario for all three cases normalised to the living area of 210 m.. Both, the amplitudes and the settle averages, are in accord with the stand-alone setting. The results for the summarized cooling energy demand are shown in Table 2 for two set temperatures. The advantage of the EcoHaus is obvious with a saving of up to 30 % in comparison with the regulations case and up to 60 % in comparison with the practice case. In reality, the practice case is supposed to show a significantly higher cooling load, since air leakages are not considered in the model and in this benchmark, some passive strategies (round shape and north-orientation) are implemented in all cases due to the same geometry.

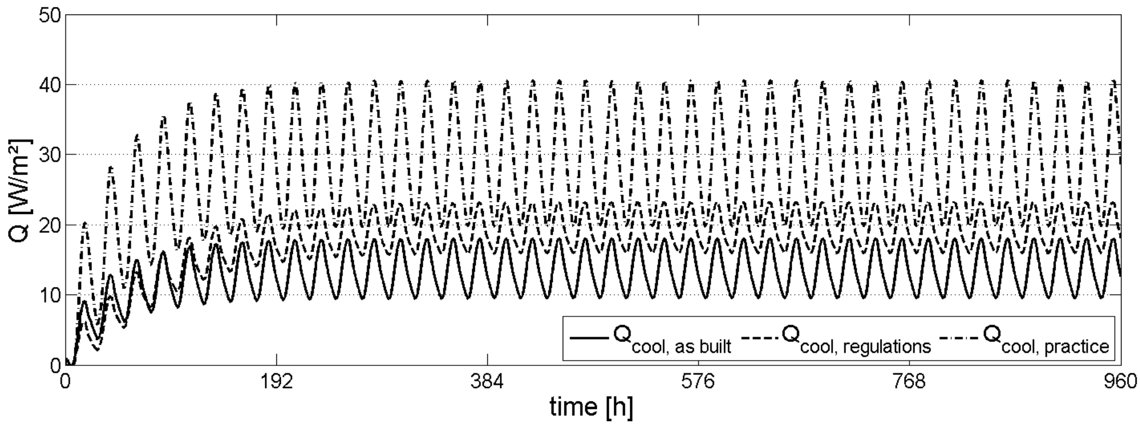

Figure 4.7: Cooling loads for summer scenario with set temperature 297 K

During the winter period a cooling by natural ventilation is possible. Therefore, the winter scenario has no relevance for the cooling load considerations.

Table 2: Accumulated cooling energy demand for 40 days in kWh for the summer scenario

Set temperature \ Cooling energy	as build	regulations	practice
24 °C	2600	3550	5340
20 °C	3240	4660	8120

5. Conclusions and Outlook

The benchmarking for the summer period shows that – based on model calculations with a fixed geometry – the EcoHaus saves 30 % of the cooling energy demand in comparison with a building built according to the Muscat Municipality regulations. Further, it saves 60 % of the cooling energy demand in comparison with a building built according to the standard construction methods.

In preliminary considerations, the EcoHaus is examined in a stand-alone setting, where the thermal properties of the house are investigated. The high insulation decouples the inside of the house from the environment and promotes the radiation influence on the temperature but also damps the amplitude in comparison with the environment temperature. The resulting high dullness can be advantageous. For example, the temperature stays stable enough during the night without uncomfortable cooling.

All parts of the envelope participate differently in the air volume energy balance. The period of time in each day, in which they are exposed to the sun and the insulation differ strongly. The main window front is oriented to the north side, which means that it is never exposed to direct sun radiation. Therefore, heat entrance or transmission of direct radiation at the thermal weak point of the house is avoided. This design enables the house to be equipped with a window of huge size without increasing the cooling load too much. As a result, the rooms are sufficiently lit by daylight without compromising on energy efficiency. For a residential purpose in the Omani cultural context, more privacy would be required and shades would need to be installed.

The comparisons show the high impact of the passive design strategy to construct a highly insulated, protective envelope. Other passive strategies like the compact volume are included in the model with the geometry for all examined cases. In result, the cooling load is at a low to average level in all cases, showing the advantage of these strategies. The geometry differs significantly from common residential houses. A comparison with the actually built design of single-family villas in Muscat – that do not consider any passive strategies – would show the advantages of the EcoHaus design even more. Due to the modularity of the simulation, this is possible, also for new house designs, but it requires a new superordinate code.

The benchmarking extracts the cooling energy demand quantitatively, but does not address the question of how efficiently it can be provided. Here, the EcoHaus's cooling system - a combination of a hydronic, radiant cooling device and energy recovery ventilation is much more efficient than the generally employed AC-split-unit. Furthermore, the installed cooling system is seen as a major contribution to increasing the living comfort since the air-velocity is low and with minimal audible sounds.

The study shows that significant savings in the energy consumption of buildings in Muscat and comparable hot and humid climates can be achieved through better designs and better construction systems. However, the problem of achieving better performing buildings not only lies in the knowledge generation about the best solutions, but also in the knowledge transfer to get these solutions implemented. The EcoHaus project of the GUtech in Oman is an example that through the involvement of students into research and practice, both elements, knowledge generation and transfer to the next generation in the country, can be combined successfully.

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BIM for Infrastructure Sustainability in Developing Countries: the case of Ethiopia

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Abstract

Investment in infrastructure in developing countries is essential for poverty reduction and it positively and significantly correlates to their economic growth. As infrastructure development involves consumption of considerable natural and capital resource and as it has long term impact on socio-culture of societies, it should be sustainable both in terms of delivery and service. Achieving sustainable infrastructure entails concerted considerations all the way from inception to demolition stages. In contrary to the fact that the issue of sustainability is in vogue, its implementation in infrastructure development in developing countries like Ethiopia is still at its infancy. In the traditional design and delivery approach where sustainability issues are not adequately addressed, resulting infrastructure becomes fragmented that is highly unsustainable and vulnerable. Due to presence of huge input and complex process in sustainable infrastructure design and delivery, the need for innovative information based interventions like Building Information Modelling (BIM) is inevitable. While implementation of BIM in the developed world is very encouraging, its application in the developing countries, especially in the area of infrastructure is very much limited. In this regard, the role higher educational institutes play in the diffusion of this technology into the industry is vital. The objective of this study is to explore the preparedness of Architecture, Engineering and Construction Management (AEC) undergraduate students to use BIM in the construction industry upon their graduation. Literature review and a semi-structured questionnaire were used to establish the conceptual background and acquire empirical data respectively. 95 Architecture, Civil Engineering and Construction Technology and Management graduating class students studying at the prominent state owned university in Ethiopia were included in the study. The response rate was 95% and the results of the study indicated that awareness and preparedness of the graduating students to use BIM in the Ethiopian AEC industry is very low. This is especially true to Civil Engineering students who are responsible to design and manage construction of majority of infrastructure projects in the country. Respondents indicated unpreparedness of the AEC industry and absence of appropriate software and work stations as the two major challenges to offer BIM at their university

Keywords: BIM, infrastructure, Sustainability, higher education, Developing Countries

1. Introduction

Investment in infrastructure in developing countries is essential for poverty reduction (Fay, et al., 2011) and it positively and significantly correlates to economic growth. According to the World Bank report there is a huge gap in infrastructure provision which is estimated at $1 trillion in low- and middle income countries, and the demand continues to grow as countries develop (The World Bank Group, 2008). The fact that infrastructure facilities last long signifies the need to make them sustainable by designing and constructing them to accommodate the several requirements that would emerge in due course of their lifetime. These requirements include social, economic, financial, and environmental considerations.

Achieving sustainable infrastructure entails concerted considerations all the way from inception to demolition stages. In contrary to the fact that the issue of sustainability is in vogue, its implementation in infrastructure development in developing countries like Ethiopia is still at its infancy. In the traditional design and delivery approach where sustainability is not adequately considered, resulting infrastructure becomes fragmented that is highly unsustainable and vulnerable (Sarte, 2010).

Due to presence of huge input and complex process in sustainable infrastructure design and delivery, the need for innovative information based interventions like BIM (Building Information Modelling) is inevitable. While implementation of BIM in the developed world is very encouraging, its application in the developing countries, especially in the area of infrastructure is very much limited. It is argued that lack of skilled and knowledgeable professionals is one of the bottlenecks for successful implementation of the technology. The role higher educational institutes play in regards to breeding the new BIM literate generation is vital. This signifies the need to assess the current trend in higher educational institutions in regards to training and capacitating Architectural, Engineering and Construction Management students in the developing countries like Ethiopia.

This study attempts to explain the role of BIM in sustainable infrastructure design and delivery and it investigates the preparedness of Architecture, Civil Engineering and Construction Technology and Management undergraduate students to implement BIM in the construction industry to attain sustainable infrastructure in Ethiopia. The research tried to identify the possible challenges faced by higher education institute in Ethiopia to offer BIM in these programs.

The study is limited to adoption of BIM in Ethiopia with a particular emphasis on Architecture, Civil engineering and Construction Technology and Management final year students. The findings are expected to be of assistance to Ethiopia and other developing countries in the design and delivery of sustainable infrastructure through implementation of BIM. It contributes to the body of knowledge in the area of sustainable infrastructure design and delivery in developing countries.

This article has six sections. Sections two and three discuss about sustainable infrastructure and BIM correspondingly. Sections four and five present the research methodology and survey results. Concluding remarks and recommendations are stipulated under section six.

2. Sustainable Infrastructure

2.1 Background

In the broader context the term infrastructure may refer to either "soft" or "hard" infrastructure. Hard infrastructure entails provision of physical structures for basic services including energy, water supply, sewerage, transportation, waste removal, sanitation, communication, health and education. While hard infrastructure is about provision of physical assets, soft infrastructure is about development of skill and knowledge and access to appropriate services (Casey, 2005).

Infrastructure can also be categorized as economic and social infrastructure where economic infrastructure is part of an economy's capital stock used to facilitate economic production. Structures including power utilities, piped gas, telecommunication, roads, drainage, railways, runways and seaport are typical examples of economic infrastructure. Social infrastructure on the other hand facilitates investment in human capital with a result of improving workforce productivity. Health, education, safety and recreation service facilities are typical examples of social infrastructure (UN-HABITAT, 2011). This study is limited to hard and economic infrastructure.

According to the World Bank report (Fay, et al., 2011) despite the fact that 10 percent increase in infrastructure investment contributes to one percent growth in GDP, there is a gap in infrastructure provision which is estimated at USD 1 trillion in low- and middle-income countries, and the demand continues to grow as countries develop. While developing countries are engaged in massive construction undertakings to curb their infrastructure deficiencies, only limited progress has been made so far (Calderon & Serven, 2004).

African countries, especially, sub Saharan Africa countries trail behind other regions in terms of infrastructure delivery and quality. This has becoming an impediment to their economic development and a major constraint on poverty reduction. To fill the infrastructure gap, an estimated USD 93 billion, which is about 15% of GDP a year investment in infrastructure is needed in Africa (UN-HABITAT, 2011). Infrastructure access gap looms large in the developing world where an estimated 748 million people live without access to safe water, 1.2 billion without electricity, 2.8 billion still cook their food with solid fuel such as wood, 1 billion people live more than two kilometres away from an all-weather road, 2.5 billion without sanitation, and more than 1 billion without access to telephone services (Lin, 2005; Todaro & Smith, 2012; Fay, et al., 2011).

Ethiopia is a country in East Africa with one of the fastest growing economies in the world and having an average growth rate of above 10% for the last decade where this momentum is expected to continue at a rapid pace over the next five years (AfDB; OECD; UNDP, 2014). With a population of more than 90 million it is the second most populous country in Africa following Nigeria.

The Global Competitiveness Report 2014-2015 (World Economic Forum, 2014), positioned Ethiopia 125th out of the total 144 countries considered in the survey in terms of overall quality of infrastructure where the report highlighted the need for significant improvement to enhance competitiveness of the country's competitiveness in the global market.

According to the United Nations report (United Nations Human Settlements Programme, 2011), only less than 20 percent of the Ethiopian population has access to any modern infrastructure. Surveys indicated that infrastructure constraints are responsible for an estimated 50 percent of the productivity handicap faced by Ethiopian firms (Foster & Morella, 2011).

In the course of time, infrastructure and utilities age and will require substantial maintenance and retrofitting if not demolished. Martland (2012) argues that social and environmental impacts of infrastructure systems likely become more apparent over their life time suggesting the need to consideration of sustainability aspect starting from the very early stage of the project design. According to Kibert (2013), the built environment has direct, complex, and long-lasting impact on the planet than any other human venture.

According to a report by CIB (1999) sustainable construction entails sectorial contribution made by the AEC industry in the areas of environmental, social, ecological and cultural aspects in the effort to achieve sustainable development. Sustainable construction is defined by Agenda 21 for Sustainable Construction in Developing Countries discussion document as follows (CIB & UNEP-IETC, 2002): "Sustainable construction means that the principles of sustainable development are applied to the comprehensive construction cycle from the extraction and beneficiation of raw materials, through the planning, design and construction of buildings and infrastructure, until their final deconstruction and management of the resultant waste." (pp 6)

Williams (2007) described the sustainability design process as integration of design into the ecology of the place which is the flow of materials and energy residing in the community. Compared to conventional design, sustainable design needs additional criteria and items (Azapagic & Collett, 2006). To implement sustainability on real projects, it needs to understand sustainable practices and then choose appropriate measures to facilitate sustainability realization (Chang & Tsai, 2015). As a sustainable approach new options to substitute the services that were provided by the old infrastructure need to be looked into (Williams, 2007). The emergence of BIM which is an important milestone in the AEC(Architecture, Engineering and Construction) industry affects the traditional approaches to project design and collaboration (Kibert, 2013). The next section describes the concept and benefits of BIM.

3. Building Information Modelling (BIM)

3.1 Background

Yan and Damian (2008) described BIM as powerful software tools used in the construction industry offering a considerable benefits throughout life cycle of a building including design, construction and facility management. BIM is a fairly new innovation in the construction industry changing the conventional way of designing, constructing, and operating buildings and infrastructure. The aim of BIM approach is to be able to digitally view and access information about the construction project from a single-source model (Krygiel & Nies, 2008). Unlike 2D drawings where drawings merely show a representation of the final object, BIM models have simulation capabilities. High level of accuracy and design efficiency can also be achieved by using BIM (Krygiel & Nies, 2008).

Building Information Modelling (BIM) is a relatively new technology and has been in use in many countries where several researches and surveys were made to assess level of adoption of the technology (Jung & Lee, 2015; Hussain & Choudhry, 2013; Abubakar, et al., 2014; Langar & Pearce, 2014; Wong, et al., 2010; Mohannadi, et al., 2013; Rogers, et al., 2015). The AEC industry will be able to utilise the full potentials of BIM only if it is widely endorsed by the stakeholders and adopted throughout the industry.

3.2 BIM Implementation and Barriers

In contrary to the fact that BIM offers immense benefit to the construction industry, its adoption is impeded by several barriers. Liu, et al (2010) conducted a study to identify factors influencing adoption of building information modelling in the AEC industry and indicated that maintaining staff with sufficient knowledge to perform facility management using BIM is one of the limitations faced by companies to adopt BIM. Hartmann and Fischer (Hartmann & Fischer, 2008) indicated the scarcity of BIM conversant practitioners as one of the major hindrances for its widespread adoption.

Adoption of new technologies requires identification of potential barriers and key effective implementation strategies in order to ensure successful diffusion and implementation of the technologies. Research in UK indicated that lack of BIM knowledge and skills raised concern and delay in the uses of BIM in the UK (Young, et al., 2008). According to Fox and Hietanen (2007) lack of highly skilled cross trained staff with both construction and IT skill is one of the barriers hindering realization of BIM benefits.

3.3 BIM in Higher Education Institutes

The introduction of AutoCAD about thirty years ago paved a way to computer assisted design in the construction industry. Currently, computer-based design courses are streamlined and given in several undergraduate courses specially in developed countries. According to Dean (2007) BIM should be taught in educational institutions as graduates with BIM literate graduates have more advantage over BIM illiterate graduates. Fox and Hietanen (2007) highlighted that students and graduates with BIM knowledge and proficiency play an important role in the use of BIM within their organizations. A research in the UK recommends rearrangement of construction courses at universities to better equip students to meet the growing demand of the construction industry (Bataw, et al., 2015).

Construction education should keep itself updated with new innovations and industry. According to Deutsch (2011) BIM should be integrated into Architecture, Construction and Engineering programs. Ahbab, et al. (2013) stated that educational institutions should produce BIM enabled professionals for adoption of BIM in the construction industry. Cooksey and Schiff (2012) recommended that students should be able to acquire knowledge about the capabilities of BIM and effective use of the tool before they join the profession.

4. BIM for Sustainable Infrastructure

The AEC industry is becoming more and more complex and requiring more specialization. Specialization in turn opens a door for fragmentation in the industry and contributes to the decline in efficiency of the industry compared to other industries (Krygiel & Nies, 2008). In line with complexity of building and infrastructure systems, the presence of plentiful design requirements and the complex interrelationship between these requirements suggest the need for an integrated approach to design, construction and operation of buildings and infrastructure.

The construction industry is currently under immense pressure globally in terms of timely delivery, consideration of sustainable practice, value for money, etc. Several attempts were made to improve the situation through devising alternative procurement methods, introducing better innovative construction technologies and innovative processes including Computer Aided Design (Abubakar, et al., 2014) .

Vallero and Braiser (2008) indicated that BIM offers a great potential for sustainable design through increased teamwork and integration across different disciplines. BIM helps to test "what if" scenarios at the early design stage of projects and enable designers analyse several options which is an essential element of sustainable infrastructure design (Vallero & Braiser, 2008). Crotty (2012) stresses that safety, soundness and sustainability concerns of the public will be accommodated in software programs in a BIM-based industry. Malina (2013) suggests that BIM can be considered as a more sustainable and cost effective tool to deliver sustainable buildings.

A holistic design which is an approach for sustainability of the AEC industry calls for collaboration of different professional including architects, engineers and urban planners where these professional share information and tools supporting this approach need to emerge (Shen, et al., 2009). BIM enables designers to iterate and analyse sustainable design options faster than in a more traditional process (Krygiel & Vandezande, 2014).

One of the emerging project delivery methods called Integrated Project Delivery (IPD) is claimed to have many of the attributes of construction delivery systems very much compatible with Energy and Environment certification systems. According to Kibert (2013) BIM is instrumental in the successful implementation of IPD by providing the possibility for good collaboration on construction projects.

A study has indicated that BIM is a very effective tool to teach students concepts of building sustainability. It is argued that while sustainable building design and construction is being gradually integrated into construction curricula in higher educational institutes due to the complex nature of the subject, its instruction and learning is a challenge (Shen, et al., 2012).

5. Methodology

The research methodology employed includes literature review in relation to the role of higher educational institutes in facilitating BIM adoption rate of the construction industry. The review also used to identify the role of construction education institution in adoption of the technology in the AEC industry. Following the literature review, a semi-structured questionnaire was developed and a survey was conducted among final year Architecture, Civil Engineering, and Construction Technology and Management undergraduate students to assess their acquaintance with BIM and their perception about its benefits and practicability. The survey is designed to explore Architecture, Civil Engineering and Construction Technology and Management students level of preparedness to use BIM upon their graduation. It further aims to assess students willingness to learn BIM if they are given the opportunity.

The survey was conducted at the Addis Ababa University, the largest and oldest university in Ethiopia. The University is located in Addis Ababa, the capital city of Ethiopia and it is a flagship state owned educational institute. It was the first institute to start all the three undergraduate programs namely Architecture, Civil Engineering and Construction Technology and Management in the country. In 1955 a four year Civil Engineering program was introduced followed by Building engineering program in 1958. Lately a bachelors program in Construction Management and Technology program was opened in 2002. The university is considered as a trend setter in the country and it is fair to assume that it is a very good indicator of the situation in educational institutes in Ethiopia especially in terms of AEC studies. As graduates of the three field of studies involve in the design, construction and facilities management of infrastructure project the study focused only on these programs.

The research questionnaire has three sections: it begins with background questions followed by structured questions asking students to give their opinion about their competence and orientation towards BIM. The second section also includes a question asking students to prioritize the possible challenges of offering BIM courses in their respective programs. The last section has semi-structured questions dealing with students awareness and the types of BIM software programs they are acquainted with.

6. Results and Discussion

This next sections presents results of the survey and discusses on the findings.

The questionnaire survey was conducted at the end of 2015. The data analysis included descriptive analysis and comparative statistics.

A total of 100 questionnaires were distributed to a randomly selected students and 95 completed questionnaires were returned which is a 95% response rate. Out of the total respondents 33.7% (32) of them are female and the remaining 66.3% (63) of them are male. According to their field of studies students studying Architecture and Civil Engineering constitute 31.6% each and the remaining 36.8 % of the respondents are students from Construction Technology and Management. In the researchers opinion, the field of study composition of the respondents is a fair representation of the professionals involved in infrastructure planning, design, construction and facilities management. All respondents are final year students and are expected to join the AEC industry within one to five months time depending on their program structure.

Table 1 depicts that all architecture students are aware of BIM but only 33.7 % of them are aware of its benefits. 31.8% of architecture students said they have used BIM during their studies and only 27.9% of them indicated they have taken a course on BIM on campus. 23.2% of Civil Engineering and 18.3% of Construction Technology and Management students said they have never heard about BIM. As to awareness of BIM and its benefits, 66.3% of the respondents responded positively out of which half of them were Architecture students. In all cases Architecture students have shown better awareness and level of competence about BIM. However, involvement of Architects in Infrastructure design and construction in Ethiopia is limited when compared to the other two field of studies.

Table 1: Respondents awareness about BIM

Questions / *Field of Study*	*Never heard about BIM*	*Aware of BIM and its benefits*	*Used BIM on campus*	*Taken a course on BIM on campus*
Architecture	-	*33.7%*	*31.8%*	*27.9%*
Civil Engineering	*23.2%*	*13.5%*	*10.2%*	*10.1%*
Construction Technology and Management	*18.3%*	*19.1%*	*14.8%*	*3.8%*
Total	*41.5%*	*66.3%*	*56.8%*	*41.8%*

As shown in Table 2 the respondents indicated unpreparedness of the construction industry and absence of adequate and appropriate software and work stations as the two major challenges to offer BIM at the institute under consideration.

Table 2: Challenges of offering BIM at higher education institute as rated by respondents

Field of study / *Challenges*	*Architecture*	*Civil Engineering*	*Construction Technology & Management*	***Cumulative***
Unpreparedness of the Ethiopian construction industry to widely implement BIM	*4.03*	*3.84*	*4.03*	***3.97***
Absence of adequate and appropriate software and workstations	*3.67*	*3.35*	*3.86*	***3.61***
Lack of awareness of the institute management and academic staff	*3.10*	*3.41*	*3.79*	***3.42***
Lack of well trained staff	*3.43*	*3.32*	*3.24*	***3.33***

Note : *1 = Strongly disagree; 2=disagree; 3=neutral; 4=agree and 5=strongly agree*

86% of the respondents showed a very high interest to learn about BIM and 93% of them indicated that BIM would be very instrumental to improve the AEC industry in Ethiopia. Of the total students who responded that they are aware about the benefits of BIM, 52% of them failed to provide correct answers to the questions asking about benefits of BIM. This implies that the awareness of the students about BIM could be even below than the figures indicated in Table 1.

7. Conclusions

Investment in infrastructure is key for economic development especially for developing countries like Ethiopia. As infrastructure development involves consumption of a considerable natural and capital resource and as it has long term impact on socio-culture of societies, infrastructures should be sustainable both in terms of delivery and service. One of the innovative tools to help the AEC industry deliver sustainable infrastructure is BIM. While developed countries are in a better level in making use of BIM, developing countries are still struggling to benefit the great advantages of the technology. The role higher educational institutes play in the diffusion of this technology into the industry is vital.

Results of this study indicated that awareness and preparedness of AEC graduating students to use BIM in the Ethiopian AEC industry is very low. This is especially true with Civil Engineering graduating students who are responsible to design and manage construction of majority of infrastructure projects in the country. According to the study Architecture students have better acquaintance and competence in using the program showing the prospects that Civil Engineering and Construction Technology and Management program can also enable their students gain the knowledge and skill their students need.

To pave a way to make use of the vast potentials of BIM, educational institutes in Ethiopia should go extra mile to equip their students with this technology. Teaching students BIM at a university level before they join the industry should be reasonably less costly and it plays a vital role to help the industry move towards wide implementation of BIM for delivery of sustainable infrastructure.

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Colonias Building Information Modelling Toolkit (CBT): A Process to Guide Policy Decisions

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Abstract

Colonias are substandard and low-income self-help housing developments along north of Mexico - US border. There has been an increasing concern over sustainable development and energy efficient design techniques which addresses both new and existing housing. However, there is a need for housing policy focuses on informal self-built low-income housing context (Sullivan and Ward 2012). In this paper, we discussed the potential way of integrating BIM technology to address sustainable improvements in informal settlements housing policy.

This paper builds on our previous research that proposed a new tool, Colonias BIM Toolkit (CBT) to model and assesses the incremental changes over time and the building performance (Yenerim 2014). To explore this goal, we have investigated the possible use of CBT based home models and energy estimates for policy stand point. Our provision was to guide residents towards better individual decisions on design of their homes by utilizing this tool. The proposed technique can be applied to any informal settlements around the world. However, as a matter of convenience, the proposed technique was tested on Colonias in Laredo, Texas. We proposed a technique to devise a Building Information Modeling toolkit to model informal settlements and a multiple analyses to produce a probabilistic estimate of energy consumption. We argue its benefits through one colonias home in Laredo, Texas which has been built in three stages over three years.

Our hypothesis was that BIMs of homes and communities can be stored as a database to be used by policy makers and researchers on investigating their growth pattern and to set up regulations on rehabilitation of these structures. If policy makers have data on existing construction techniques and materials of homes and a 3-dimensional visual data on the form of homes, policy makers can monitor and control the form of houses and the growth of the settlements. Moreover, having estimate of existing energy consumption of homes and communities can enable policy makers to set up regulations and rules for more sustainable home design and rehabilitation of existing ones.

Keywords: Informal housing, colonias, Colonias BIM Toolkit, Sustainable Cost Efficient Housing, policymaking

1. Introduction

The aim of our research is to determine basic aspects of the practicality of a model-based approach to guide policy decisions about informal settlements in terms of energy conservation. We speculate that modelling an entire community of homes in an informal settlement and simulation of homes could provide insights about energy consumption, visual qualities, and other considerations, enabling analysts to examine multiple scenarios of how the community might change. Policy-makers could use the growth patterns and consumption patterns to plan regulation and interventions to achieve improved outcomes and to help residents to build more formal homes. Our study has shown the feasibility of using Building Information Modelling (BIM) and energy simulation to support analysis and prediction of the performance of homes that can be aggregated to show the performance of communities. To predict the performance of homes, we have determined the probable performance of homes by utilized parametric variation and simulation. Our models have not yet been calibrated; future work could examine the predicted energy consumption against the actual consumption. We believe that our process can be used for informal settlements around the world to estimate current and future energy use and guide development of policy.

In a previous study, we devised a toolkit (the Colonias BIM Toolkit, or CBT) from BIM technology to enable rapid modelling and simulation of the homes that make up a community (Yenerim 2014). Our process was to collect physical data pertaining to house footprint, materials and construction techniques by using a face-to-face interview with residents and in-depth on-site home inspection. The CBT includes a library of building components and systems observed in a test sample of homes in colonias. Our study used colonias along the border between Texas and Mexico as an example of informal settlements.

In this paper we present the use of the toolkit to model a single house and then perform a parametric study of energy simulations to determine a range of possible energy performance.

2. Informal settlements and Building Information Modelling

One of the major challenges is the unpredicted sprawl of informal settlements and their potentially deleterious impacts upon environments and explosive growth in consumption (UN-Habitat 2003). Informal settlements are substandard low-income housing development for people who cannot afford formal housing structures. They occur in most developing and developed countries (UN-Habitat 2003; Amis 2002; Burdett and Sudjic 2007; Davis 2006; Turner 1977). According to literature, there are several methods for upgrading informal settlements : relocation, resettlement, or self-help in-situ construction (Huchzermeyer and Karam 2006). Self-help improvement through participation of residents is frequently cited as the most successful way of rehabilitation of these settlements.

Informal settlements can consume high levels of energy in comparison to formal settlements with building codes and construction standards (UN-Habitat 2008). However, an estimated energy use of existing structures or communities may be difficult to determine due to lack of knowledge of existing construction methods and insulation values. There is a lack of knowledge about the construction techniques and materials about these structures. Moreover, estimating the energy consumption of communities could enable policy makers to set up regulations and legislations on energy efficient home improvements and improve building code regulations for these structures. It could also be possible to use technology to assist field agents in advising residents how best to upgrade their homes in self-help projects.

For a test case, we selected the colonias in Texas as having many characteristics in common with informal settlements in other parts of the world. As a substandard housing development, most of these structures do not meet building codes (Bradshaw et al. 2005; Donelson and Esparza 2010; HUD 2008; Parcher and Humberson 2009; Ward et al. 2010). As a result, colonias residents pays more for their energy bills per square footage than an average U.S. resident pays (Gharaibeh et al. 2009; Giusti and Estevez 2011; Gharaibeh et al. 2009; Ward et al. 2010).

Three main housing types within the colonias have been identified: self-help homes, single or double wide manufactured homes and modular homes, and recreational vehicles (Sullivan and Ward 2012). Many homes combine all three of these. The self-help housing process results in a variation in construction materials: wood, concrete blocks, cardboard, and even dilapidated trailers (McKenzie 2002; SOS 2012). A common scenario is that a resident chooses a lot in colonias and lives in a temporary structure such as a trailer or camper. The residents build their homes by themselves or with the help of other residents and family members. Availability of money and materials is one of the major determinants for the how long the construction process would take place. Moreover, according to their changing needs such as expansion of their families, residents continue to add more rooms and expand their homes.

Because of being built over an extended period of time using materials that are ready at hand at the moment and being constructed outside of regulatory oversight by unskilled or semi-skilled labour, colonias homes show a great variety in terms of the quality of the structure. On one hand, some homes are built by reputable developers and homebuilders, while other residents live in make-shift structures, repurposed farm buildings and dilapidated trailers (Sullivan and Ward 2012; Ward et al. 2011). To that extent, although there are several studies focused on colonias homes and their materials, there are still unknown parameters about these houses.

Contemporary advanced computer software could provide those working to improve homes in the colonias with new and more effective methods to effect change and establish policy. Building Information Modelling (BIM) is an object-oriented modelling technology that is becoming widely accepted in building industry, replacing Computer-Aided Design (CAD) technology (Eastman et al. 2008). BIM integrates graphical and non-graphical information and enables users to control them through established parameters (Eastman et al. 2008). Furthermore, BIM facilitates the conduct of simulations that can predict the performance of building designs. In our study, we selected BIM technology to take advantage of its several capabilities such as 3-dimensional visualization of a structure, ability to document data, library of components and system families, parametric modelling capability, and simulation tools.

Our research is focused on exploring the benefits of the use of software, expressed as the CBT, to estimate the existing energy consumption of homes in the colonias and monitor the growth of the communities to aid in development of policy. Our approach is intended to model existing homes and communities rapidly, and to estimate current and future energy consumption of informal communities. By collecting models, it will be possible to build an extensive database which can be helpful to monitor the increase in energy use due to the growth of these settlements. We discuss the potential benefits this toolkit for policy makers to establish guidelines on low-cost energy efficient design and construction strategies for residents and to improve the building codes. We argue that policy makers can provide assistance in more sustainable energy efficient improvements in design and construction methods according to the adopted architectural patterns by residents.

3. CBT Methodology: A Process to Guide Policy Decisions

Modelling and simulating homes in informal settlements is difficult due to the lack of data about construction and other factors that affect energy performance. We have used parametric modelling and simulation, and statistical methods to determine potential likely range of energy performance of a home. We have tested 20 scenarios on unknown parameters of the homes.

We used Autodesk Revit 2014 for modelling homes and Autodesk Green Building Studio (GBS) to perform energy simulation. Several factors have an impact on energy use of buildings: building components, such as floors, walls, ceilings, roof, and window and doors, air movement through the envelope of the building, heating, cooling and lighting systems ,residents, and outside factors such as; wind, sun, temperature, and humidity. When it comes to informal settlements, it is even more difficult to predict these variables because these structures are self-built substandard construction which, most of the time, do not meet building codes. We used Autodesk GBS web-based tool which runs DOE-2 at the background. Autodesk Revit and GBS are interoperable with each other, we exported BIM of homes as a gbXML file. GBXL is editable spread sheet with DOE-2 inputs. It embeds all the parameters assigned in Revit environment. After adjusting the parameters for multiple energy analyses run, we uploaded them to GBS and performed energy simulation.

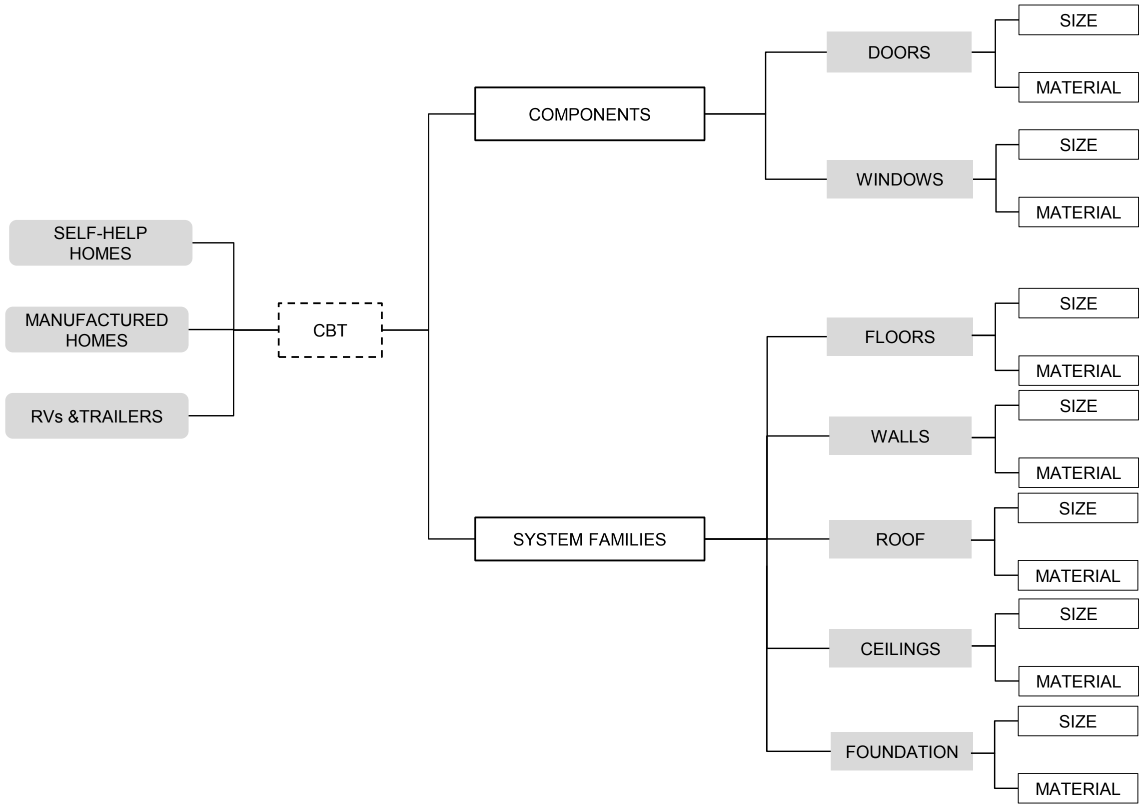


Figure 1: Conceptual Diagram of CBT Development

Although Autodesk Revit has its own library of materials and building component and system families, they are inadequate to model the non-standard constructions in colonias homes. We developed CBT as an Autodesk Revit template file which includes unique library of building components and materials used in colonias homes. The Colonias Autodesk Revit Library encompasses existing architecture and construction patterns of colonias self-help housing in and near Laredo, Texas. Three types of homes observed in Colonias were considered for each component and system family (Figure 1). The variation between each type was determined by considering size and material parameters. Age is also another important parameter in terms of the likely construction methods within a home (Ward et al. 2010). We have referred to age parameter to identify scenarios for unknown parameters.

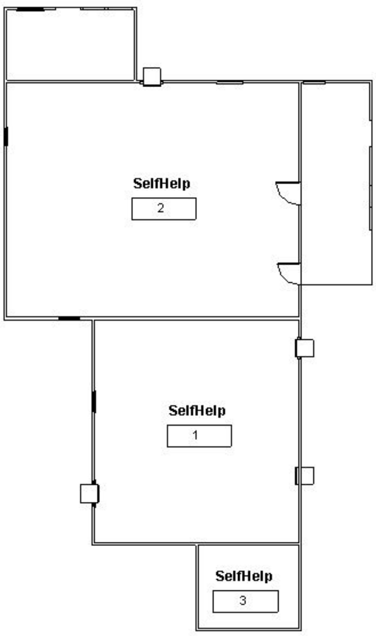
3.1 Development of CBT

Three colonias in Laredo, Texas were selected as a test case. Data was collected from 30 self-help houses as a representative sample from these colonias using face-to-face interviews with residents and on-site home inspection. We used two data collection instruments: (1) interview questionaire for residents on construction techniques of their houses and (2) home inspection checklist for site observation (Yenerim, 2014). The data collection instruments were built on existing studies (Keall et al. 2010; Meng and Hall 2006; Reimers-Arias 2009; Ward et al. 2010).

We were able to compile a list of materials used and measure the home. Three types of houses, self-help homes, manufactured homes and recreational vehicles or trailers, were considered, and represented within under categories. To that extent, CBT design kit includes a wide range of materials and construction techniques. However, there are several unknown data elements that are required for energy simulation: (1) R-values of the building components, (2) heating and cooling systems, and (3) air infiltration value. To overcome this challenge, we performed multiple analyses to produce a probabilistic estimate for energy consumption.

3.2 CBT Test Case

The use of the CBT is demonstrated through one self-help colonias home. The home was built in three stages in 1999, 2001 and 2002 (Figure 2). It comprises wood frame structures on concrete slabs with shingles on the roof. Residents reported to have used tile as a floor finish. According to the interview with the residents, first, they have built a structure with 1 kitchen, 1 dining room, 4 bedrooms, and 2 bathrooms. The second stage structure consists of 2 bedrooms and 1 bathroom. In the final stage, the residents added 1 bath and a porch.



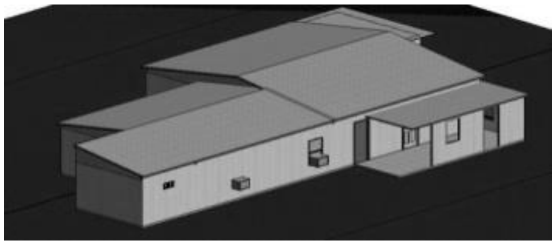


Figure 2: Plan of the home (left) and BIM of the home created by utilizing CBT (Yenerim 2014)

To model the house without R-values, HVAC type, and air infiltration value, we developed 20 scenarios and ran 20 simulations to generate a probabilistic range. We have tested a combination of two educated guess on air infiltration values by utilizing Lawrence Berkeley National Laboratory database (Bazjanac 2008), two different insulation thicknesses on building components, and natural ventilation, and 3 HVAC systems (Yenerim 2014). The results suggest that total annual electricity use ranges from 15,806 kWh to 25,141 kWh and total energy use intensity falls between 37 and 60 (kBtu/ft^2/year).

Table 1: 20 energy simulation runs

Scenario	Infiltration	RUNS	Annual Elec Use	Annual Fuel Use	EUI
SCENARIO-C	WORST INFILTRATION	**WORST.xml**	**17,373**	**7**	**40**
		WORST.xml_Infiltration_0.17_ACH	15,806	7	37
		WORST.xml_Infiltration_3.5_ACH	20,829	7	47
		HVAC_RES 17 SEER/0.85 AFUE Split/Pkgd	17,171	13	43
		HVAC_RES 14 SEER/0.9 AFUE Split/Packaged Gas	24,829	13	59
		HVAC_RES 14 SEER/8.3 HSPF Split Packaged Heat Pump	24,717	7	56
	MOST LIKELY INFILTRATION	**MOSTLIKELY.xml**	**15,990**	**7**	**37**
		HVAC_RES 17 SEER/0.85 AFUE Split/Pkgd	16,224	10	39
		HVAC_RES 14 SEER/0.9 AFUE Split/Packaged Gas	24,038	10	56
		HVAC_RES 14 SEER/8.3 HSPF Split Packaged Heat Pump	23,661	7	53
SCENARIO-B	WORST INFILTRATION	**WORST.xml**	**17,790**	**7**	**41**
		WORST.xml_Infiltration_0.17_ACH	16,174	7	37
		WORST.xml_Infiltration_3.5_ACH	21,302	7	48
		HVAC_RES 17 SEER/0.85 AFUE Split/Pkgd	17,443	15	45
		HVAC_RES 14 SEER/0.9 AFUE Split/Packaged Gas	25,090	15	60
		HVAC_RES 14 SEER/8.3 HSPF Split Packaged Heat Pump	25,141	8	56
	MOST LIKELY INFILTRATION	**MOSTLIKELY.xml**	**16,361**	**7**	**38**
		HVAC_RES 17 SEER/0.85 AFUE Split/Pkgd	16,467	12	41
		HVAC_RES 14 SEER/0.9 AFUE Split/Packaged Gas	24,293	12	57
		HVAC_RES 14 SEER/8.3 HSPF Split Packaged Heat Pump	24,054	8	54
		MAX VALUE	**25,141**	**15**	**60**
		MIN VALUE	**15,806**	**7**	**37**
		MEDIAN	**19,310**	**8**	**46**

Modeling and analysis required less than a day. Therefore, it is very practical.

4. Discussion

Our investigation shows that, using CBT, a researcher can model homes and communities in a very quick way and can perform energy simulation to predict their current energy use. Having an estimated current energy use of individual homes can lead to an estimated energy use of the community. These numbers can be useful for policy implications and to monitor the growth and its reflection in energy consumption. These data can be assembled as a database for colonias and be updated as new data collected and as homes are updated. Scenarios of future homes and communities can be modelled with relative ease, allowing policy-makers to consider different outcomes and ranges of outcomes. This process of developing and utilizing BIM toolkit for modeling informal settlements and perform energy analyses can be applicable to other informal settlements as well.

Having visual models of homes would be beneficial for policy makers as well. They can have knowledge about existing architectural practices. By architectural practices, we refer to both design patterns, and construction standards and materials. It is crucial because they reflect the traditional and cultural mind-set of residents. It is very important for policy makers to understand the existing construction activities adopted by residents in order to propose improvement techniques and methods acceptable by residents.

By utilizing aerial photography from different years, an analyst may examine the changes on individual homes and on a community as a whole. It may be possible to calibrate a model of a community based on change of building form and energy use over time, enabling increased accuracy of predictions for the future.

In order to make the results more accurate and reliable, more accurate and detailed data collection for each home is required. By increasing the number of sample homes, and also number of runs, energy simulations results become more accurate. We have tested only 20 scenarios on a single home for this study and have a range of energy use of the residents. However, with more and more energy simulation runs of a significant number of homes in a community, it would be easy to extrapolate these results to the whole community and have a lower standard error of the whole community.

5. Conclusions

Although BIM has been widely used as a design and modelling tool for formal structures, applications in informal settlements context is new. Nevertheless, BIM is a powerful tool for modelling informal settlements. Using a toolkit, such as the CBT, it is possible to model rapidly a home or many homes in an informal settlement. Missing data, such as insulation and infiltration levels, may be estimated by systematically varying parameter values and conducting energy simulations to reach a probable energy performance. Given the BIM of the home, it is possible to project future modifications to the home and estimate future energy costs, aiding policy-makers to project future energy needs and guide development of policy. As the sample of homes in a community is increased, the range of probable community-wide energy consumption should narrow, leading to greater confidence in predictions.

We demonstrated how BIM of informal homes and simulation can be used to inform, and determine policy decisions related to design and construction of homes. In this paper, we argued that multiple analyses can produce a probabilistic estimate of energy consumption. As the sample of homes increases, the accuracy of the energy consumption of the community increases, aiding support of policy decisions. For example, the uncertainty around the energy analysis of a single home can be demonstrated by the standard deviation of possible outcomes of its simulation. This uncertainty can be quite large for a single home since the unknowns associated with the home can create a big range of energy analysis outcomes. As we repeat the analysis with different houses and increase our sample size, the standard error (variation of sample mean) would decrease and the precision of the analysis around the average single home would increase. The larger the sample, the more precise our analysis would be for the total community.

Having the CBT and BIM of homes allows testing and evaluating alternative materials, insulation, heating and cooling systems and even alternative layout design options (Yenerim

2014). Besides estimating energy use based on heating and cooling loads, BIM of homes has other benefits; it allows users to perform wind, daylighting, and cost of the home.

To sum up, by having 3-dimensional BIM of homes and parametric simulation results, policy makers could determine not only required insulation improvements, glazing options, or HVAC system alternatives for the existing structures to upgrading existing informal settlements, but also the form and location of the additions. Moreover, policy makers could provide low-cost passive design techniques such as extending roof overhangs, use of porch or planting trees for shading purposes. Our focus is Texas colonias in this study but the 3-dimensional BIM of homes and energy simulations of colonias homes in other states such as New Mexico, California and Arizona could also enable policy makers to identify scenarios considering energy use in different climates. To that extent, developing a toolkit for different colonias and creating BIM of homes located in different states would be beneficial for policymakers. As these are self-built and self-managed homes, residents can improve their homes to meet the required building codes for this area by themselves.

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An Investigation of BIM Readiness of Owners and Facility Managers in Singapore: Institutional Case study

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Abstract

Over the past five years from 2010 to 2015, Building Information Modeling (BIM) has gained significant popularity in Singapore's building and construction industry with the implementation of the first BIM roadmap by BCA (Building Construction Authority). It is observed that, the project stakeholders adopt BIM in their work flow mainly in the design and construction processes. It is unclear the extent to which successful BIM adoption be extended to post-construction Facility Management (FM) stage. Considering that most of the buildings in Singapore are existing buildings constructed and operated without any BIM experience, it is important to know how the building owners react to BIM adoption in FM. In this research, we selected a large institutional organization in Singapore to investigate the BIM readiness of the building owner and facility managers. Our aim is to evaluate the awareness and willingness of BIM adoption, identify the motivators and challenges of BIM implementation, and explore the strategies and potential issues of BIM adoption in FM. The research provides value to the implementation of the upcoming BCA's second BIM Roadmap with the focus on process transformation, BIM for specialty contractors, BIM for design-for-manufacturing-and-assembly, BIM for facilities management, and BIM research and development. We adopted a qualitative method of unstructured interview with open-ended questions to collect rich information and data from the interviewees with greater details and depth of content. The transcripts were coded for qualitative analysis. Interview data revealed that the owner and facility managers have a fairly high degree of awareness of and willingness to BIM adoption in FM, with many external and internal motivators and challenges identified. Some potential issues which may hinder the BIM adoption are discussed in five key components, i.e. people, process, technology, policy, and BIM manager.

Keywords: Building Information Modeling, BIM, Facilities Management, FM, Institutional Buildings, Singapore.

1. Introduction

Building Information Modeling (BIM) is an emerging virtual design and construction technology which has been revolutionizing the architecture, engineering and construction (AEC) industry over the past decade. BIM redefines the process of asset delivery and provides multi-disciplinary virtual models generated from a wide range of data and exchange files in many levels of detail or development (i.e. LOD, a measure of project development and information certainty in the associated BIM models; see also BIM forum, 2013) throughout the life cycle of building and infrastructure development and operation. The three-dimensional (3D) models and the rich underlying data allow for various trades to collaborate and coordinate the information with each other to improve productivity and increase return on investment (ROI) attributed to the virtual modeling and proactive problem solving approaches.

Researches on BIM have increased significantly in the recent years. Yalcinkaya and Singh (2015) reviewed 975 academic papers related to BIM between 2004 and 2014 and reported that out of 220 papers in the factor of "BIM implementation and adoption", 4% were published between 2006 and 2008, 38% were published between 2009 and 2011, and 58% were published between 2012 and 2014. Other BIM research factors include energy management, academy and industry training, information exchange and interoperability, safety management, urban/building space design and analysis, construction and project management, design codes and code compliance, as-is, as-built data, promotion and technology development, maintaining and managing facilities, and architectural design process. The following trends can be observed: a) BIM researches become more and more popular since 2004, especially after 2009; b) BIM researches cover a broad range of topics in the building life cycle; c) the majority of BIM researches focus on the project development phase, while researches in the post-construction phase are limited; and d) BIM researches on owners and facility managers are much less than those on architects, engineers, and contractors among all the project stakeholders.

At present, the benefits of implementing BIM in the design and construction phases have been increasingly recognized and realized (Barlish and Sullivan, 2012; Bryde et al., 2013; Eadie et al., 2013). However, the benefits of implementing BIM in the whole of building life cycle, especially in the operation and maintenance phase, have not been equally demonstrated and explored. For most asset owners, the true benefits of BIM in the post-construction stage are difficult to be measured using quantitative means. Therefore, evaluation should not only focus on the operational improvements enabled by BIM, but those of a managerial, organizational, infrastructure and strategic nature (Love, et al., 2013). Adopting BIM in the traditional facility management (FM) workflow requires a fundamental change of business practices, rather than merely a technical enhancement. The barriers need to be identified and evaluated at various levels of business organization, within which the majority of workforce currently have little or no prior experience in BIM applications.

This research project aims at identifying the barriers and drivers of large clients towards BIM adoption and implementation in the post-construction phase. It focuses on the perspectives of building owners and facility managers, who are the decision makers in adopting BIM and the executing BIM implementation, respectively. This project is part of a comparative research of BIM adoption between Australia and Singapore for whole of life BIM model delivery (from project inception stage to facility management stage). We conducted five formal interviews with five employees of a large institutional organization in Singapore, who represent the owner, the FM team, and the project management (PM) team. The audio recordings were transcribed and coded for qualitative analysis. The results generated from this study help understanding the challenges and motivators of BIM adoption in FM, assess BIM readiness of owners and facility managers in the context of Singapore institutional built environment, and provide strategic recommendations in several political, technological, economic and social themes.

2. Background

Singapore has substantially accelerated BIM adoption with the implementation of the first BIM roadmap by BCA (Building Construction Authority). Over the past five years from 2010 to 2015, BIM has gained significant popularity in Singapore's built environment. Figure 1 shows a summary of the challenges and strategies in BIM adoption identified by BCA (Cheng 2011). BIM implementation in the public sector was initiated with selected projects between 2010 and 2012 (see Table 1). Subsequently, mandatory BIM e-submissions were enforced progressively between 2013 and 2015 with specific milestones given to the architecture and engineering disciplines. By July 2015, it was stipulated that architecture and engineering BIM e-Submission be implemented to all new building projects with gross floor area (GFA) of 5,000 m^2 and above.

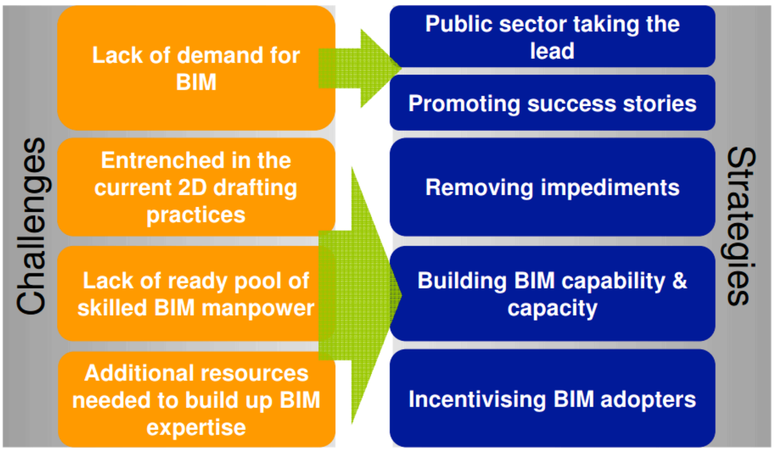

Figure 1: Singapore BCA's first BIM roadmap: Challenges and Strategies

Table 1: Singapore BCA's first BIM roadmap: Implementations

Year	Implementation
BIM Implementation in the public sector projects (2010-2012)	
2010	*Establish Centre for Construction IT help key agencies and construction firms to kick start BIM*
2011	*Work with key agencies on pilot projects*
2012	*Work with key agencies to prepare consultants and contractors who undertake the public sector projects to be BIM ready*
Mandatory BIM e-Submission (2013 – 2015)	
2013	*Mandatory Architecture BIM e-Submission for all new building projects > 20,000 m^2*
2014	*Mandatory Engineering BIM e-Submission for all new building projects > 20,000 m^2*
2015	*Mandatory Architecture & Engineering BIM e-Submission for all new building projects > 5,000 m^2*

BCA's first BIM roadmap primarily targeted on architects, (structural, mechanical, electrical, and plumbing) engineers, and contractors. From a discussion with several BCA staff in the late 2015, it shows that the majority of submitted BIM models are created at LOD 150 to 200 levels (i.e. the schematic design stage) just to meet the compliance requirements. Nevertheless, it is no doubt that the mandatory BIM submissions have greatly accelerated BIM adoption in Singapore in the design and construction workflow, though there is still a long way to go for BIM adoption and implementation to be extended to the entire building life cycle.

In October 2015, BCA announced the second BIM roadmap (2015-2020) which promotes BIM adoption to all asset stakeholders in the whole building life cycle. Six key measures were introduced, including: a) driving BIM collaboration throughout value chain; b) building BIM capability of specialist contractors; c) providing new training programs at all levels; d) promoting BIM for Design for Manufacturing and Assembly (DfMA); e) promoting BIM for FM and smart building; and f) promoting BIM-based research and development (R&D).

To extend BIM adoption into the post-construction phase, a paradigm shift of the present best practices in building life cycle management is required. Admittedly BIM for FM applications are still rare in Singapore according to the discussion with the above mentioned BCA staff. This is not only because of the fact that the vast majority of buildings do not have any BIM models or do not have BIM models with sufficient details, e.g. LOD 500 as-built models or LOD 600 as-is models, but it imposes great challenges to five key components in the built environment, i.e. People, Process, Technology, Policy, and BIM manager (Bew and Underwood, 2010; BIM Journal, 2011). While 'People' and 'Process' are instrumental to improvement and change, without 'Technology' these elements cannot be sustained. BIM adoption will inevitably result in major transition of skills, practices, and knowledge associated with people and processes by taking advantage of technology advancement and subsequently enabling more technological innovations. 'Policy' plays an important role in terms of providing standards and guidelines to mitigate the risk of mistakes and failures. 'BIM manager' is a critical success factor to ensure the other four components work in unison.

Considering that most building owners and facility managers in Singapore have little or no real experience in BIM, which is evident from the lack of BIM adoption and implementation in FM, it is valuable to investigate the BIM readiness of building owners and facility managers in terms of awareness, willingness, motivators, challenges, strategies, and roadmap. Some benefits of the research are as follows. First, it helps understanding the current status of BIM adoption in the FM stage before the second BCA BIM roadmap is implemented. Second, it helps identifying the key drivers and barriers of BIM adoption and implementation in FM. Third, it helps establishing an enhancement framework to expedite BIM for FM. Last but not least, it allows to benchmarking the performance of BIM for FM in Singapore with those of other countries for further improvement.

3. Research Settings

The main objective of this study is to identify the barriers and drivers for BIM adoption in FM and evaluate the BIM readiness of owners and facility managers in Singapore. We decide that a qualitative method of unstructured interview with open-ended questions is more suitable for collecting rich information and data from the interviewees with greater detail and depth in content. A large institutional organization in Singapore is selected as the case study, which owns more than 200 buildings and has hundreds of internal staff and external workers. The organization still adopts a 'traditional' facility management framework, where the workflows are based on 2D drawings. Most of the existing buildings do not have BIM models. Several new buildings are being tendered or constructed with BIM models at LOD 200 to 300 levels (i.e. the detailed design stage). This is a typical large organization in Singapore, in terms of FM practice. It has not formally started BIM implementation in the FM, but some BIM applications have been initiated in the PM phase.

The interview team comprises three co-authors of this paper, who have fairly good understanding of BIM in terms of theory, technology, best practice, and the BCA's BIM roadmaps. Two interviewers are based in Singapore and familiar with the local industry context. The other interviewer is based in Australia, who provides an additional perspective to this research.

The interviewee team comprises five employees from the same organization. Three interviewees are from the department of facility management: one director (F1), one senior associate director (F2), and one contract manager (F3). None of them have real BIM hands-on experience. The other two interviewees are from the department of project management under strategic planning division: one senior associate director (P1) and one assistant manager (P2). P1 has no prior BIM hands-on experience. P2 previously worked as a BIM coordinator in a design firm for two years. The interviewee team consists of senior management, middle management, and executives of both FM and PM processes. Collectively, they represent the building owner and facility managers to provide a reasonable sample for the research study.

Questions cover the interviewee's background and awareness of BIM related to his/her work, the interviewee's willingness of BIM adoption in his/her workflow, the challenges or barriers of BIM adoption in FM, the motivators or drivers of BIM adoption in FM, and the strategies to be taken.

Figure 2 shows the research framework where the key value of this research is to provide strategic recommendations to: a) remove the barriers of BIM adoption in FM at organizational level; b) increase the motivators of BIM adoption; and c) facilitate the implementation of BCA's second BIM roadmap.

One of the limitations admitted by the authors is that this research is based on a single case study. The validity of the research findings are subject to further validations with other organizations in Singapore, though many of them may share similar sentiments due to the rather standardized industry environment and the strong policy and regulatory guidance. Meanwhile, the open-ended questions allow the interviewees to share insightful experiences and opinions based on their job backgrounds. However, it is difficult for the authors to provide a list of individual questions here as most questions (except for the opening ones) are based on the conversation context. Nevertheless, the questions are primarily focused on the awareness, willingness, challenges, motivators, and strategies of the BIM adoption in FM. Lastly, the authors adopt a simplified framework in this paper based on Figure 2, without extensively exploring the interrelationships of various interviewee inputs, which will be covered in another paper.

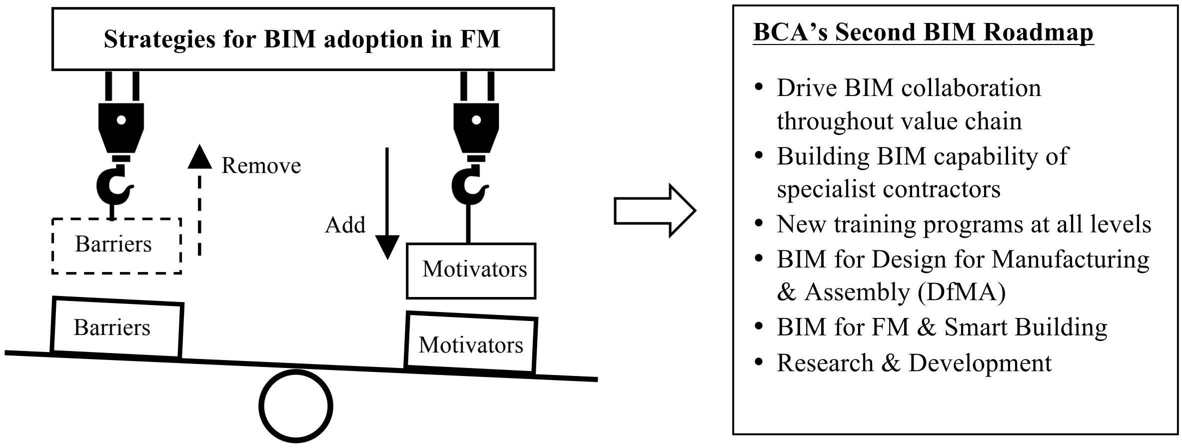

Figure 2: Research framework for promoting BIM adoption in FM

4. Data Collection and Analysis

All interviews were audio recorded and transcribed. The transcripts were then coded in NVivo for qualitative analysis. The top level coding structure includes the following elements: status, motivators (or drivers), challenges (or barriers), and strategies.

4.1 Status of BIM adoption in FM

The interviews with F1, F2 and F3 indicate that BIM for FM has not been adopted in the organization. All five interviewees are aware of BIM, though only interviewee P2 has prior BIM hands-on experience in another design firm. Regarding the willingness to adopt BIM for FM, interviewee F1 (FM director) expressed that "*We are keen to start it*", "*We don't let the authority or the agencies push us to do that. We feel if it is the right way, let's do it*", "*In fact, we are quite tempted to do that, just by lock, stock and barrel*", and "*So now the question is how to create that kind of journey ourselves*". It is therefore clear that the organization is at the early stage of BIM adoption, and the senior management of FM has a strong interest in initiating BIM adoption and implementation.

4.2 Motivators of BIM adoption

Motivators are a combination of factors that encourage or force BIM adoption in the organization. Interviewee F1 admitted that "there is this external push and this internal push". We classified these factors as externa motivators and internal motivators.

External Motivators

The first external motivator is **authority encouragement and enforcement**. In Singapore's context, currently there is no policy requiring or insisting that FM group takes up BIM, but BCA encourages early BIM adoption for FM. F1 disclosed that funding could be available if they start looking into it. Similar case can be found in the implementation of BCA's first BIM roadmap, where BIM adoption was first tested out in the public sector between 2010 and 2012, and subsequently mandatory adoption was required for the industry once the experience was built up. Likewise, it is possible in the future that using BIM for FM becomes a compulsory requirement, which will increase the risk of non-performance.

The second external motivator is **peer effect**. F1 disclosed that he was invited to participate an overseas study trip to Europe, and witnessed some best practices of BIM applications for FM. F1 commented that the BIM-FM system demonstrated is at "*mature stage. They are using at the facilities management stage. ... Here they call it various D: 3D, 4D, 5D and 6D. They are at the 6D level right now*", and "*We didn't see the difficulty, how they reached it. We saw the outcome, the final outcome that it really benefits the facility management group, yeah, and their operators. In fact, their contractors are all into that system as well; it's all interrelated*". Peer effect or peer pressure is a well-known influence that encourages people in a peer group to change their attitudes, values and behaviors to conform to those of the influencing group or individual. In this case the showcase of mature BIM applications for FM certainly provided a high level inspiration, especially when the influenced peer already had a strong desire to adopt BIM.

The third external motivator is **organizational image**. F1 disclosed that "*being a leader in many areas, at the senior management level when I attended the meeting they also say - why don't we just take a step forward?*".

Internal Motivators

The first internal motivator is **benefits to organization**. F1 disclosed that "*We can see the benefits at the facility management level rather than at construction level*", and "*looking at from other requirements like Green Mark or even like Barrier-Free Accessibility, we believe in it; actually it works*".

The second internal motivator is **desire to be ahead**. F1 disclosed that the senior management of the organization suggest "*So instead of being pushed, why don't we just take the first step and get it done ourselves?*".

The third internal motivator is **catching up with the PM office**. F1 disclosed that the FM department in the organization is linked to the PM department. Based on the BCA's first BIM roadmap, most new buildings of the organization will have BIM models submitted in the future. "*So I am doing the catching up with the other group*".

The fourth internal motivator is **benefits to FM**. F1 suggested two benefits as data and data analytics, which could enable preventive and predictive FM. "*I would say data; I think more importantly, I think it is the analytical part of it. I think, okay, if I don't look at that difficulty, I look at the benefit straight away, I think they link all the data together and generate a lot of what we call analytics to guide the facility management in terms of preventive maintainers. So we don't have to do what we call... 'guessing game'.*" "*So we should move more to preventive, even better predictive, and I think we have this kind of expectations from various laboratory and institute that we should actually be, keep improving on maintenance stuff, before it breaks down.*

So I think it ties with a core mission, yeah, and these tools really, from what they demonstrated is definitely really useful.". F2 (zone manager) suggested an example of asset lifecycle planning. "*Asset lifecycle replacement for example. So right now we are not able to fine tune the real details and currently we don't have the nitty gritty details of specs ... if everything could be easily integrated into one source where everything is overlapped, so it's not only just BIM only but that's why we are moving towards into our first phase which is going into the modular software where we can actually track repair cycles.*"

The fifth internal motivator is **benefits of efficiency and cost**. F2 believes BIM could help speed up information retrieving and handling. "*I think it's more about being able to manage information a lot faster. Instead of having to work on just CAD drawings and then having to put information together for different sources you have everything as one integrated source. That will cut time pretty much.*" F3 (contract manager) commented several times about the potential reduction of time (and cost) in retrieving drawings and other related data. "*Yes they will need probably I would say at least 20-30% of their time (to retrieving information).*"

Other mentioned benefits include visualization, clash detection, scheduling, and construction management, which are related to the native benefits of BIM technology.

4.3 Challenges of BIM adoption

The interviewees disclosed many challenges concerning BIM adoption and implementation, which are summarized as follows.

- **Cost**. F1 disclosed that "*normally cost and resources are the barriers*", and there is a lot of initial investment as well as maintenance cost to create and operate the infrastructure for BIM-FM. Estimated cost for the organization over a period of 10 years could exceed 10 million Singapore dollars.
- **Time**. F1 disclosed that it took 12 year for the European organization he visited to reach mature stage of BIM-FM application. Although he is confident in shortening the duration to less than 10 years, it would still be a long period of time and therefore there could be many uncertainties. "*Normally, once I start showing ten year, or data that shows what goes beyond 10 years I know I will lose their interest.*"
- **Return of investment (ROI)**. F1 disclosed that the initial calculation of ROI (for the planning purpose) is rather low, around 6% to 8%, which makes it difficult to get support from the senior management. "*Unlike my other projects where I show returns of 12 to 15%, and let's say solar PV, renewable energy; it scored a higher return, 12%. And even then they're still hesitant, because 12%, because there will be a lot of unseen things.*"
- **Technical competency**. The organization has over 100 internal employees and 2000 external contracted workers for various types of asset operation and maintenance tasks. Most of them do not have much information technology (IT) background. "*So there's a big gap there.*" Internally, it is estimated that the training cost for BIM is high, and many employees will retire in 10 years. "*So the question is, is it worth it? And second, this group of staff that we have actually at a certain level at age, yeah, they have about maybe 10 more years to retirement.*" Externally, "*getting educate the contractor is another issue because so far even through a normal submission where we got a simple submission for procurement you already have problem. So to get them to use BIM I think it's a challenge*".

- **Training and contractor buy-in**. On top of technical competency, one practical challenge is to provide training to the entire ecosystem to ensure sufficient qualification. This is not a trivia task considering the large number of internal staff and external contractors.
- **BIM model availability**. The organization has more than 200 buildings. "*The drawings are not being related to BIM format. For us to convert to that level is a massive exercise, so I think that that's one hesitation*." In fact, this is a major barrier for any organization to begin with BIM adoption.
- **Software**. At present, a mixture of vendor supplied and in-house developed proprietary software are seen in the BIM-FM applications. Interoperability is a common issue. The interviewees expressed their concerns about software selection and maintenance.
- **Organizational structure change.** The organization is currently undertaking several structural changes in the area of asset management. Drawing and documentation management is one of the examples, which resulted in temporary impact to the business operation. If BIM adoption is determined, additional complexity would be created.
- **Investment priority**. FM investment has lower priority, compared with other core business functions, in the organizational budget planning.
- **Tangible results**. Intangible benefits need to be translated into dollars or tangible value for quantitative evaluation and comparison, otherwise it is hard to convince the senior management. Meanwhile, clear objectives, path, and schedule need to be provided in the proposal.

4.4 Strategies for BIM adoption

Although the organization has not formally started BIM implementation for FM, the experience shared by the interviewees is still useful to the non-BIM users as a reference. The strategies summarized from the interviews include the following.

- **BIM study trip**. It seems that peer effect has a very strong influence in encouraging BIM adoption. It is not a simple duplication. The interviewee who joined the study trip did make a lot of contemplation and attempted to adapt the practice into the local context. The biggest value is that the visitor could see the final outcome and the tangible benefits of BIM-FM applications. Another value is to allow the visitor to make more realistic estimation of time, cost, schedule, and resources.
- **Case study**. BIM implementation is no-double a long and tough journey. It is less risky to start with simple case study, for example one or two new buildings. The downside is that it will require a long time to generate sufficient feedback.
- **Jump start**. Time is critical. Another strategy is to take the action immediately, on certain areas first. "*… they're asking us to jump start, certain areas don't bother, don't go and do, don't try, no more experiment. Just jump start*."
- **BIM department**. F1 disclosed that "*I definitely need a BIM department to push item because every initiative, whether it's on safety or on BIM, definitely you always need a champion there, and this is why I've got my colleague*." Before the BIM department is established, he suggested appointing a few people to be the champion. "*I was following the other safety model where a few people are singled out to be the champion for the BIM, and then for example, it leads to changes into the organizational group. So I am envisioning the same thing for my colleagues, those from contract and procurement.*"

- **Progressive cascading effect.** The interviewee suggested a progressive cascading effect to build the system and let the contractors to follow up, by the influence of both owner and authority. **"***I do not see immediate, a big jump immediately. I see a gradual transformation. I definitely need to build up the BIM champion. I need to put that into every part, procurement part, it's what the contractor part, to ask them to be slowly moving to the BIM, enable part of it. And it cascaded down to all my partners and the suppliers, and of course I hope that the agency can support me on this item because it takes two roles. Mine will be the encouragement part because I cannot force it very hard because it will result in a high construction or management cost. But hopefully they just see a push from their levels, and to make sure every time the contractor try to get certification, this definitely will be requirement.*"
- **BIM model and data acquisition**. BIM model and accurate data are two major constraints and should be handled with high priority. "*Now, we were hoping at new buildings level the consultant, contractors, even at the building owner level, we've got all the inputs correctly, so when the drawing reach us we don't have to do so much work, and then we can straight, start extracting the info or make the use of all this data that's residing in the BIM."*
- **BIM Specifications in the contract.** Previously BIM requirements were not explicitly indicated in the contract. P1 (strategic planning manager) disclosed that "*now we are starting to put in specifications for our BIM projects, ... we are in the midst of appointing a consultancy for first project where we will have a full suite of BIM implementation, so that's where we are as today*".
- **Standard information template.** The interviewee F2 talked about standard information template for contractors. This practice has been seen in the pilot COBie applications, i.e. Construction Operations Building Information Exchange (Smith E et al. 2012).

5. Discussions

The interviews show that the organization under investigation has fairly high BIM readiness by owner and facility managers in terms of awareness and willingness. However, many related issues cannot be ignored, which are discussed with the previously mentioned five key components: people, process, technology, policy, and BIM manager.

- **People**. Firstly, the interviewees P1 and P2, both from the project management office, expressed their concerns on the shortage of skilled manpower. "*whether it is basic draftsmen, or BIM coordinators and BIM managers, especially for local employees, it is hard to find, and if they are to look for foreign employees, they are also constrained, make sure manpower are on station, all this, so it's a challenge, so everybody is hungry for the manpower, everybody is finding, so, this is the main constraint here*", and "*So I guess our main challenge is basically resources, like people with the right knowledge and to drive it in that direction*". The same issue of skilled manpower will be seen in the FM-BIM process. Secondly, for the hundreds of existing manpower internally and externally, most of them are non-IT trained. It takes many measures to upgrade their skills and readjust their scope of work to adapt to the new workflow. Thirdly, future FM-BIM applications will require new talents in many new areas (such as high performance building science, sensors, data processing and analytics, and smart applications), who may be in a shortage as well.

- **Process**. The success of BIM for FM is strongly impacted by the upstream PM processes. FM-BIM requires high level of detail, ideally at LOD 500. However, most present building projects in Singapore rarely deliver BIM models beyond LOD 350 or 400 (i.e. the construction stage). Many facility managers may not have chance to obtain complete BIM models. On the other hand, advanced FM-BIM applications (such as preventive and predictive analyses) require deep knowledge in the domain. With the complexity of FM BIM models, a lot of research and development as well as process integration are needed.
- **Technology**. The BIM technologies can be broadly divided into two categories, geometric and non-geometric. After over a decade of development, software solutions have become more and more mature in geometric modeling, object library creation, and interoperable integration. Nevertheless, modeling and model updating are still largely based on the manual processes, which are time consuming and costly (Volk et al. 2014). This is one of the major challenges of BIM adoption in the FM. The non-geometric technologies include a wide spectrum of information and communication technologies (ICT) and data technologies. FM-BIM is still one of the areas that need significantly more innovations, for example, smart and sustainable applications.
- **Policy**. The present BCA's second BIM roadmap provides indicative guidelines. For the FM industry to massively convert to the BIM platform, a lot more supports and incentives are needed. Examples are pioneering local FM-BIM showcases, providing FM-BIM guides, providing FM-BIM benchmarks and appraisals, providing FM-BIM training and certification, etc.
- **BIM manager**. An experienced and qualified BIM manager is critical to the success of BIM adoption and implementation in FM. The BIM manager must not treat FM-BIM as little "bim" (lowercase), in terms of software. He or she must treat FM-BIM as BIG "BIM" (uppercase), in terms of integrated design and exchange of project data (Jernigan 2008). BIM is a combination of tools, platforms, processes, databases, communications, and organizational cultures. The BIM manager is the person to maximize the benefits of this new infrastructure to the FM teams.

6. Conclusions

With the release of Singapore BCA's second BIM roadmap, applications of BIM for facility management are recommended in the Singapore built environment sector, which potentially become a compulsory requirement in the future. This research project aims at investigating the awareness, willingness, motivators, challenges, and strategies of building owners and facility managers. A qualitative method of unstructured interview with open-ended questions were adopted to collect rich information and data from the interviewees of a large institutional organization in Singapore. Interview data revealed that the owner and facility managers have a fairly high degree of awareness and willingness to adopt BIM in FM. Three external motivators are authority encouragement and enforcement, peer effect, and organizational image; and five internal motivators are benefits to organization, desire to be ahead, catching up with the PM office, benefits to FM, and benefits of efficiency and cost. The challenges can be found in many aspects, which include but are not limited to, cost, time, return of investment (ROI), technical competency, training and contractor buy-in, BIM model availability, software, organizational structure change, investment priority, and tangible results. Finally, the potential issues related to BIM adoption in FM were discussed based on five components, i.e. people, process, technology, policy, and BIM manager.

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Evaluating the Usability Aspects of Construction Operation Building Information Exchange (COBie) Standard

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Abstract

Constructions Operations Building information exchange (COBie) is a rapidly evolving standard to capture the digital information of facilities. As the building information modeling (BIM) for facilities management (FM) research is gaining greater emphasis, COBie standard is becoming increasingly central to the discussion. COBie can be delivered in different formats. For the ease of use by the end users, spreadsheet format of COBie deliverable is the most applied one since spreadsheets provide some end-user implementation techniques and have been in use for decades. Although the end-users are familiar with spreadsheet actions, dumping all the facility data to a repository with number of workbooks and associated fields has some unintended effects and poses new challenges in handling and using the COBie data. Therefore, this research evaluates the functional and usability aspects of the COBie spreadsheet deliverable from the cognitive perspectives for end-users, and identifies the key points that can increase the functionality of COBie data structure. The research applies the initial phases of design thinking principles to identify the issues with COBie spreadsheet in general by reviewing the literature about spreadsheet design, human-spreadsheet interaction, spreadsheet errors, and information visualization. The identified usability issues and functionalities provide basic steps towards improving the current spreadsheet representation of COBie. The findings will contribute to future development of COBie, driven from the perspective of user interaction and usability.

Keywords: COBie, Facilities Management, BIM, Usability

1. Introduction

In the Architecture-Engineering-Construction (AEC) and Facilities Management (FM) industry, one of the central issues has been to determine how to structure digital information of a facility such that it enables data sharing among different disciplines throughout the project lifecycle. From that viewpoint, there is an increasing call to use Building Information Modeling (BIM) data in FM (Yalcinkaya & Singh 2015), because a lot of BIM data for an upcoming facility is generated in earlier phases of the project, especially in the design phase. Overall, the dependent facility information is created by numerous BIM, FM and construction management (CM) software applications throughout the project lifecycle. However, all these applications structure and present the FM data in their own proprietary formats which causes inefficiencies in interpreting and processing the data. Construction Operations and Building Information Exchange (COBie) is one of the most dominant, open and vendor-neutral industry standard that describes product and process of collecting and validating building lifecycle data generated during various phases of project lifecycle (buildingSMART 2010; East 2007). Although COBie is relatively new when compared with other AEC/FM standards, it is being widely promoted for BIM and FM. The end-result of the COBie specification can be considered as a common template in which the information structure and the delivery format of COBie specification is planned to reduce inefficiencies in facility information handover.

Currently, COBie-based information can be delivered in any of the three formats, IFC STEP (standard for exchange of product model) Physical File Format, ifcXML (extensible mark-up language format of IFC) and/or SpreadsheetML (open XML schema used by spreadsheet application such as MS Excel). IFC STEP and ifcXML can be interpreted and visualized in various parsers and/or web browsers. However, interpreting these formats requires some information technologies (IT) knowledge which not all end-users have. Given the end-users' inexperience and limited familiarity with the first two file formats, spreadsheet has become the most common way to represent COBie. Spreadsheet format of COBie deliverable provides some useful end-user implementation techniques such as sorting, querying, and/or simple mathematical functions if needed. It is human readable, checkable and editable as well. A COBie spreadsheet deliverable includes several workbooks and columns in which the users export the information from BIM and/or computer-aided facilities management (CAFM) software applications' data mapping or export tools; and/or fill in manually. The data is distributed in workbooks and associated columns such that each row includes specific entities of facility data. Depending on the delivery phase and the project size, a COBie spreadsheet can include thousands of rows of facility data.

Despite the easiness of spreadsheets and familiarity of end-users with spreadsheet logic and actions, storing and representing large amount of facility data in a tabular repository with number of dependent sub-sections may have unintended effects and challenges in handling and interpreting COBie data, for example, challenges in visualizing the overall content, duplication of data entries, understanding data dependencies, memory overload due to high amount of number and text-based data, etc. Similar issues are also discussed in the literature about the usability and cognitive aspects of spreadsheet (Chen & Chan 2008; Kohlhase 2013; Hendry &

Green 1994; Thorne & Ball 2008). Accordingly, the main difficulty that end-users have in understanding the data in COBie spreadsheet can be summarized as the high amount of data and lack of explicit dependencies between the cells and workbooks. Users need to recognize the data and their dependencies in COBie spreadsheet, which imposes a heavy memory load. The schema of the COBie spreadsheet is available in COBie Responsibility Matrix (East 2013) to check and interpret. However, handling two separate files or adding one more workbook to the existing COBie spreadsheet may increase the memory load even further. Responsibility Matrix (East 2013) to check and interpret. However, handling two separate files or adding one more workbook to the existing COBie spreadsheet may increase the memory load even further.

In this paper, we highlight and address the complexities and challenges involved while handling and interpreting the COBie spreadsheet. The contribution of this research is twofold. First, we present our findings by reviewing the literature about spreadsheet design, human-spreadsheet interaction, spreadsheet errors, and visualization. We have identified the issues that are common with the COBie spreadsheet representations. Second, we propose a framework to enhance the usability and functionality of COBie spreadsheet representation. Findings of this study and the proposed framework are expected to identify and outline the potential areas of future development for COBie, especially from the point of view usability and interaction with the data.

2. Background

2.1 Development of COBie Standard

In 1983, the National Research Council Building Research Board (BRB) proposed an integrated database solution for facility information (Scarponcini 1996). Other computerized systems such as CAFM, CMMS, etc. were already available to organize, manage and deliver FM information. The variety of software products and their versioning caused inefficiencies in automatic transfer of data. Consequently, the manual information delivery is still commonly used, even though it is inefficient, error-prone and tedious (William East et al. 2012). COBie specification was developed to overcome such challenges and establish a non-proprietary version of exchange data (East 2007). The development process began in 2006 under National Institute of Building Sciences (NIBS) FM and Operations Committee with an extensive review of literature and private industrial/association efforts. The development of COBie standard is mainly focused on two aspects. First, to determine the useful minimum in terms of specific information requirements, responsible actors and associated life cycle phases. Second, to define data exchange standards to eliminate existing inefficiencies in information exchange. The life cycle information exchange were evaluated based on business cases, specific business requirements, information handover plan and implementation with software applications (East 2007). Association efforts played a vital role in the development of COBie. Machinery Information Management Open Systems Alliance (MIMOSA), an industry sponsored non-profit organization, published important specifications such as the Open Systems Architecture for Enterprise Application Integration (OSA-EAI) (MIMOSA 1998) and for Condition-Based Maintenance (OSA-CBM) (MIMOSA 2006). These standards describe how to integrate asset information and how to transfer information in a condition-based maintenance system. Similarly, IAI and its open-source framework for exchange of facility information IFC, describes the majority of components, systems, ownership and the process history. Twelve published data exchange standards for the process industry were reviewed to identify equipment, process, systems, procurement, operations and management datasets for the development of COBie (East 2007).

The practices of the public sector were also considered in the development of COBie. US Naval Facilities Engineering Command (NAVFAC), Unified Facilities Guide Specifications (UFGS) provides Operations and Maintenance Support Information (OMSI). OMSI as an information package includes the key information produced during design, construction and commissioning of a facility. The information is organized in three groups: facility information, primary systems information, and product data (NAVFAC 2014). The OMSI package is generally submitted in three formats including hard copies, electronic (PDF) format and compatible with CMMS applications. The main information types and delivery phases were evaluated in the development of COBie. The Electronic OMSI (eOMSI) provides the required facility information in a structured spreadsheet file with a specified template, during the information handover. Besides OMSI, the Department of Public Works (DPW) of US offers a specification called Operations and Maintenance Manuals which covers a variety of facility information such as system descriptions, installed equipment lists, etc. This specification was also considered in the development of COBie. Besides these, such specifications and/or submittal processes provided by US Department of Defence and National Aeronautics and Space Administration (NASA) were also considered in the development of COBie (East 2007).

2.2 Human-Spreadsheet Interaction

Spreadsheet platforms are popular tools for storing, analysing and visualizing data across all domains, ranging from business to science. In Human-Computer Interaction (HCI) community, spreadsheet is often referred as a task-oriented platform with high computational power. By providing a combination of an expressive high-level formula language with an easy tabular format to organize and display data, spreadsheets are easy to learn and use. In addition, spreadsheet actions can effectively guide the decision-making process without the need for complex computing actions and professional support. Therefore, the flexible and direct approach to data manipulation and management in spreadsheets has led to a widespread usage (Panko 2000). Besides, almost in every business or professional domain, spreadsheets are not only used as a single-user application, but also in multi-actor environments as a collaboration tool, and as means of communication, exchange and integration of domain knowledge (Nardi & Miller 1990).

Although spreadsheets are powerful, simple, easy-to-use, and facilitate the tasks of single/multiuser organizations, yet crucial errors can easily occur. Several studies mentioned the common mistakes and challenges of spreadsheets usage in different scenarios (Panko 2000; Powell et al. 2008; Chen & Chan 2000). There are two levels of a spreadsheet: (1) concrete and visible surface level, and (2) abstract and hidden level beneath the surface (Saariluoma &

Sajaniemi 1989). The tabular layout appears at the surface level, while the connection of cells is established in a network defined by the dependencies in the deep/hidden level. One of the basic difficulties during the handling of spreadsheets is establishing the connections among the data distributed in cells and workbooks (Hendry & Green 1994). For large spreadsheets like COBie, tabular layouts for textual and numerical data do not show any direct mapping with the deep level; and in most cases, users deduce the semantic connection among the cells, columns and workbooks by visually checking them, which imposes a heavy memory load. Consequently, the process of investigating dependent data can be tedious and error-prone because many spreadsheets, including COBie, contain widely separated data.

Therefore, it is desirable that the data shown at the surface level, and its dependencies with the deep structure, are represented and integrated in a visual and interactive way, such that users can find the relevant information with lesser cognitive load. This remains a challenge in most spreadsheet-based solutions, and this limitation is carried onto COBie by default.

3. Research Method

The primary objective of this paper is to outline the issues which make COBie data less accessible and usable by users, including inexperienced and non-FM and/or operations and management (O&M), who would likely have difficulties in understanding and using the large COBie spreadsheet effectively. To reach this objective, it is essential to understand the characteristics of the existing representation, and the current challenges and expectations of the users, such that these can be addressed through ideations and enhanced features. This research adopts the initial steps of design thinking process which relies on the co-evolution of the problems and solutions through an iterative process (Dorst & Cross 2001; Poon & Maher 1997) to understand the issues with COBie representation, formulate the problem, and ideate the solutions with respect to the findings of the literature review.

The implementation steps of design thinking are generally organized in five basic steps which are: (1) Understand: understanding the experience and expectations of the users, whom we are designing for, through surveys, observation, interaction and/or self-experiencing the problem; (2) Define: processing and synthesizing the findings in order to form a user point of view for the proposed solution; (3) Ideate: exploring the variety of solutions by generating diverse possible solutions from a range of ideas; (4) Prototype: transforming the ideas into a tangible form to experience and interact with the proposed solution(s); (5) Test: testing the prototype, observe desired users' experience and get feedback to refine it. Following subsections present the understand and define sections of the design thinking as applied in this research to evaluate the current spreadsheet representation of COBie standard and understand the issues with it. Since this paper reports a work in progress, the next steps are currently underway and will be reported in future publications.

4. Problem Identification and Definition: Requirement for COBie Improvement

4.1 Step.1 Understand Spreadsheets and COBie Spreadsheet

The first step is to understand the problem context and assess the key challenges in effective usage of COBie spreadsheet in its current form. As described in previous sections, the underlying usability and navigational challenges with large spreadsheet is one of the key challenges and problems that is carried onto COBie by default, and this needs to be addressed. Therefore, it is important to understand how users interact with the large spreadsheets, navigate through the data, and establish the semantic connections; and what are the causes and effects which increase the cognitive load while handling spreadsheets.

Based on literature (Woods 1995; Woods & Watts 1997), it was found that navigation through large spreadsheets affects the decisions and actions that contribute to a user's ability to find and understand the relevant information. When the virtual representation of any type of data is distributed and much bigger than the actual computer screen, users cannot process the data parallel, in-mind, with what they see on screen. Instead, they split up the large structure and navigate the preceding/succeeding sections via zoom and/or move-to actions. In literature, this issue is referred as the key-hole effect (Woods & Watts 1997). Another issue in dealing with large spreadsheets like COBie is getting lost in which the user becomes lost in the virtual environment and fails to achieve the original task while he/she navigates and searches within the data. According to Woods (Woods 1984), the users "... do not know their present location in the system relative to the display structure and find it difficult to decide where to look next within the system" Another problem is referred as trashing (Henderson Jr & Card 1986). As in the COBie spreadsheet, when the user tries to find dependent information -sets- from different workbooks, he/she must serially shift among different workbooks which causes extra time and memory load. The increase in the memory load can also trigger the mental workload by focusing on the interface instead of the original tasks. While the user is experiencing the spreadsheet structure, he/she may need to memorize certain amount of semantic links and paths between different sections to achieve their task. In many cases, the professionals of AEC/FM industry are expected to deliver their tasks in a limited time and under limited sources; and experiencing the COBie spreadsheet within these conditions can be challenging. In this case, users generally tend to adapt their existing work style to the limitations of the environment/systems. To find a specific COBie data, user can simply use the search functionality of spreadsheet applications. However, in case of the need for checking the dependent information of the specific entity, user has to perform this action repetitively.

COBie data can be generated automatically with BIM, construction management (CM), FM software application and/or their add-on modules. This method provides efficiency by enabling faster production and preventing duplications. However, not every software application has the functionality to export all the data required in each workbook of COBie spreadsheet. Besides, COBie is not designed to handle every specific information requirements that can vary in each project. Therefore, users may need to enter the data manually which can cause duplication.

Since data entities in COBie have one or more dependencies, this mistake can cause duplication and/or omission of data for specific entities. As specified by (East 2007), the handover of COBie file should occur in different phases of the project. Therefore, the data in a COBie spreadsheet increases in each delivery with new data entries and/or addition of new attributes of the existing data. Users may want to see the changes in each phase of delivery or the information sets.

Visualization of any data improves human perception by increasing the cognitive capability and reducing the complex cognitive work. The easy recognition of sensory symbols based on shapes, colours, photographic images and their meaning in the human brain, facilitates recognition of patterns without the need for pre-attention (Duncan & Humphreys 1989). It is also because the rich content of visual triggers such as colour, size, shape, position, etc. reduce the need for explicit serial process of the data. Instead, the large network of neurons in the eyes can rapidly capture the features of visual representations and implicitly pick the visual patterns with the image-based meaning of symbols. In contrast, all geometric and non-geometric data of a facility is represented in numerical and textual form in COBie spreadsheet, which increases the cognitive load of users. Processing and deriving the semantics from COBie dataset is slower than any appropriate visualized form, because the textual or numerical data is processed in a consecutive series of activities while the visual representation is processed in parallel with the perception (Ware 2012). Therefore, one of the key issues of current COBie implementation is the lack of information visualization that could enhance comprehension and reduce cognitive load.

4.2 Step.2 Define Requirements with COBie Spreadsheet

The previous section gives an overall picture of COBie and spreadsheets, and the common challenges that a user is likely to face when they are interacting with them. As a next step, to outline the problem definitions and the potential enhancements, it is essential to state the target user's role and expertise assumed in this research. The proposed development is intended for all potential users of FM data, including inexperienced and/or non-FM/O&M people who have limited to no experience with the COBie spreadsheet. These users may need to interact with and use the COBie data in different ways, including potential responsibility to interpret and generate COBie data for the later phases of the project lifecycle. The reason why we also focus on the inexperienced users is to keep the proposed development as inclusive as possible. From our ongoing and previous interactions with industry partners and collaborators, we know that in both FM and O&M domains, many professionals have expressed difficulties in understanding and using COBie spreadsheet. Therefore, we aim to define the requirements for a solution that can not only increase the efficiency of experienced users while they interact with the COBie data, but also enable lay users to access relevant COBie data. To keep the problem definition as discrete and simple to understand, we structure the requirements as a set of statements, each following the same template: "**As a user, I ... I need to/have to ...**" Based on this template, the list of requirements for targeted improvements in COBie can be defined as: **As a user, I**

- lose my focus while navigating among workbooks. **I need** a platform in which navigation is easier (interactive).
- am having difficulty to process COBie data within different workbooks. **I need to** see all the relevant COBie data and dependencies at an easy and abstract level.
- have difficulty to see the dependent information within workbooks. **I need to** explicitly see the dependencies of a specific COBie data.
- cannot search a specific data based on its dependencies. **I need to** be able to find the specific COBie databased on its dependencies.
- have difficulty in understanding the semantic links among different COBie entities. **I need to** see my search results in a simplified format.
- want to access a specific data entity and its dependencies. **I need** the functionality that does not force me to navigate repetitively.
- want to select the COBie data entity with the 3D BIM model and see selected entity's dependencies. **I need** a platform in which BIM model and COBie data is mapped with each other
- may have duplications when I enter COBie data manually. **I need** a platform that warns me for duplications and prevents multiple data entries automatically.
- have difficulty tracking the new COBie data in each delivery phase of project. **I need to** track previous and new information sets effectively.

These requirement statements were defined and validated through an iterative process in a collaborative setting. The iterative process led by the researchers, included other researchers, software developers and industry partners. More importantly, consistent with design science, the requirement definitions also evolved as the researchers conceptualized and ideated on potential solutions with respect to the current solutions. Consequently, some of the requirement statements such as "... *have difficulty in understanding the semantic links among different COBie entities.* ***I need to*** *see my search results in a simplified format*." have been more concretely defined.

5. Limitation and Future Work

The reported findings are part of an on-going research, which means the requirements and our understanding of the limitations of the current COBie implementations may improve further as we refine our prototypes and solutions for a visual and interactive COBie (VisualCOBie) representation that is currently being developed and tested. The VisualCOBie platform has already undergone a few iterations and it will shortly be introduced in another publication, once additional validation and usability tests are conducted empirically.

One of the other limitations of this research was the limited understanding and usage of COBie in Finland, where the research is being conducted. This limitation is further compounded by lack of academic articles reviewing COBie. This limitation can be seen in two ways. First, the authors had to rely on feedback with only those industry partners who had familiarity and reasonable understanding of COBie from international markets. Second, considerable amount of COBie related issues were identified from discussions within the research community, as well as from online discussion forums on COBie. Third, the lack of adequate understanding about COBie in the Finnish industry, and the lack of academic articles on COBie also prove the key point that even though COBie is being promoted as the key data format to enable the use of BIM for FM, it is yet to capture the attention of the end-user. In addition, it also means that this paper raises a timely issue, bringing attention in the academic community towards COBie and its strengths and weaknesses in its current form.

6. Conclusion and Discussions

The main contribution of this paper is the evaluation of COBie from the perspective of end-user interaction, usability and functionality; and defining the requirements for improvement of COBie from usability perspective. The findings presented in this paper are part of an on-going research aimed at developing an interactive and visual solution for COBie data. Based on a critical review in a research that adopts design research methodology, the main limitations of the COBie standards are traced back to its dominant representation as a set of spreadsheets, with large amount of textual data. Consequently, the usability issues associated with large spreadsheets such as getting lost and keyhole effect automatically emerge with COBie as well. In addition, similar to many other situations where spreadsheets are used as collaboration tools, COBie spreadsheets are also expected to be filled and contributed to by various actors, and at various stages of the project lifecycle. This collaborative aspect creates further usability challenges, because users need to track the changes and additions to the data, leading to issues such as version management and duplication.

Based on the review, it is evident that the widespread use of spreadsheets, their low usage barrier, and their ease of information gathering and editing capabilities, were the dominant reasons for spreadsheets being the primary representation for COBie data. At the same time, it appears that one of the key reasons for the usability challenges associated with spreadsheets, and hence with COBie, is the lack of mechanisms to explicitly map and visualize the dependencies between the different data entities spread across different parts of the spreadsheets as well as across different workbooks. Thus, it can be argued that the information management issues and process view of data integration were the key factors considered so far in COBie development, while the usage and usability factors have so far remained overlooked. This problem of ignoring the usability and end-user perspective is not limited to COBie, but it is a typical trend in construction technology related developments. Not surprisingly, many of these technological developments fail to reach the desired rate and desired level of adoption, because users find them difficult to use, despite their technical capabilities. Singh et al (2011) make similar arguments, emphasizing that the support technical requirements that improve usability and focus on the end-users should be considered in parallel with the operational technical requirements, and not as separate add-on activities. Therefore, this research puts usability and the end-user perspective at the core of the chosen design science methodology, and such an approach is directed towards addressing the industry feedback and commonly reported grievances about the complexity and lack of understanding about COBie.

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Walk the Talk: Creating a Collaborative Culture in an Activity-Based Workplace

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Abstract

Creating organisational change by moving in to new premises has recently gained increased interest and attention. Business driven and process oriented relocation strategies – continuing after the relocation – enable organisations to re-design both space, current business practices and corporate cultures. The question, however, is whether such projects succeed in the end of the day. This paper explores how the process of moving in to a new workplace concept strategically may be used to change an organisation's collaboration culture. This is studied from the perspective of cultural artefacts, change management as well as physical and structural change. The discussion builds on semi-structured interviews with 65 employees from a Norwegian organisation. The findings indicate that the physical change, supported by process activities and change management actions, paved way for a cultural change towards more collaboration amongst employees as well as increased collaboration across hierarchical levels. However, misalignment in some areas between the new concept and existing cultural assumptions, values and norms, also restricted the organisation in fully achieving the intended ends. Therefore, the study highlights challenges and issues to overcome in order to use facilities as a tool for strategic change. The findings further underline the importance of creating a continuous change process, extending beyond the moving process itself.

Keywords: Artefacts, Change management, Workplace concepts, Activity-based working, Socio-materiality.

1. Introduction

Succeeding with organisational and cultural change is a challenging task (Schein, 2004; Balogun, 2006). Often advocated spatial efforts to enhance organisational collaboration, especially through open workspaces, common pathways and increased sightlines have also been found to have their limitations and sometimes fail in achieving the intended ends (Pepper, 2008; Becker et al., 2003; Rylander, 2009). Becker et al. (1994) however argue that business driven and process oriented relocation strategies – continuing after the relocation – may better enable organisations to re-design both space, current business practices and corporate cultures. It is furthermore becoming more and more recognised that in order to succeed with strategic change, different organisational factors need to be aligned with the new strategy. This approach recognises that the physical workplace is an integral part of the organisational structure and culture. Interweaving organisational structures and culture in organisational change processes, may thus provide organisations with greater opportunities to achieve transformational change (Becker et al., 1994; Schriefer, 2005; Miles, 1997). In this perspective, the organisational structures or space may function as a catalyst for change (O'Neill, 2007; Inalhan and Finch, 2012; Allen et al., 2004) or the other way around, be used in order to reinforce and stabilise the change (Bate et al., 2000). However, in execution of organisational change strategies, Miles (1997) argues that organisations often start up by changing structures and infrastructures. Changing people, culture and core competencies generally require a longer process. This article aims to explore the culture-structure relationship in an organisational change process.

1.1 Cultural Artefacts and Organisational Change

When executing a strategy, managers must handle a number of different factors, organisational culture being one of the most important (Balogun and Johnson, 2004; Schein, 2004). According to Schein (2004), an organisational culture consists simultaneously of three reciprocally connected levels: *(1) artefacts*, *(2) espoused believes and values,* and *(3) taken for granted assumptions*. The three levels are based on the degree to which the phenomenon is visible to the outsider. Taken for granted assumptions being on the lowest level and artefacts on the highest – most visible level. Artefacts, physical and/or non-physical, are all organisational phenomena that one may see, hear and feel. Espoused values and believes, as well as assumptions have been found to have a significant role in determining employee perspective, adaptation to and use of space (Hirst, 2011). Although not always visible to the observer, they are expressed and shared through social processes (Schein, 2004). Artefacts are furthermore environmental signs conveying information about social orders – thereby influencing and constraining social actions (Baldry, 1999; Bechky, 2003). Therefore artefacts are often considered as a form for organisational message (Cooper et al., 2001; Allen et al., 2004). Klingmann (2007: 259) argues that architecture is "a visual symbol for the expression of a corporation's culture and personality". Thus, space may be used as a cultural creator – forming and reinforcing the culture (Schein, 2004; Steele, 1973).

Space and artefacts are also socially produced and culturally constructed – leading people through embodied experiences in the form of feelings, emotions, and memories (Kornberger and Clegg, 2004; Taylor and Spicer, 2007; Dale and Burrell, 2008). Language and the way we talk about space further construct spatial experiences, not only steering our interpretation of space but also forming actions, behaviour, interpretations and judgements (Airo et al., 2012). As people make subjective judgements of physical environments, the experience and judgement of a particular place may not simply be reduced to strategies, intentions, managerial and architectural plans (Ropo et al., 2013). For example, Rylander (2009) found that project managers, designers and users, through their different understandings, perspectives and experiences apply substantially different meanings to a new workplace concept. In line with the concept of affordances developed by Gibson (1979) actions are formed not only by the space and its artefacts, but also by social processes informing people about space and its meaning. In this perspective, artefacts do not determine behaviour but rather provide cues of socially accepted behaviour in a particular context (Värlander, 2012; Gibson, 1979).

Artefacts are furthermore commonly used to lead, manage and divide people and support hierarchies (Vaasgaasar, 2015; Taylor and Spicer, 2007; Grenness, 2015; Baldry, 1999). Building on such argumentation, leadership may be formed without the presence of the leader, this through artefacts providing the observer with information forming actions and the meaning-making process (Ropo et al., 2015; Greenlees, 2015). Size, location and furnishing of individual offices are especially often used for this purpose (Muetzelfeldt, 2006; Baldry, 1999). Edenius and Yakhlef (2007) also argue that spatial markers and symbols are useful in order to formalise rules. However, when spatial change is made without addressing the other cultural dimensions, unintended changes within the political culture of the organisation may occur (Markus, 2006). Ultimately, if new artefacts are in contrast to other artefacts and/or existing assumptions, values and norms an equivocal message may be created, leading to misinterpretations and possibly unintended outcomes (Schein, 2004; Gibson, 1979; Pepper, 2008).

1.2 Leadership and Cultural Artefacts

Space in it self does not hold meaning. Meanings attached to space is rather created, changed and defined by time and former experience. The same process goes for culture and leadership, this as leaders create culture, and culture defines and creates leadership (Schein, 2004). Leadership is, however, not only a social phenomenon, this as "leadership is being shaped, modified and constructed by material workplace arrangements" (Ropo et al., 2015: 2). The ways in which leaders and organisational members act, behave and use space – such as the CEO's position at the head of the table – are in fact cultural artefacts, affording people and their actions (Schein, 2004; Gibson, 1979). Thus, space is connected to the way organisations are used to seeing and regarding leaders. The general trend to move from a 'hierarchical' control system to 'horizontal' network structures, is however changing the role and view of leadership (Dale, 2005). In this perspective, transition to open, transparent and activity based workplaces, where leaders and employees work side-by-side, may influence new cultural assumptions (Blakstad, 2015), decrease boundaries and hierarchies (Värlander, 2012), and support values of equality amongst organisational members (Grenness, 2015; Bakke, 2007). Nevertheless, ownership of space is still deeply connected to assumptions such as status, importance and value. Transition to a non-territorial workplace without owned space may for some imply lower status, lack of interest in employee comfort (Hirst, 2011) and even signal that everyone is replaceable (Bakke, 2007). Leaders that are forced to give up their office may thus feel that their personal status is threatened (Elsbach, 2003).

As change in cultural artefacts challenge existing norms and assumptions, this may result in strong emotional reactions and even resistance. To cope with the new workplace, organisational members need to 'unlearn' old values and norms an 'relearn' new ones (Grenness, 2015). Building on the argumentation by Schein (2004), placement of oneself in relation to others and to different functions symbolise factors such as membership, status and social distance. Here, leader's actions, functioning as cultural artefacts, are pivotal in forming values, behaviours and norms (Balogun, 2006). Especially top-level management actions and belief in the value of the change have been found to be pivotal in succeeding with organisational relocation strategies (Bakke, 2007; Schriefer, 2005). Miles (1997) further argues that successful change managers are those who take any opportunity, no matter how trivial, to demonstrate and act the change. This may constitute a new corporate storytelling, which may act as an effective support mechanism for the change processes. Behavioural stories may function as a means of guiding employees in their everyday decision making processes, help employees to understand the rationale for change and be a tool for communicating a message (Stegmeier, 2008). This is a continuous process where the 'change agent' assists others in the transition from the present state to the desired state (Becker et al., 1994).

Schein (2004: 170) argues that, "shared assumptions arise only over the course of time and common experience". To this end, actions and use of space may function as meaning-making triggers contributing to organisational learning (Balogun, 2006) and through 'learning by doing', activities gradually form new sets of rules and norms (Steele, 1973). The open office environment daily offers opportunities to support the change effort and "lead through own appearance and action" (Vaasgaasar, 2015: 80). In the transition to new workplaces, managers need to 'walk the talk' – explaining the new strategy through their own actions. This is an iterative process were managers often are challenged, this as the transition itself may lower their status and force them to start to earn status in other ways than through physical artefacts and cues (Grenness, 2015). Higgins and Mcallaster (2004), however, observed that top managers generally do not perceive the links between changing strategy, changing culture, and changing cultural artefacts. As assumptions are often taken for granted, managers are also seldom aware of their own assumptions and what effect this has on the change process (Schein, 2004). If manager behaviour is not in line with the new strategy this may become a hindrance, allowing employees to act on old values and norms (Balogun, 2006; Balogun and Johnson, 2004).

2. Methods and Case

The empirical material draws on semi-structured individual and group interviews with 65 employees from a Norwegian professional service network provider. The organisation provides services within fields such as auditing, consulting, financial advisory, risk management as well as tax and legal. Participants were purposely selected from the different business areas and levels within the organisation, this to include organisational members with different roles, work tasks and responsibilities. In between interviews, use of the workspaces was studied through unstructured observations. Brief informal discussions with approximately 40 employees were also conducted during the study. The study was conducted in three main phases approximately 1,5 years after the transition to the new headquarters. Data from each phase was analysed before moving onto the next phase. To identify differences and similarities between the business areas, data from the units was furthermore coded and analysed separately. The focus was, however, on cross-unit analysis, thus the reported findings cut across all units, unless otherwise stated.

The change started early in the process with a new organisational strategy. The intention of the relocation was to set *"a new standard for collaboration"*. The strategy focused on better collaboration and utilisation of knowledge within and across the different business areas. The organisation wished to build on the newly implemented strategy, and by transition to the new building, reframe the culture-structure relationship. The new concept was activity-based, supported by free-seating and clean-desk principles. Due to high resistance towards free-seating, confidentiality requirements and other practical needs, some departments were allowed to have individually owned workstations. The different zones range from silent- and semi-silent zones, project areas, meeting- and collaboration rooms to open centrally located areas for social interaction. Signs hanging from the ceiling mark each zone. The signs have a colour, a symbol and a short description – explaining and giving cues to what activities are appropriate within each zone. The main focus was on facilitation of interaction processes, as explained by one manager: *"It is important that the new building facilitates employee interaction. The building cannot create interaction by itself, but it may facilitate interaction*".

3. Findings

3.1 Collaboration within Departments and across Hierarchies

Where free-seating and space-sharing structures were implemented, employees reported that internal communication and collaboration had increased. Work in the new office was described as "more social" and collaborative than in the old office. Several employees commented that, as they often worked close to others they had gained a larger internal network and also befriended new colleagues. As told by one of the employees: *"You come in contact with people that you normally don't come in contact with". "I've got new friends here",* comments another. Several experienced that this eased seeking help from others. Many also remarked that they had gained a closer connection and more knowledge about different areas within their own department. Working in open workspaces was furthermore reported to help streamline work processes.

Perceptions, however, varied between departments. In departments where individual workstations had been implemented some managers and partners seemed to perceive an increase in collaboration, however, most employees did not perceive any noticeable increase – rather in some instances a decrease. At these locations several employees stated that, as one were afraid to disturb others, one did not 'dare' to talk in the open landscape. Thus a 'whispering' culture was created at several areas. As employees became more used to the open landscape, this code of conduct gradually changed towards more interaction at most areas. Nevertheless, some groups still struggled with social interaction at the time of the study. At these areas the norm and assumption was that work processes were mainly conducted as individual tasks, thus the workspace ought to be quiet allowing for individual concentration. This sub-cultural norm and the high value placed on individual work also effected interaction within adjacently located groups. In the words of one employee: *"I find it useful to throw out a question to colleagues in an open workspace, however, I don't feel comfortable with doing that here".* Some, especially lawyers, further stated that, due to confidentiality requirements it was challenging to discuss work related issues in the open landscape. A perception, however, not shared by all – especially not by partners and managers. Contrarily, these groups argued that confidentiality was no problem as long as one followed the organisational confidentiality ethics and guidelines and also used the available collaboration rooms. Nevertheless, some used individual work processes and the confidentiality requirement as legitimate claims for having own offices.

To facilitate random encounters and collaborative work processes, each floor had a centrally located coffee area, furnished with lounge furniture and high-stand tables. Despite this and the signs, explaining the purpose of the zone, these areas were mainly seen to be unused after the transition. In the beginning, many believed that spending time in these areas was perceived as "being lazy" or "non-efficient". As one employee stated: *"As a consultant, you charge the customer by the hour. You need to be efficient. Hanging out in a sofa may give the wrong impression".* To change such assumptions, some managers hung additional signs, emphasising the value of collaboration and informal interaction. To 'walk the talk' some further started to spend more time working and collaborating from these areas. At the time of the study, use of these spaces had remarkably increased. To facilitate team collaboration, open landscape 'project areas' were also located adjacent to the informal areas. Also, these areas were mainly unused after the transition. The general openness and caution of sharing sensitive information to others seemed to restrict employees from using these areas. Furthermore, as these areas also were new functions with which employees did not have any experience, some reported that they were insecure with regards to what kinds of work processes and activities that were appropriate or allowed. However, at the time of the study, these areas were highly appreciated and believed by many to be crucial for collaborative working and creating 'workflow'. Being able to share documents on screens on the walls and spread out work material were seen as especially important. Several employees also commented that the project places were efficient in sharing knowledge and informing others – *"the people just passing by"* – about on-going projects.

The former workplace concept had a hierarchical workplace structure with individual offices mainly assigned to seniors, managers and partners. Going from this to a workplace structure where members from the different levels of authority shared workspaces created challenges as well as benefits. The new workplace facilitated a flatter structure allowing organisational members at different levels to sit 'side-by-side', thus collaboration across hierarchical levels was seen to have been improved. Many also described the organisational hierarchy as being flat, especially with comparison to similar organisations outside the Scandinavian countries – an observation in line with research on Scandinavian workplace cultures (e.g. Grenness, 2015). Arguably, the new workplace was perceived to better reflect the low-hierarchical structure. Transitioning to a new workplace also changed the hierarchical map of the workplace. In the former workplace, free-seating had been implemented in one department. However, informal rules and behavioural norms, grounded in the hierarchical structure and culture, defined where different organisational members were *expected* to find a desk. As such, areas for managers, partners, seniors and newly employed had been created. With few exceptions, these sub-groups had disappeared during the transition in to the new office. The exceptions were mainly related to areas were members from the top-level management situated themselves. As a result others seemed to avoid situating themselves at these particular places. Nevertheless, as most top-level managers situated themselves adjacent to the informal areas, they also – through their choice of place – invited employees to engage in interactions by the 'manager's' table. Employees' perception was that when top-level managers and also other managers worked from these areas they simultaneously signalled that they appreciated a low-hierarchical culture and were open for inquiries and interactions. Several employees also reported that knowing partners and managers spatial patterns both eased finding them and also eased knowing when they were available for inquiries. Moving managers and partners from assigned offices were, however, by some seen to create higher boundaries and challenges in terms of communication. Previously, the sign of an open door functioned as a cultural artefact informing organisational members of the person's availability. Uncertainty of whether the persons were actually available for questions or having to ask them to join in for a conversation at another location seemed for some to make the threshold for making contact somewhat higher. Few managers and partners on the other hand perceived this to be a challenge, rather stating that inquiries had increased – however, becoming shorter and more efficient. Managers and partners also perceived that working next to others facilitated 'workflow', tacit knowledge sharing and sharing of sensory experiences.

3.2 Collaboration Across Departments

In the old building, a centrally located staircase connected the different departments and was described as a place where people 'bumped into each other'. The new office – higher and narrower in structure – seemed to decrease spontaneous encounters and therefore also collaboration between organisational members from different departments. However, areas such as an in-house coffee bar, the previously mentioned social and project areas, and a project area accessible for the whole organisation on a separate floor, created substitute areas for spontaneous encounters and collaboration activities. Employees who spent more time at these locations did not, to the same extent, share the view that spontaneous encounters or collaboration across departments had decreased. Contrary, these employees believed that the new facilities provided better locations for more relaxed and 'deeper' conversations and interactions. Especially the in-house coffee bar functioned as an area where organisational members from different departments were seen to interact with each other. Stated by one employee: *"I went to work at the coffee bar one time, and a person that I just had sent a mail to came in. So we sat down and had a brief conversation"*. Additionally, internal staircases connecting some of the floors were found to benefit spontaneous interactions.

Nevertheless, the view shared across the organisation was that knowledge of and connection to other departments had diminished. Many assumed that, as they did not see members from other departments as much, they did not collaborate as much. The ultimate effect is, however, questionable, as most employees perceived that their own work had little or nothing to do with other organisational departments. However, in instances where specific projects were held across different departments, employees were seen to move around more, also working from multiple floors. The sharing structure and freedom of movement within the building did in this perspective offer opportunities for work in and between the different departmental floors. The perception of less cross-departmental collaboration may further be related to the fact that the organisation since the transition had experienced a significant growth. Some employees expressed that this had resulted in less communication and fever instances of informal group meetings – also within their own departments. In this perspective, some artefacts from the old workplace had also been lost. For example, the staircase in the old building facilitated weekly status meetings, also called 'stair-meetings'. Although these meetings still occurred, they were not as frequently held and no longer perceived as an important cultural artefact. Ultimately, some expressed a loss of a former 'homey' culture and feared that as the organisation continues to grow this would continue to affect the organisational belonging.

3.3 Time and Management

Prior to the transition, workshops and process activities were conducted with the aim to discuss issues such as, what 'a new standard for collaboration' meant for each department. The general answer to this question was that: *"The new standard for collaboration is something we develop together over time"*. As previously described the patterns for socialising, collaborating and communicating had since the transition gradually changed. When moving to the new workplace many seemed to categorise the workplace into primary, secondary and tertiary workstations. The 'own' work desk was perceived as the primary workstation, meeting- and project rooms functioned as secondary workstations and informal meeting places were perceived as tertiary workstations. As the different cultural dimensions gradually changed, many started to regard the former secondary and tertiary workstations more as primary workstations – ultimately considering a multitude of workstations as being suitable for conducting different work processes. A 'mentality change' was also seen to have happened amongst some groups of managers and partners. Prior to the transition, several of these groups requested a separate area assigned to them, a request, however, turned down by the management as they believed it to be against the strategy and the desired collaborative culture. After the transition none of the interviewed managers and partners requested such an area. However, at one department the free-seating structure was gradually redefined into one area for managers and partners and another area for 'others'. This was not a formalised structure, rather as one employee put it: *"When managers and partners always choose a place in the same area, no one else dare to sit there"*. Thus, there were still instances were managers' and partners' behaviour maintained a hierarchical structure, thus the social relationships across hierarchical levels were not yet fully developed. As a result, behavioural artefacts restricted development of a collaborative culture.

Statements and actions given by specific organisational members were further seen to influence organisational members' assumptions and norms. Early in the process, the CEO and the top-level management informed the organisation of the intention and vision for the new workplace concept. Doing so they also stated that they would work in the same workplace, with the same sharing principles as everyone else – adding that anyone that wanted something else could come and talk to them. Few came. Since the transition the CEO and the top-level management have kept their words, working according to the free-seating structure. Also other managers and partners commented that they felt obligated to be early adopters and give good examples for co-workers. This question was also raised in the process where managers and partners were told that if they didn't feel that they could lead the change, they should at least try not to be openly negative. Nevertheless, few partners and managers perceived that there had been any focus on them as regards to being 'change agents'. Although managers' behaviour was found to be important for 'leading the change', few regarded their actions in the office to be of any importance. Several organisational members, however, commented on specific managers, their actions and how this had been important for creating a 'new standard'. Placing oneself in a highly visible area, working from different locations and actively participating in the everyday work environment were by many seen as important cultural artefacts. Contrary, when managers and partners seemed to do the opposite – creating own areas, choosing the same place every day or removing them selves from the work environment – employees often reacted negatively, arguing that they should at least try to lead by example and try the concept. As a result, some groups of employees also had a tendency of breaking the concept rules, creating sub-groups and their own rules. Noticing the importance of the process and management actions, some managers emphasised the value of putting enough resources into the process: *"If you really want to create a transformational change then you need to put resources on changing minds"*.

4. Discussion

Implementing a new workplace concept with an open shared space structure did in many ways facilitate "a new standard for collaboration". However, creating a new standard for collaboration did not only require a physical change but also a change within the other cultural dimensions. In line with the argumentation by Schein (2004), the findings illustrate that where a change in assumptions, values and norms had not happened, no remarkable change occurred or unintended outcomes emerged. As for the departments where individual work was valued higher than collective work, the new spatial artefacts worked in direct contrast to the existing cultural norms and values. As such, employees also resisted the new workplace, arguing that it did not support them in meeting the intended ends – findings also in line with Grenness (2015), Rylander (2009) and Pepper (2008). In this perspective, the new artefacts in themselves did not have the power to 'break through' and change the other cultural dimensions. However, at departments where team and project work processes were valued higher, change was more seen as an alignment and modification of the physical workspace to better fit the culture and the already implemented strategy. To this end, the workplace and its artefacts both paved way for the change as suggested by O'Neill (2007), Inalhan and Finch (2012) and also Allen et al. (2004), but also, as suggested by Edenius and Yakhlef (2007) and Bate et al. (2000) functioned to formalise rules which further stabilised and reinforced the change.

As suggested by Schein (2004) and Hirst (2011), employee assumptions, values and behavioural norms guided and formed adaptation to, use of, and satisfaction with the new workplace. Old assumptions such as: the standard desk is the primary workstation, and that fun and informal conversations are not an important part of core work processes did thus create barriers for change. The fear of 'sharing information' and the pending confidentiality discussion at some departments represented a 'confidentiality culture' where information should be 'guarded' and properly handled by the employee. During the transition, the value of knowledge sharing, however, became more and more prominent at most departments than the value of confidentiality. As managers also took a more present part in the landscape, breaking down the hierarchical boundaries, this further supported the non-verbal message and ultimately the change initiative. The change in values influenced both use and the ways employees related to and talked about space, findings also supported by Airo et al. (2012). By time, the new concept started to work more in harmony with a newly formed organisational collaborative culture – stressing the fact that structure and culture must co-evolve (Bate et al., 2000). The process here was one of continuous learning, changing and learning from changing. The process of 'unlearning' and 're-learning', as emphasised by Grenness (2015), may in this perspective be seen as an iterative process where old and new values and assumptions are tested against each other. This in turn, stress the need for a change management process extending beyond the transition itself, as also emphasised by Becker et al. (1994).

As a new set of assumptions, values and norms gradually was created at some departments, and especially as some hierarchical structures were broken down, employees also got more freedom to start to explore the new concept. However, the fact that the project was seen to be finished soon after transition and that no formal structures were developed to follow and further steer development of the original vision, may also have hampered goal achievement. The focus on spatial change as a tool for affecting cultural change, also contributed to the creation of a rather rational deterministic thinking. Supporting the argumentation by Värlander (2012) and Rylander (2009), the deterministic perspective was found to be challenging and partly unfruitful in achieving the intended ends. The additional cues and behavioural artefacts implemented by some managers and partners may in this perspective have been crucial for achieving the intended ends. However, as some managers' and partners' actions and use of space also reinforced hierarchical levels, the boundaries within the organisation were not eliminated – rather redrawn in the new office. In line with Becker et al. (1994), Balogun (2006) and Miles (1997) corporate managers' and partners' actions strongly defined the value of the new cultural artefacts as well as the meanings employees assigned to the different spatial solutions. As such, sub-cultures and norms became visible in the open workplace structure. The lack of physical boundaries between groups and members, also allowed for cultural norms to transmit and travel between groups. Due to the complicated interaction between the spatial workplace and the organisational identity, as well as the different identities within different sub-group, achieving the intended ends were seen to require as extended process. Thus, the study stresses the need not only for a continuous iterative change management process but also the need for applying a set of different tools, measures and strategies within the overall strategy.

5. Conclusions

The article illustrates that use of a new workplace concept to effect cultural change is dependant on an alignment between spatial artefacts and other structural and cultural dimensions. If an organisation attempts to utilise a relocation process for strategic change organisational aspects, cultural values, norms and assumptions needs to be addressed and handled as an integrated part of the strategy. This will ultimately lead to a situation where space and culture may co-evolve into alignment. In a physical transition it is further important not only to renew critical cultural artefacts, but also to maintain those that already support the new strategy and the desired culture. In accordance with the perspective of space as socially constructed, management and sub-groups' use and relation to the concept were also found to be important in shaping new cultural assumptions and norms. Arguably, implementation of new workplace concepts with the intention to affect and change cultural dimensions need to be handled as an on-going process, continuing after the relocation and also supported by management action and behaviour as well as supported by a multiple set of integrated tools and strategies. Organisational members' appropriation of space and buildings are furthermore significant in achieving high levels of building usability. Addressing the socio-material relationship in research as well as in the development and implementation of new workplace concepts may provide the building sector with more knowledge with regards to buildings' usability and strategic use of the built environment.

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How employees value the support of activity based and traditional work environments

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Abstract

New Ways of Working (NewWoW) are popular, both for increasing employee and organisational effectiveness and attracting new talent. As Corporate Real Estate management (CREM) is responsible for delivering a supportive office environment for employees and the organisation as a whole, they must align by providing a work environment that aims for employee satisfaction, increased support of productivity and other added values. This is often done through introducing the shared workspaces and facilities of activity based working (ABW). However, lack of proof of advantages of such work environments is feeding a more reserved attitude towards NewWoW. This paper aims to provide evidence for differences between traditional and ABW environments in workplace support of organisational goals as perceived by employees.

Online questionnaires (2010-2014) from the Leesman Database amongst 47,913 office employees (mainly Western European organizations) were analysed for employee opinions on workplace support. Respondents were split in two groups based on their workspace: ABW or a traditional, dedicated seat. Statistical tests of differences between both groups provided insight in five types of added value.

The ABW employees were more positive on all added values included in the questionnaire and the support of their workspace for important activities. Also, they were more satisfied in general and with most of the individual features and facilities of their work environment. Only satisfaction with their desk, chair, personal storage, phone equipment, desk/room booking systems, in-office network connectivity and the ability to personalise was lower than the employees working at dedicated seats. The design of the ABW workspace had a more positive (perceived) impact on culture, corporate image and environmental sustainability. Further, they agreed more with statements that the design of their organisation's workspace contributes to a sense of community, creates an enjoyable environment to work in and enables them to work productively.

The results from this analysis provide CRE managers with proof for implementing ABW environments in their office portfolio. Not only did employees that work flexibly feel more supported in their work by their workplace, they also felt that it better supports general strategic organisational goals like productivity, corporate image and sustainability.

Keywords: added value, work environment, employee preferences, chi square tests, independent samples t-tests

1. Introduction

The workplace is said to be a strategic tool for organisations, but there is still little evidence to show how and in what contexts (Kampschroer and Heerwagen, 2005; Blakstad et al., 2009; Steen and Markhede, 2010). Therefore, for many organisations it is still mostly a costly resource for which cost reduction is the main aim (Gibler et al., 2010). However, corporate real estate (CRE) managers at contemporary organisations increasingly try to work with a workplace strategy aiming at a more optimal cost/benefit ratio (Jensen, 2009; Pullen et al., 2009). For benefit they look at the added value of the physical work environment for employees and the organisation as a whole. Jensen et al. (2012) detected six different types of added value of CREM in their review of the literature:

- Use value: quality in relation to the needs and preferences of the end users;
- Customer value: trade-off between benefits and costs for the customers or consumers;
- Exchange value: economic trade-off between costs and benefits;
- Social value: connecting people;
- Environmental value: environmental impact;
- Relationship value: experiencing high-quality services.

While exchange value lies fully within reach of the CRE manager, the effect of the other added values is (partly) indirect and thus cannot be isolated from other variables, which makes it harder to prove the relevance (De Vries et al., 2008). These added values do not only have an effect through the real estate itself but also through the employees (use, social and relationship value) or clients and society (customer and environmental value). As employees and clients are important for knowledge organisations, a positive influence on this should be highly valued by their corporate management. Unfortunately, measuring these indirect added values is often troubled by a lack of outcome indicators, making it hard for CREM to show proof. As Feijts (2006) suggested that the indirect effects explain the majority of performance changes, this deserves more research.

With the rise of strategic CREM, many companies have redesigned their buildings and workspaces to influence employees' attitudes and behaviours (Robbins, 2003). Large companies are increasingly moving towards new ways of working practices (from here on called NewWoW) (Inalhan, 2009) and the so-called activity-based office concept. But evaluating whether these designs have succeeded in their goals of adding value is difficult and not done much yet (Pullen, 2011; Maarleveld et al., 2009; Laihonen, et al., 2012). Particularly little is known about the consequences for employee attitudes and well-being (Ten Brummelhuis et al, 2012; Peters et al, 2014). Therefore, this paper focuses on the question how contemporary office design relates to organizational performance, from the viewpoint of the office employees working in it.

The next section provides a short overview of the literature on the contemporary work environment and different added values it might have. Then the research approach is explained, which is based on statistical analyses of questionnaires among 47,913 employees from 115 different organizations. In the results section the findings are described, followed by a discussion and recommendations for further research.

2. Contemporary work environments

Despite of the hype and well-known terminology, a survey taken by Van der Meulen (2012) showed that 67% of the organizations that are orientating themselves on NewWoW implications do not know exactly what NewWoW encloses nor what benefits it could provide. Half of the respondents even had negative associations with it. The coverage on NewWoW in magazines and journals is often either very positive or very negative (Pullen, 2011). This has led to a more reserved attitude of some organizations towards introducing NewWoW (Baalen et al., 2011) and the effort to convince management to do so, has increased over the years (Van der Meulen, 2012).

The term Activity Based Working (ABW) has become a widely used expression for different office concepts that support NewWoW and is regarded as one of the most advanced concepts (Ross, n.d.). These concepts have in common that all users, from employee till general management, can choose to work at all available workspaces and collective facilities and where nobody is allowed to claim their own workspace. ABW offices offer a variety of different types of workspaces aimed at supporting different activities. So there are no dedicated seats and people are supposed to choose different workspaces throughout the day, based on their activities at that moment. Besides exchange value through cost reduction (a decrease of m^2's), added use value through increased employee satisfaction and productivity are important goals of organizations implementing ABW (Van der Voordt, 2004; Baalen et al., 2011). A positive image and as a consequence attraction and retention of scarce personnel and clients, more flexibility and environmental impacts (CO2) have also been mentioned as additional aims of the ABW environment (Ruostela et al, 2014; Blok et al, 2011; Van der Voordt, 2004).

But expectations and realizations of NewWoW do not always coincide (see Figure 1). In a study of Baalen et al (2011) among more than 250 organisations, all aims of implementing ABW, except more flexibility, showed a lower achieved effect than the original expectation. While the effects on the organisational process (flexibility, costs) largely matched expectations, effects on employee output (productivity) and organisational image towards their employees (employee wellbeing, satisfaction, image) lagged behind. In a before/after study questioning employees that moved towards an ABW environment, Blok et al (2012) also showed no higher appreciation of use value (satisfaction and the suitability for work tasks) nor social value (collaboration with other employees). Top-down implementing new working conditions is said to be insufficient to achieve positive work outcomes, as it might not change the actual behaviour at the office and could even be a source of stress (Peters et al, 2014). So it seems important to know in more detail what employees with dedicated seating think of their work environment versus the ones working in an ABW environment to discover which added values are perceived by them.

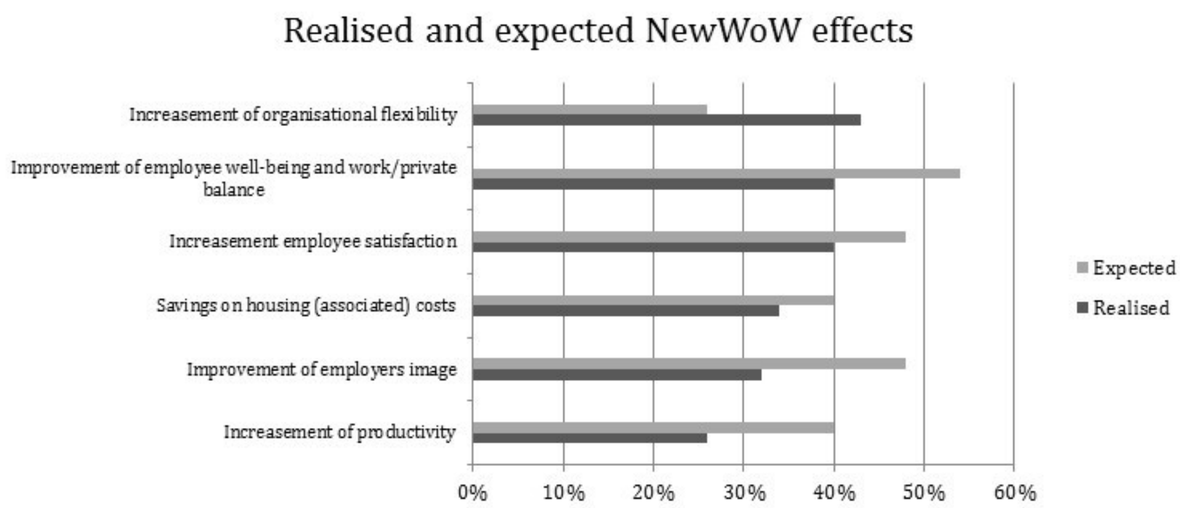

Figure 1: Realised and expected NewWoW effects (Baalen et al., 2011)

3. Research approach

As this paper focuses on employee opinions about the work environment, an existing large, multinational dataset of employee questionnaires was used. The questionnaires have been developed and collected by Leesman ltd (from 2010 up to February 24, 2014). Their online surveys of employees question various workspace aspects and some general data on the respondent (e.g. age, gender, position etc.). Average response rate to the Leesman survey is 64%. The so-called convenient sample taken for this paper included 47,913 employees from 115 different organizations divided over more than 370 locations (average 369 employees/location).

Respondents mostly worked at organizations in Western Europe that approached Leesman to survey their employees. Although the database contained respondents from 22 countries spread over all continents except Asia, 59% of the respondents work in the UK and 22% in Sweden. The other 19% had a very diverse origin. The organisations belonged to many different sectors, both profit and non-profit. Because of the non random sampling method the results were interpreted with care. However, the large number of organizations and employees included supported generalizability to Western European Offices.

From the complete set of 47,193 respondents, those who pointed out to spend <50% of their time at the primary office were not taken up in the sample (= 4,122 respondents or 8.6%). This guaranteed that respondents who only visit the office for short periods of time did not influence results. The rest was split in two groups (ABW flexible environments versus traditional environments with dedicated seating (TradWoW)) based on the work setting they indicated to work in most of the time. TradWoW employees worked at a private office, cubicle, technical area (e.g. drafting table), shared office with own desk, own workstation in open plan area or other. ABW employees mostly worked at a pre-booked hoteling or hot-desk, shared team table, informal work-setting, flexi/shared workstation or touchdown area. The NewWoW group obtained 6,243 (14.2%) respondents and the TradWoW 37,557 (85.8%) respondents.

To look at the employees' opinion on use value, the following survey questions were used:

- Opinion on importance of workspace design (on a 7 point scale of -3 to 3);
- Perceived support of activities that were important to them (For 21 different office activities the respondent was asked to state whether it is an important activity for them (yes/no). If yes, the respondent was asked to rate support of this activity by the workspace design on a 6 point scale of -3 to 3, without 0. Support of all activities was added up and averaged);
- Satisfaction with 31 features and fifteen facilities of the physical work environment (For each feature and facility the respondent was asked to state whether it is important (yes/no). If yes, the respondent was asked to rate satisfaction for his or her current workspace (on a 5 point scale of -2 to 2). A respondent indicating to find a certain feature/facility not important was not asked about satisfaction with this aspect. This is considered to be neutral satisfaction (=0) in the further analyses. Satisfaction with all features and with all facilities was also added up and averaged to get total scores);
- Opinion on workspace design enabling them to work productively (on a 7 point scale of -3 to 3)

For customer value, the questionnaire contained one question on the impact of workspace design on corporate image. Exchange value was disregarded as employees do not have insight in workplace costs and how efficiently these are managed. Social value was studied with questions on workspace contribution to workplace culture and a sense of community at work. Environmental value was measured by the perceived impact on environmental sustainability. Relationship value was measured with questions about whether the environment is enjoyable to work in and whether they are proud to bring visitors. All these questions were asked to be rated on a 7 point scale (of -3 to 3).

To test differences between both groups, either $\chi 2$- or t-tests could be used. As the 7-point scales are quite large, one could argue that t-tests on the group means are allowed, although it is not a fully continuous scale. But as several of the variables did not show a fully normal spread (most lean towards the positive side of the scale), $\chi 2$-tests were used to test significance of differences observed for most of the added values. For the use value, new variables were calculated in SPSS, namely the mean satisfaction with all features and with all facilities of the work environment and the mean support of important activities. These were tested with t-tests to look for differences between both groups, as these were continuous variables with a normal spread. All statistics are visible in Table 1.

The flexible and the dedicated seating group did not show significant differences with regard to gender (58% male, 42% female), age (normal distribution), part time employees (6%) or time working at this organisation. Only on the country of residence, the groups showed significant differences ($\chi2(23, N=43791) = 2817.6, p = .000$). The NewWoW group consisted of 75% UK employees (vs. 47% in TradWoW) and employees from the Netherlands, Germany, France and Sweden, so only European countries. In the TradWoW group the Swedish account for 24% of the group (vs. 8% in NewWoW) and several other non-European nationalities were also present.

Table 1: Statistics on all the added values

	statistics			
	n	*χ2-value*	*t-value (equal variances assumed)*	*p-value (* = sign.)*
use value				
importance workspace design	*43516*	*28.3*		*.000**
support of important activities	*43550*		*-12.0 (no)*	*.000**
satisfaction with all features	*43561*		*-9.1 (yes)*	*.000**
satisfaction with all facilities	*43561*		*-23.4 (no)*	*.000**
enabling to work productively	*43524*	*89.5*		*.000**
social value				
contribution to workplace culture	*43519*	*360.8*		*.000**
contribution to sense of community	*43521*	*144.8*		*.000**
relationship value				
enjoyable to work in	*43520*	*407.3*		*.000**
proud to bring visitors	*43522*	*1845.5*		*.000**
customer value				
impact on corporate image	*43521*	*1505.9*		*.000**
environmental value				
impact environmental sustainability	*43524*	*1139.4*		*.000**

4. Results

The design of the workspace mattered to most employees (85.2% agreed with this statement), both in ABW and in dedicated seating environments (see Figure 2). But in ABW environments significantly more employees agreed on this (see Table 1). Looking at the use value that was experienced by both groups of employees, on all matters the ABW employees were more positive than the ones with dedicated seating. The perceived support of important activities by ABW employees was higher (M=.79, SD=1.2) than among the dedicated seating employees (M=.59, SD=1.2). Workplace satisfaction in general with the features and with the facilities also showed significant higher scores for the ABW group than the TradWoW employees. ABW employees scored (on a scale from -2 to +2) the features on average with .19 (SD=.45) and facilities with .39 (SD=.49) and dedicated seating employees with .13 (SD=.46) and .24 (SD=.47). Looking at the individual features and facilities, satisfaction of ABW employees was higher for all facilities (except desk/room booking systems) and for most of the features (e.g. indoor climate, parking, meeting rooms, accessibility, noise and décor), except for their desk, chair, personal storage, phone equipment, in-office network connectivity and the ability to personalise. The last question on use value regarded the support of productivity and again ABW employees felt better supported by their workspace (see Figure 3 and Table 1).

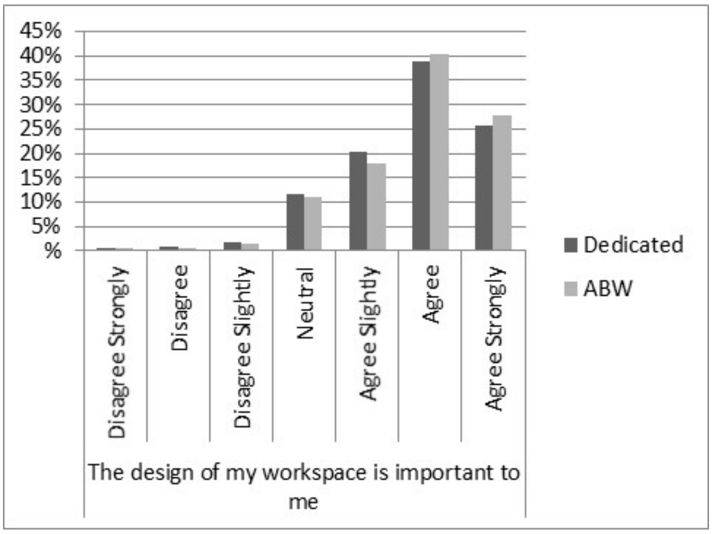

Figure 2: Importance of workspace design

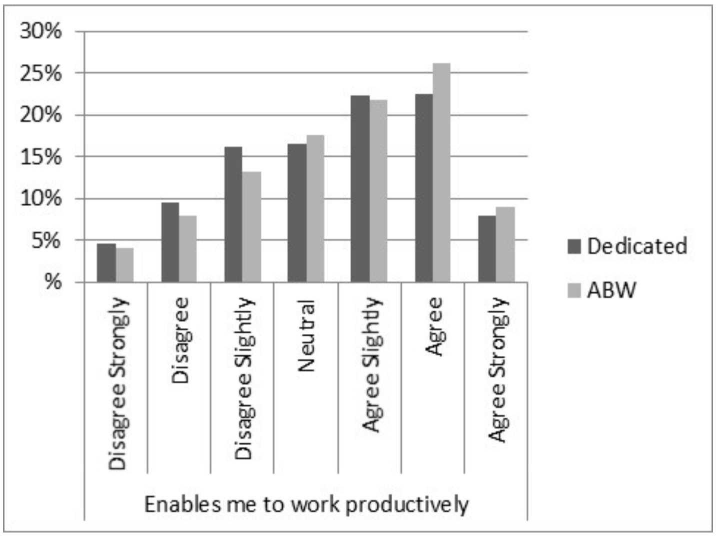

Figure 3: Added use value through support of productivity

Besides use value, the ABW employees also valued the added social value of their workspace. The impact on workplace culture was more positive and also the contribution of the workspace to a sense of community at work (see Figure 4 and Table 1). Both these items are known to help connect people. The last indirect added value through the employees is relationship value, which also scored very highly in the ABW environment. The employees felt more strongly about the fact that it creates an enjoyable environment to work in and they felt more proud to bring visitors to their workplace. Figure 5 shows that especially pride was much higher among the ABW employees.

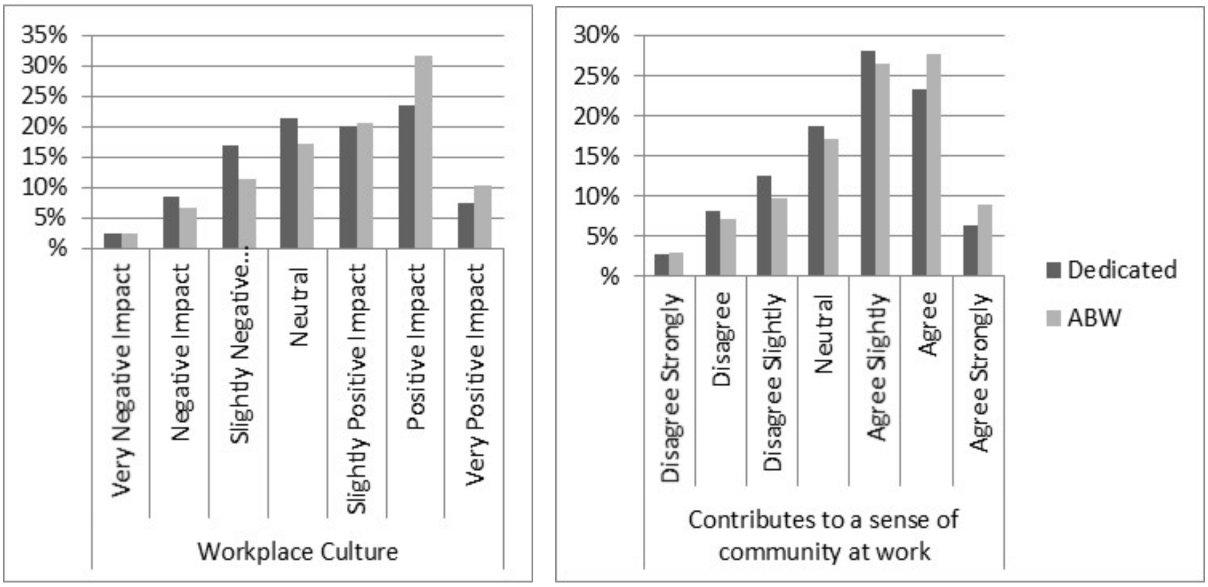

Figure 4: Added social value

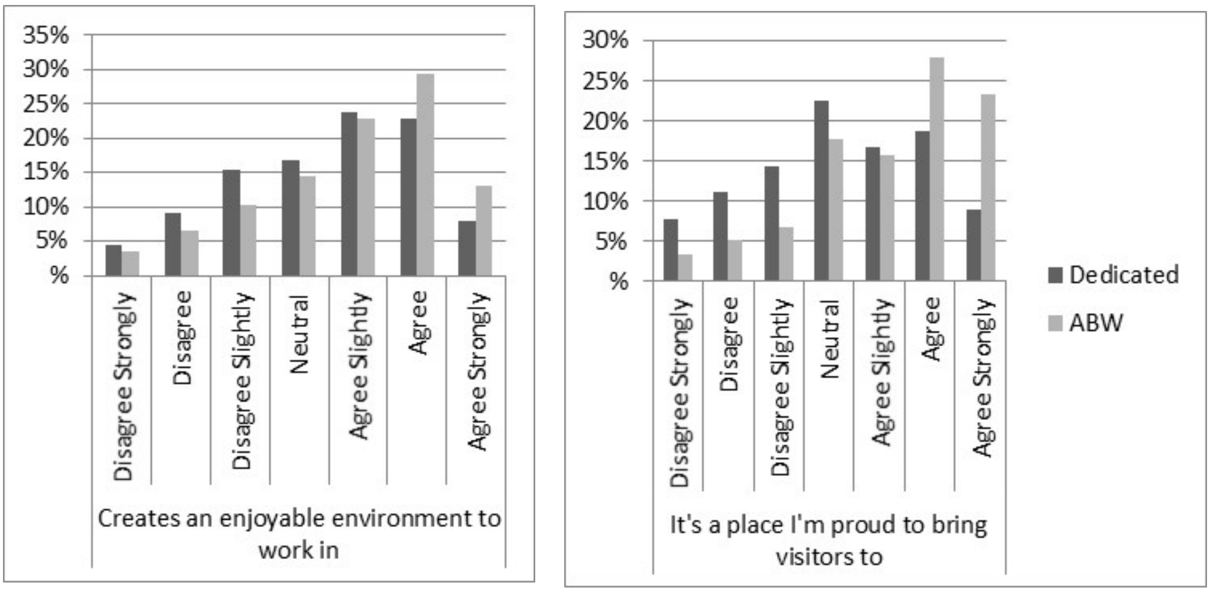

Figure 5: Added relationship value

Although customer value and environmental value are indirect added values which are best measured by opinions outside the organisation, it is also interesting to know what employees have to say about it. With regard to customer value, employees felt more strongly that their ABW environment had a more positive impact on corporate image and environmental sustainability (see Figure 6). Opposed to use, social and relationship value, these 'outside' values might be the hardest for CREM to quantify the actual effect for, as it is not common to question customers and society about this. For the question on environmental sustainability 42.2% of the respondents remained neutral, which might also imply that they did not know how to value this aspect.

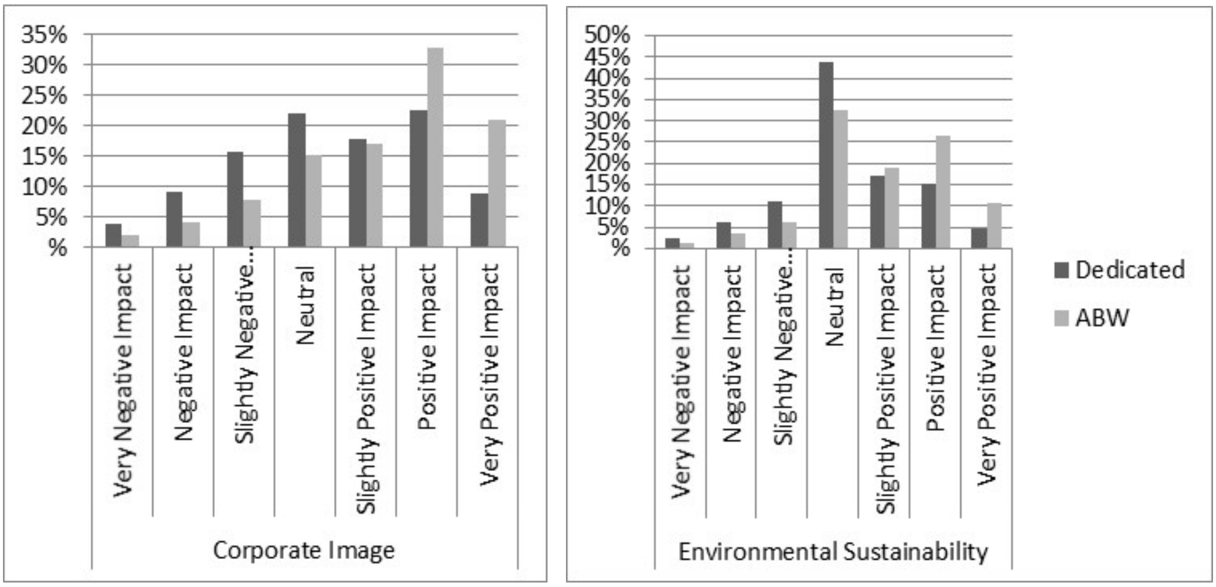

Figure 6: Added customer value and environmental value

5. Discussion

In today's knowledge economies, the employees are the most important asset. To measure their perception with regard to use value, social value and relationship value probably has provided valid results, as these are perceived values. However, for customer and environmental value it would be better for future research to also include research among clients, passers-by and local residents. In future comparisons of NewWoW and TradWow environments, it is also important to take the building itself into account. It is likely that the ABW environments in general were newer (or more recently renovated), which has probably led to more modern climate installations and decor.

The results of these analysis showed that ABW environments scored better on almost all aspects and added values. That would imply that all organisations can improve their performance by moving from dedicated seating towards these types of work environments and NewWoW. However, ABW might not be suitable for all job types and also not for all types of people. Also, research has shown, that these environments are not always used as intended, because people still claim the same seat everyday anyway and do not change during the day (Appel-

Meulenbroek et al, 2011). If employees are not guided well during the implementation, they might even oppose the intended changes on purpose (Inalhan, 2009).

It is unknown which added value is the most important for organisations and their performance. For knowledge organisations it would seem that social value is particularly valuable as knowledge sharing increases the innovativeness of the organisation. Asking about the contribution of the work environment to workplace culture and a sense of community probably did not cover this entire concept of social value yet. Innovation requires stimulation of both interaction and creativity (Oseland et al, 2011) and CREM can take specific steps to do so with the physical work environment design (Kastelein, 2014; Dul and Ceylan, 2014). These studies have not yet identified whether ABW are better at it than traditional work environments, so this is subject to further research.

Looking at satisfaction with some of the individual features and facilities that scored negative for both groups, it becomes clear that people walking past your desk and noise levels are not solved satisfactory in any of the work environments (as there was no significant difference). And although satisfaction with temperature control and art/photography were significantly less negative among ABW employees, they were still dissatisfied a lot. After desk, chair and different types of office equipment, temperature control was important for the highest percentage of respondents. So research how CREM can add value with these important aspects is necessary, as it does not seem that the modern ABW environments have succeeded (much) in doing so.

6. Conclusions

The physical work environment is very important to office employees, both in contemporary as in more traditional work environments. Therefore CRE management can add value to the organisation by offering important features of the physical work environment and facilities to the satisfaction of their client's employees. The results of this study suggest that on average (European) employees were happier and supported better with ABW environments than with dedicated seating, so introducing these office concepts seems promising for CRE managers to add more value. Besides the exchange value that it will bring (through reduction of m^2's), the respondents felt that also all the other added organisational values benefit from it. The challenge for CREM remains to express all the added values in terms of money, as interventions in the physical environment do require an investment and thus approval of corporate management.

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Measuring the added value of housing for primary education

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Abstract

The purpose of this paper is to investigate which theoretical elements of adding value by real estate are applied in practice in accommodating primary education and in what way these are elements relevant to the stakeholders. A literature study of usual CREM strategies has been used to build a theoretical framework with regard to the value a building can create for different stakeholders. Then interviews were held with various professionally involved people in order to understand to what extent the general theory is taken into account with regard to "added value" for the stakeholders of primary school buildings. The factors marketing, increased satisfaction of employees, increased productivity, flexibility, and reduction of costs were mentioned explicitly as possibilities to add value for stakeholders by real estate. It seems reasonable to assume that the sector of primary education strategically focuses little on increasing the value of real estate. The article summarizes the theory of the added value of real estate for organisations. The empirical findings show that professionals are aware of the possible added value of real estate for the primary process. The added value is expressed in many ways and is also perceived differently by the stakeholders. However, the possibility to add value by real estate hardly ever plays a role in a real estate strategy, nor is it used as an argument to increase available budgets. Due to the limited number of interviews, further research is needed regarding the assumed relationship between real estate strategies and the perception and behaviour of the different stakeholders. In The Netherlands, various studies have been conducted into the importance of CREM theory for decisions on real estate for Higher Education. Similar research on housing for primary education is almost lacking. The data show that not all potential possibilities to add value with real estate for primary education seem to be applied in practice.

Keywords: Corporate real estate, Added Value, Primary education, Stakeholders

1. Introduction

The main purpose of this research is to give insight in the way primary school buildings can add value, from the perspective of different stakeholders. Most of the recent literature (Jensen et. al, 2012 and 2014), (Beckers et. al., 2015) is about the added value of the process of CREM or FM to an organisation. Research with a focus on the meaning of added value for the different stakeholders of a specific school building itself, is lacking for primary education.

In order to get the best out of the real estate of an organisation, it is vital to see real estate not only as a shell within which the organisation's everyday activities and processes take place, but to see it as a capital asset that can be used for goals that may be achieved in the longer term (Appel-Meulenbroek, 2007). Lindholm (2006) concluded that the possibilities of adding value through real estate often were not recognized or even considered. Therefore, it is an obvious assumption that a strategic planning with regard to the real estate of organisations also can influence the results. A lot has been written about what this means for the "for profit sector". More and more, the CREM principles are applied to real estate with a public function.

De Vries (2007),Den Heijer (2011) and Kok (2014) did research on the importance of CREM and FM for decisions on real estate for higher education and universities. Their research showed that housing had a direct influence on the primary process of universities. For instance, the change in the funding of universities has led to a change in the process of prioritising. Previously, cost efficiency, architectural quality and centralization were prioritised, whereas factors like customer appreciation and social cultural aspects are considered more important now (Geselschap, 2013).

For higher education institutions there also is research available about the relationship between Corporate strategies and real estate management. Beckers (2015), for instance, found that the CREM strategies in use, nowadays are more clearly aligned with the corporate goals of an institution. Based on a comprehensive literature review De Kok (2014) found that the assessment of added value of a facility depends on the perceived functional or emotional advantages offered by that facility in relation to the costs, efforts and the risks involved in using that facility. According to Appel-Meulenbroek (2014), it is obvious that more fundings will be made available for investments in real estate if there is proof that real estate adds value to the organisation. Most likely, the CREM principles can also be applied to other sectors in education in The Netherlands, like for instance primary education. Similar research on the effects of real estate management on certain decisions with regard to housing for primary schools has not been done yet.

In the current situation, school boards receive the financial means for exploitation of the school directly from the Ministry of Education. Financial means for building and renovating school buildings are not included, because, in principle, a municipality is legally obliged to place a school building at disposal. For this, the municipalities receive funds from the so called "Municipal Fund". These funds, however, are not "earmarked" for school buildings. Based on the current regulations, one could opt for further decentralisation. This implies that the financial means for the realisation of the school buildings are made available to the school boards and that further agreements with the municipality have to be made about the conditions in which way the means can be spent by the school board. In primary education, this possibility is hardly made used of. Although there are other possibilities to divide the financial means for school buildings, the question remains whether these possibilities provide sufficient freedom of policy to the school boards in the present situation. It could very well be that, if the means could be spent directly by the school boards, it would be possible to create school buildings that add more value to the organisation.

Real estate is generally recognized as the fifth business resource (Joroff, 1993). Several authors have written about the "added value of Real Estate". Nourse and Roulac (1993) and Krumm et. al. (1998), among others, wrote about the added value of real estate for an organisation. Later, Lindholm et. al. (2006) and Jensen (2010) wrote about a "framework that describes how real estate and facility management can create added value, either in a corporate real estate context or in a facility service provider context".

In the current situation the complicating factor is that the municipality, as a result of current regulations, often is the beneficial owner of the building, and the school board just the legal owner. In this situation, the question arises whether the real estate should be seen as the fifth business resource to the school board or the municipality. The role of the real estate as a business resource for the municipality is very different from the role it has for the school board. Because municipalities are the beneficial owners of the school buildings, they will probably steer towards financial performance indicators (cost minimization), whereas a school board is likely to be more interested in the added value that the building can give because of the role it plays in the educational process.

This article aims to answer the following questions:

1. What is, in general, perceived as "the added value of real estate";

2. Who can be regarded as the stakeholders of housing of primary education in The Netherlands;

3. To what extent are the theoretical possibilities of adding value with real estate recognisable in relation to the stakeholders of the school buildings for primary education.

Below the methodology that has been applied when answering these questions will be described. Subsequently, the results will be summed up, followed by the conclusions.

2. Method

The first two questions are necessary in order to describe a solid theoretical framework. The answers to these are based on a literature study. This research has provided a theoretical insight with regard to the possibilities for creating "added value" and the stakeholders that can be distinguished when it comes to housing of primary education. This resulted in a hypothesis regarding the relationship between the stakeholders and the possibilities to add value with real estate. Subsequently, this hypothesis was tested through interviews.

These interviews were held with representatives from several groups of stakeholders, in order to find out to which extent the principles from theory actually "live" in practice. These interviews were held with four school board members, four actors with an advisory role, and a representative from a municipality. A representative of one of the largest school boards in The Netherlands, a board member and an advisor of one of the most progressive school boards in The Netherlands, a member of a board of public education that has been involved in a lot of new housing projects during the past years, and finally a representative of a municipality, a representative of a school board and an advisor that are currently working on a number of innovative school buildings have been interviewed. The question has also been answered by a legal expert in the field of housing of education and to a housing advisor who has been involved in several school construction projects.

The interviews were held according to the narrative method. The only question asked was: "from your perspective, which added value could housing of primary education have for the various stakeholders (municipality, school board, employees, parents and children, and the environment)?". The purpose of this approach was to find out to what extent the theoretical possibilities of adding value to an organisation by means of real estate, for the benefit of the stakeholders, was recognised by the interviewed professionals. The interviewer has asked as little extra questions as possible. The interviews were recorded with the consent of all interviewees and were transcribed completely afterwards.

3. Current Theory

Here the result of the literature study will be described. Firstly, the functions that real estate can fulfil will be taken up and the existing theory with regard to the value of real estate for an organisation will be described. Subsequently, the different stakeholders of real estate and which types of added value theoretically are applicable to each of them will be taken up.

3.1 Functions of Real Estate

Each individual real estate object has multiple functions. In his thesis "Focus on customer value", Smeets (2010) mentions five functions of real estate at object level. These five functions are listed below.

- the protecting function: Real estate fulfils the human need of conditioned space by providing both the necessary biological/physiological and physical shelter and mental shelter in the social and psychological sense. In short: we need a roof over our heads that protects us against weather conditions and that gives us privacy.

- the utilitarian function: Accommodation and organisation of necessary human activities and utterances, both personally, socially, culturally, educationally, sportily, economically, etc. Concretely, real estate offers a place to work, to learn, to train, etc.

- the domain and spatial function: The relationship of real estate with the environment in all its different levels makes it the starting and ending point of a social and economical network, in other words a meeting point in terms of accessibility, as well as a starting point for economical and social relations and activities. At the same time, it offers the option to withdraw from these.

- the communication and symbol/status function: Real estate is a medium to disseminate the (intended) own identity and the distinguishing status of the acquired social and economical position. It gives the possibility to realise a certain desired look by, for instance architecture.

- the financial/economical function: The capital intensive character, both in terms of investment needed and maintenance , implies a relation between the financial and fiscal equity position and its development. Thus, an owner who lets a property has a source of income. A user considers the costs of property as necessary within the production process.

The same functions are described in a slightly different wording by De Vries (2008). She gives a broader interpretation to the communication and symbol/status function, and includes the domain and spatial function in this category. According to De Vries, this results in only four functions. Since for real estate for education in particular the domain/spatial function is very clear, Smeets' principle will be followed.

Because it fulfils the above mentioned functions, real estate is often regarded as the fifth business resource of an organisation (Joroff et. al. 1993). Just like capital, know-how, technology, and human resources, real estate can add value by contributing to the realisation of an organisation's goals (Den Heijer, 2011). Previous literature, as summarised by De Vries et. al. (2008) shows that there are in fact two ways to improve an organisation's achievements. On the one hand by increasing the turnover, on the other hand by reducing the costs. Liow and Choulet (2008) call this the "Business perspective of CRE", with the following indicators: "costs", "profitability", and "productivity". In addition they mention "the financial perspective of CRE", which means that owning real estate influences a "firm's credit facility, its financial statements, and its operating economics.

According to Appel-Meulenbroek (2007), real estate has a direct influence on the achievements of an organisation, for instance through lower maintenance costs and reduced energy consumption, but mainly through the indirect effects that the real estate has on employees, visitors, and processes. Therefore, real estate has an important role in the process of creating value by an organisation.

In the past, several authors have defined the various interventions with regard to real estate that can influence an organisation's achievements. Veuger (2014) states that "by Corporate Real Estate Management (CREM) the real estate portfolio can be brought into line with the requirements of the core business of the corporation". His research, based on a comprehensive literature study, resulted in a number of lessons learnt from Corporate Real Estate Management. These lessons are listed in the figure below.

	13 Lessons
1	Real estate can contribute to improving an organisation's social objectives.
2	A company-specific approach to creating value from real estate management makes a greater contribution to the company's objective.
3	Making the added value measurable is essential for the role as a real estate discussion partner in a company in which strategic decisions are made.
4	Becoming more flexible in the static nature of real estate and the speed at which society develops can be addressed by consciously thinking about the longer term. Decisions need to be taken in this regard that create opportunities for future optimisation.
5	Real estate interventions and effects reinforce the organisation's objective.
6	One of CREM's jobs is to formulate and implement an optimum solution.
7	CREM is playing an important role in reducing the burden of debt and building a dominant market position.
8	Sustainable competitive advantage compared to other companies is determined by three generic strategies that do not always go together: focus, differentiation and low cost.
9	Effects follow different eventualities and depend on the organisation's starting position and culture.
10	Cause-effect chains are unclear due to influences by several factors and performances are formed by complex end-means chains.
11	Real estate interventions depend on starting position and policy choices, in which context is subject to change.
12	A target-focussed company provides more consistent reasons for real estate interventions.
13	Collaboration is necessary in order to achieve social results, in which one monopolistic arrangement cannot deliver the benefit of values. Politics also has its own dynamics and interests that can cause rational considerations to disappear into thin air.

Figure 1: Lessons learnt from Corporate Real Estate Management (Veuger 2014: 132).

This has been elaborated concretely by Lindholm et. al. (2006). It appears from the above that different interventions can influence all kinds of achievements of real estate. Real estate can be of added value for an organisation through (1) increased value of property, (2) marketing, (3) increased innovations, (4) increased satisfaction of employees, (5) increased productivity, (6) increased flexibility, and (7) reduction of costs.

After this the question who can be regarded as stakeholders of housing of primary education will be answered. Subsequently, these stakeholders will be linked to the different ways in which real estate can add value to an organisation. It is important to understand this in order to be able to weigh the interests of the stakeholders when making a decision with regard to the real estate.

3.2 Stakeholders

When deploying a building, various stakeholders can be distinguished (among others Den Heijer, 2011, De Vries, 2007, and Mobach, 2009). Generally, this mainly concerns the owners, the users, and the environment of the real estate.

From the perspective of the Corporate Real Estate Management (CREM), Den Heijer (2011) distinguishes the stakeholders according to different functional domains: Strategic (Policy makers), Financial (Controllers), Functional (Users), and Physical (Technical managers).

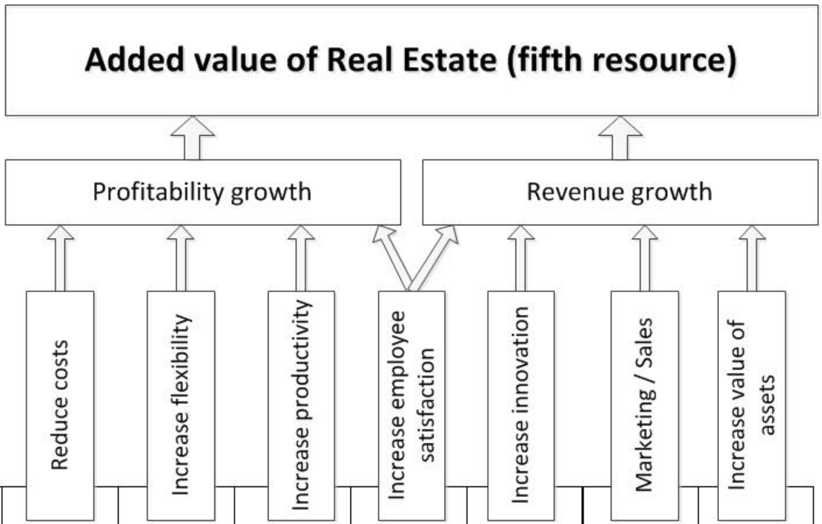
Kemperman et. al. (2013) describe creation of value as "the sustainable result for all parties" and they distinguish value for customers, value for employees, and financial value. Stakeholders of companies are individuals, groups of individuals, or organisations that are influenced by how the companies function (Van den Bosch, 1996).

Lindholm (2006) notes that an important part of the effects of CREM in practice is measured with instruments that are based on the Balanced Score Card (BSC) system, which was developed by Robert Kaplan and David Norton in 1992. Within the BSC system, four focus areas are distinguished: the financial, the managerial, the innovating, and the customer perspective. When these four perspectives are linked to the stakeholders that have been defined with respect to housing of education, it appears that the stakeholders sometimes have to do with several perspectives.

Converting this to school buildings, it seems that municipalities and school boards have interests in their role as owners, and that employees and parents and children have interest from their role as users. It is not unlikely that these stakeholder interests could overlap partly. For instance, a school board does not only have interests as an owner, but as a user as well.

It is more difficult to interpret the environment as a stakeholder of a school building. When thinking of a specific building, one could think of the immediate neighbours. On a more abstract level, one can even consider society in general, because of the significance of primary education. However, confining ourselves to the aspects that are manageable for decision makers with regard to a specific building, it concerns the immediate neighbours and the nearby area.

The above mentioned has provided a theoretical framework according to which the interests of the stakeholders of housing of primary education can be related to all possible real estate strategies. The table below shows the relation between the stakeholders and the previously mentioned strategies to add value to an organisation through real estate. The figure shows that, for most stakeholders, real estate can add value in many different ways. The figure shows the assumed relevance of the way in which real estate can add value for the different stakeholders. This assumption has been tested by means of a number of interviews with school boards, municipalities, and advisors.



Stakeholders perspective:	Reduce costs	Increase flexibility	Increase productivity	Increase employee satisfaction	Increase innovation	Marketing / Sales	Increase value of assets
Municipality	Y	Y	N	N	N	N	Y
School Board	Y	Y	Y	Y	Y	Y	N
Employees	N	Y	Y	Y	Y	Y	N
Parents/Children	N	Y	Y	Y	Y	Y	N
Environment	N	Y	N	N	Y	Y	N

Possibility to add value (Assumed):
Y: relevant for stakeholder
N: not relevant for stakeholder

Figure 2: own adaptation D. Kootstra 2015, based on Lindholm et. al., 2006

4. Empirical findings

Finally, the results based on the interviews will be given. As mentioned before, the interviews were held according to the narrative method. The only question asked was: "which type of added value should housing of primary education, seen from your perspective, have for these stakeholders: municipality, school board, employees, parents and children together, and the environment?" The different stakeholders were mentioned in the question, but not the different ways in which the building could add value for them.

This way was chosen in order to get an idea of the awareness of the different parties with regard to the possibilities of adding value to the organisation through the property. For that reason the results will be listed per strategy and not per stakeholder.

(1) Increased value of the property: Contrary to what was expected, this possibility to add value to an organisation was not mentioned in any of the interviews. Assumed was that added value could at least be found in limiting the depreciation of buildings. Considering the situation with regard to funding of housing of primary education in The Netherlands, where the municipality is the beneficial owner of the school buildings, it was expected that this possibility of adding value would be relevant for the municipalities at least.

(2) Marketing: This function of real estate is clearly recognisable in the sector of primary education. The interviews confirm clearly that a new, or at least a good-looking building "sells" to parents who are looking for a school for their child. Marketing is used in different ways though. Some school boards choose to use the building as an instrument to increase their market share. Other school boards have, from this very understanding, made agreements to divide the children over the different school buildings as well as possible, in order to get to an efficient capacity utilisation of the buildings.

The Marketing function is related to the environment as well. As said, in this research "environment" is explained as the immediate neighbours and the nearby area. In particular the municipality seems to be designated to look after the interests of the environment as a stakeholder. This is because of the steering tools a municipality has available for spatial planning. Seen from this role, the municipality can influence the location and the appearance of a school building.

Sometimes schools are placed in an accommodation where cooperation with for instance a community centre or an organisation organising activities for children is brought about. Also, a few examples were mentioned where the municipality stimulated sustainability investments. However, this was not done for financial reasons, but proceeding from a sustainability ambition.

(3) Increased innovations: Of course, the school as a "not for profit" organisation is not aiming for market innovations. The primary process is focused on childrens' learning and not on innovations. It turned out from the interviews that the stakeholders do apply innovative concepts in order to achieve education that suits modern times. With this in mind, the building teams are made up multidisciplinary. They are also advised professionally, to make sure that a new building does not just become a modernised version of an old building. Innovation as a way to increase revenues is obviously not an issue for primary schools. The benefits of an innovative building concept will mainly be reflected in the increased user satisfaction, increased productivity, increased flexibility and cost reduction, as mentioned below.

(4) Increased satisfaction of employees: The role that a building plays in the work perception of employees was recognised in most cases. As the employer, the school board is responsible for this aspect. None of the interviews have given reason to believe that savings in the form of less sick leave were associated with a higher budget for a school building though.

(5) Increased productivity: The interviews left no doubt about the role that is seen for a good building in primary education. Good housing is a condition for education. A building has to support an educational concept and through a good climate make it possible for children to keep learning and for teachers to keep teaching.

(6) Increased flexibility: This aspect is of importance at different levels. On the one hand, flexibility with regard to the needed capacity is a factor. One has to consider which capacity is needed in which phase of the "life" of the building. On the other hand, flexibility with regard to the possibility of using the building differently within education is important, so that one can move along with the changing methods of education.

(7) Reduction of costs: The interviewed professionals linked the financial aspects of housing for education to the school boards. As mentioned before, this does not concern the possibilities for

increased value of the properties, but the exploitation costs. Now that school boards since 1 January 2015 can dispose of the financial means for external maintenance of the building themselves, this aspect on the border of renovation and construction leads to discussions between municipalities and school boards more often. After all, municipalities are responsible for the expenses of construction, whereas school boards pay for renovation.

The interviews have given a clear indication that real estate, in accordance with the theoretical possibilities, is used as a means to reduce costs in the form of exploitation expenses, such as costs for energy, maintenance, and cleaning.

5. Discussion

Though the number of interviews was limited, the results still give reason to further investigate the assumed relation between real estate strategy and stakeholders. This research has made clear that the seven usual real estate strategies (in other words, ways to add value to an organisation) can very well be linked to the interests of the stakeholders of a school building. Only the strategy of adding value by increasing innovations does not seem to fit for the housing of primary education.

The interviews also made clear that "Environment" as a stakeholder could very well mean more than just the immediate neighbours, as was assumed. For instance, also the institutions that benefit from the use of school buildings after school time and children using the playground after school, could very well be seen as a different category of users.

6. Conclusions

On the basis of this research, the conclusion seems to be justified that a school building should be seen as the fifth business resource for school boards, but not for municipalities. The interviews confirm that the people involved seem to be aware of the meaning (or the added value) of real estate for the primary process. The different parties express this in very different ways.

The research has not provided any evidence that these aspects are used to apply the available funds for housing for education differently. Most remarkable is that none of those interviewed sees possibilities in the value development of the property, for instance by restricting depreciations.

The interviews also show that this possibility to create value hardly ever plays a role in a real estate strategy, or is used as an argument to increase available budgets. No indications have been found that school boards make use of a clearly defined strategy in which the investigated possibilities for adding value are used. Possibly, the parties concerned are insufficiently aware of these possibilities.

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Bus Transportation Accessibility – Does It Impact Housing Values?

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Abstract

Integrating public transportation and land use policies is one of the key strategies in an attempt to achieve more sustainable communities. While economic consequences are an essential dimension in decision making, there is yet very limited evidence for the impact of accessibility to bus transportation on surrounding residential property values. This study is the first of its kind investigating the price impact in Tampere – the largest city outside the capital region of Finland. An empirical strategy utilizing fixed-effect hedonic pricing models has been applied to specify valuation effects of accessibility to bus transportation.

A premium of 1.1 percent was estimated for housing units located no farther than 50 meters from a bus stop. Housing units located in zones with more diverse amenities and better bus connections were also estimated to be higher appreciated, with the exception that housing units in Private car zone sell at higher prices than units in Intensive public transportation zone. As Tampere is a relatively monocentric city with great coverage and service frequency of public bus transportation, the distance to CBD seems to be a more important determinant in terms of accessibility than proximity to the closest bus stop; one kilometer increase in distance to CBD was estimated to command 4 percent depreciation in housing values.

As there are significant differences between cities, some limiting factors should be taken into account when interpreting the results. Price impact on residential property values was studied only in Tampere, Finland, and it is important to notice that the city structure, extensive coverage of the bus network, local market conditions, and other potential differences between cities may have a notable impact on the outcomes. Thus, more studies are needed before the results may be generalized across other geographical locations.

The evidence gained in this study can be utilized when striving for more viable and sustainable cities. Understanding the influence of accessibility to bus transportation on housing values should be of interest to a wide range of city planners, policymakers, and community stakeholders.

Keywords: bus stops, bus traffic, housing prices, public transportation, residential property values, traffic related zones, urban form

1. Introduction

Integrating public transportation and land use policies has been identified as one of the key strategies in an attempt to achieve more sustainable communities (Newman and Kenworthy, 1996; Todes, 2012). It has also been recognized that public transportation investments and land use policies may induce changes in housing prices. (Du and Mulley, 2006; H.M. So et al., 1997; Henneberry, 1998).

Accessibility of public transportation is one of the factors taken into account when city planners are searching for to identify potential locations for new housing. In addition to their influence on land use decisions, public transportation stops may also impose externalities capitalizing into housing prices (Cervero and Kang, 2011). Previous studies have found that investments in public transportation may – particularly within walking distance – command a premium in housing prices (Dubé et al., 2013). However, Mohammad et al. (2013) suggest that due to researchers' tendency to publish only statistically significant results, published literature may introduce a biased general view of housing price effects from bus transportation.

Property value effects may depend on income level of residents in the area (Munoz-Raskin, 2010). Osland and Thorsen (2008) argue that there are two important components of accessibility that should be taken into consideration when estimating housing price effects. The first component is accessibility to central business district (CBD) where urban attractions are located, and most of activities occur. The second major component is recognized to be labor-market accessibility as commuting to work places is a central part of people's daily lives.

Public transportation connections are usually relatively stable, which may promote their propensity for capitalizing into housing values. However, the propensity may be dependent on transportation technology. A subway or suburban train is usually associated with higher appreciation in housing prices than bus connections (Bocarejo et al., 2013). The reasoning behind this may be that rail traffic always requires heavy infrastructure and substantial investments, resulting in relatively permanent structures. While, it is much harder to predict future development of bus connections as substantial investments on infrastructure are not needed, and thus, the system is more flexible for changes. Consequently, the impact of bus connections on housing prices may be less than what alternative forms of public transportation would induce.

Given that both positive and negative estimates of land and property values have been reported in different studies investigating rail project impacts (Mohammad et al., 2013), it is not self-evident that the impact from public transportation would only be positive. Although improvements in accessibility are likely to induce positive impacts, also a number of negative externalities, such as increase in noise and crime, can be linked to a better access to public transportation (Pope and Pope, 2012; Szczepańska et al., 2015). Attempts to control traffic volume by road tolls has been reported to have minor positive impact at least on residential leases which may result from decrease in negative externalities (D'Arcangelo and Percoco, 2015).

To date, there are relatively few studies investigating the impact of public transportation on housing values in developed countries. Mulley (2014) argues that, presently, there is a lack of evidence for the residential land value impact of bus networks in the developed countries. Particularly, the housing price impact from bus transportation in the Nordic Countries is underexplored. This study contributes to the existing body of literature, addressing the void in knowledge by investigating the impact of accessibility to bus transportation on housing prices in Tampere, Finland.

2. Data and Public Transportation System in Tampere

The data utilized in this study is from the city of Tampere in Finland – the largest urbanized area outside the capital region and home to more than 220,000 residents by the end of December 2015. Tampere is also the provincial center of Pirkanmaa region with slightly more than 500,000 residents. Tampere is an example of a quite monocentric city as for its bus network. Interestingly, the city center can be accessed through almost every bus line with only a couple of exceptions that do not pass through the city center. The public transportation system is mainly based on busses as there are no subways or streetcars. Tampere railway station is one of the central hubs in the Finnish railway network. However, the only stop for passenger trains is the Tampere central railway station located in the city center. Thus, in Tampere, the railway network only serves transportation to other cities and municipalities, but not the local traffic within the city limits. As the public transportation is relying on busses, Tampere is a potential geographical location to be studied to reveal the relevance of bus network to housing prices.

The impact of accessibility to bus transportation on residential property values was investigated by utilizing five unique datasets, including i) housing sales transactions from 2008 to 2012, ii) complete property registry for the city of Tampere, iii) spatial boundaries for traffic related zones of urban form (©SYKE), iv) locations of bus stops in the city of Tampere, and v) grid data containing information on residents' median income (©SYKE and TK). The spatial nature of the data allowed all five data sets to be combined using locational attributes.

The Finnish housing market is diverse in nature with property types ranging from single-family detached to multifamily apartment blocks. The average housing unit was constructed 39.8 years ago and sold for €137,047 (or €2,179 per square meter for a 62.9 square meter unit). The average number of rooms was 2.4 including bedrooms, living rooms, and studies, but not kitchens, bathrooms, private saunas, and walk-in closets. Private saunas are an important amenity, associated with 45 percent of the apartments sold. Housing transactions occurred on average in areas where the annual median income is 32,997 € and distance to Tampere Central Square is 4.42 kilometers. 63 percent of sold apartments were considered to be in good condition, whereas brokers reported 22 percent to be in acceptable condition and 1 percent in poor condition. Condition for 14 percent of the observations was not reported. 2 percent of the sold apartments were located in properties that have an elevator. The average distance to a bus stop was 137 meters. 22 percent of the transactions were located in Pedestrian friendly zone, 1 percent in Fringe zone, 19 percent in Public transportation zone, 9 percent in Private car zone, and 5 percent in Suburban center zone. The remainder of 44 percent was located in Intensive public transportation zone, which was the comparison level for the analysis. Table 1 presents summary statistics for the residential transactions.

Table 1: Summary statistics

Variable	*Mean*	*Std dev*	*Min*	*Max*
Sale price (€)	137,047	63,451	40,000	750,000
Property age (years)	39.8	20.1	5	160
Unit size (sq. meters)	62.9	23.9	15	275
Weeks on market	38.1	25.7	1.0	104.0
Number of rooms	2.4	1.0	1.0	8.0
Maintenance dues (€)	163	67	0.0	867.0
Floor number	2.6	1.8	1.00	12.00
I{Multi-story apartment block}	0.79	0.41	0	1
I{Townhouse}	0.17	0.38	0	1
I{Single-family house}	0.02	0.14	0	1
I{Duplex}	0.02	0.14	0	1
I{Sauna}	0.45	0.50	0	1
I{Elevator}	0.02	0.16	0	1
Income	32,997	13,234	9305	105796
Distance to CBD (km)	4.42	2.77	0.06	10.81
I{Condition: Acceptable}	0.22	0.41	0	1
I{Condition: Poor}	0.01	0.12	0	1
I{Condition: Unavailable}	0.14	0.35	0	1
I{Pedestrian zone}	0.22	0.41	0	1
I{Fringe zone}	0.01	0.12	0	1
I{Public transport zone}	0.19	0.39	0	1
I{Private car zone}	0.09	0.29	0	1
I{Suburban center zone}	0.05	0.22	0	1
I{Not within a zone}	0.12	0.32	0	1
Distance to bus stop (m)	137.49	86.56	7	756
I{Bus stop within 50 meters}	0.11	0.31	0	1
I{Bus stop within 100 meters}	0.38	0.49	0	1
I{Bus stop within 150 meters}	0.65	0.48	0	1
I{Bus stop within 300 meters}	0.95	0.21	0	1

Notes: This table presents the means, standard deviations, minimum and maximum values for the full sample of residential transactions. Price is the transaction price for residential units, in Euros (€). Time on market is measured in weeks. Building size and Unit size are measured in square meters. Property age is in years. Floor number is for the unit. The I{·} operator designates an indicator variable, taking on a value of one for the characteristic in brackets and zero otherwise. Property types included in the analysis are Duplex, Single-family (detached), Townhouse, and Multifamily (suppressed). Property condition categories include Acceptable, Poor, Unavailable and Good (suppressed). Maintenance dues are reported as monthly fees in Euros, and take on a value of zero for units in buildings that have no maintenance dues.

3. Estimating housing price impact

The empirical strategy in this study was to estimate a hedonic regression model for residential transaction prices. The objective was to evaluate price differences between different traffic related zones of urban form, and isolate the impact that proximate bus stop has on surrounding housing values while controlling for differences in property characteristics. The first estimated hedonic equation takes the following form:

$$\begin{aligned}\ln(\textit{Price}) = {} & \beta_0 + \beta_1 \cdot \ln(\textit{Property age}) + \beta_2 \cdot \ln(\textit{Unit size}) + \beta_3 \cdot \ln(\textit{Time on market}) \\ & + \beta_4 \cdot \ln(\textit{Number of rooms}) + \beta_5 \cdot \ln(\textit{Maintenance dues}) + \beta_6 \cdot \textit{Floor number} \\ & + \beta_7 \cdot \mathrm{I}\{\textit{Type: Single family}\} + \beta_8 \cdot \mathrm{I}\{\textit{Type: Townhouse}\} + \beta_9 \cdot \{\textit{Type: Duplex}\} \\ & + \beta_{10} \cdot \mathrm{I}\{\textit{Sauna}\} + \beta_{11} \cdot \mathrm{I}\{\textit{Elevator}\} + \beta_{12} \cdot \ln(\textit{Income}) + \beta_{13} \cdot \mathrm{I}\{\textit{Condition: Acceptable}\} \\ & + \beta_{14} \cdot \mathrm{I}\{\textit{Condition: Poor}\} + \beta_{15} \cdot \mathrm{I}\{\textit{Condition: Unavailable}\} + \beta_{16} \cdot \text{Distance to CBD} \\ & + \beta_{17} \cdot \mathrm{I}\{\textit{Pedestrian zone}\} + \beta_{18} \cdot \mathrm{I}\{\textit{Fringe zone}\} + \beta_{19} \cdot \mathrm{I}\{\textit{Public transportation zone}\} \\ & + \beta_{20} \cdot \mathrm{I}\{\textit{Private car zone}\} + \beta_{21} \cdot \mathrm{I}\{\textit{Suburban center zone}\} + \beta_{22} \cdot \mathrm{I}\{\textit{Not in the zone}\} \\ & + \beta_{23} \cdot \mathrm{I}\{\textit{Distance to bus stop}\} + \textstyle\sum_{i=1}^{4} \beta_{i+23} \cdot \mathrm{I}\{\textit{Year}_i\} + \textstyle\sum_{j=1}^{31} \beta_{j+27} \cdot \mathrm{I}\{\textit{Submarket}_j\} + \varepsilon. \qquad (1)\end{aligned}$$

The dependent variable is *Price*, logged. *Property age* is included to reflect the impacts of depreciation and technical obsolescence on housing values. Variables measuring the physical property dimensions include *Unit size*, *Number of rooms*, and *Floor number*. *Time on market* reflects one dimension of real estate marketing outcomes, and *Maintenance dues* reports monthly financial obligations connected to the property sale. *Distance to CBD* captures locational impacts, measuring distance to the Tampere Central Square. Indicator variables are used to classify property pricing according to property type, sauna, elevator and property condition. The sample of property sales spans from 2008 to 2012, and 4 year indicator variables are included to control for calendar year fixed effects. In addition, 31 submarket indicator variables are included to control for geographic differences in pricing at the zip code level. β are parameters to be estimated and ε is the normally distributed error term.

To capture the impact of different traffic related zones of urban form[1] on residential property values, five indicator variables are included for housing units that are located in *Pedestrian zone*, *Fringe zone*, *Public transportation zone*, *Private car zone*, or *Suburban center zone*. Indicator for *Intensive public transportation zone* is suppressed from the equation to refrain from linear combination. Variable *I{Not within a zone}* is included to capture pricing difference for housing transactions that are not located within any of the above mentioned zones. The log-linear model structure allows the coefficients for included traffic related zone indicators to be interpreted as the percentage difference in housing values to residential transactions occurred in

[1] The classification of traffic related zones of urban form is based on a spatial dataset by the Finnish Environment Institute (SYKE). For a detailed description, please see the Meta Data Portal: http://metatieto.ymparisto.fi:8080/geoportal/catalog/search/resource/details.page?uuid={96F338EA-75AF-432C-A780-31A3CDECBDF2} (in Finnish).

the *Intensive public transportation zone*. Furthermore, *Distance to bus stop* variable is included to isolate the impact of proximity to a bus stop. Results from the estimation of Equation (1) are presented in Table 2.

Table 2: Estimated price impact

Variable	*Coefficient*	*(t-stat)*
Intercept	8.831 ***	(150.9)
ln(Property age)	-0.144 ***	(-51.5)
ln(Unit size)	0.669 ***	(79.6)
ln(Weeks on market)	-0.013 ***	(-8.7)
ln(Number of rooms)	0.051 ***	(7.7)
ln(Maintenance dues)	-0.012 ***	(-5.1)
Floor number	0.010 ***	(12.9)
I{Townhouse}	0.177 ***	(38.3)
I{Single-family house}	0.266 ***	(18.3)
I{Duplex}	0.232 ***	(25.2)
I{Sauna}	0.131 ***	(36.6)
I{Elevator}	-0.001	(-0.1)
ln(Income)	0.065 ***	(13.6)
I{Condition: Acceptable}	-0.109 ***	(-36.7)
I{Condition: Poor}	-0.207 ***	(-21.3)
I{Condition: Unavailable}	-0.044 ***	(-12.3)
Distance to CBD	-0.040 ***	(-17.6)
I{Pedestrian zone}	0.125 ***	(12.0)
I{Fringe zone}	0.093 ***	(6.4)
I{Public transportation zone}	-0.023 ***	(-6.4)
I{Private car zone}	0.021 ***	(3.9)
I{Suburban center zone}	0.027 ***	(4.2)
I{Not within a zone}	-0.004	(-0.5)
Distance to bus stop	0.000	(-0.0)
Year indicators:	Included (4 variables)	
Sub-market indicators:	Included (31 variables)	
Adjusted R^2:	90.97%	
Observations:	12,449	

Notes: This table presents results from the least squares estimation of Equation (1). The dependent variable is Price, logged. The coefficients for I{*Pedestrian zone*}, I{*Fringe zone*}, I{*Public transportation zone*}, I{*Private car zone*}, and I{*Suburban center zone*} indicate the estimated price impact of traffic related zones of urban form. The coefficient for *Distance to bus stop* variable indicates the estimated price impact of distance to the closest bus stop. T-statistics corresponding to the coefficients are reported in parentheses. ***, ** and * designate statistical significance for the estimated coefficients at the 1%, 5% and 10% levels, respectively.

The estimated coefficients reveal that housing values are decreasing as properties age, likely resulting from depreciation and technical obsolescence. Housing values are increasing in unit size, but units that require longer marketing periods are revealed to sell at a significantly lower price. Units with higher maintenance dues are discounted. Units on higher numbered floors sell at a premium, estimated at 1 percent per floor. Single-family, duplexes, and townhouses all sell at positive and significant premiums relative to multifamily apartments (which is suppressed to avoid perfect multicollinearity). In Finland, the sauna is considered a precious amenity, associated with premiums in the magnitude of 13 percent. Elevator does not command a positive premium, which might not be the case if only transactions in multi-story apartment buildings were investigated. Higher median income is associated with higher housing values as wealthier people tend to live in higher appreciated neighborhoods. Housing units located farther from CBD (Tampere Central Square) sell at lower prices, so that 1 kilometer increase in distance commands 4 percent depreciation. Property condition identified as less than good (which is omitted to avoid linear combination) are discounted accordingly.

Estimates of indicator variables for traffic related zones of urban form reveal that housing prices are relatively highest in the Pedestrian zone, which usually indicates location in downtown area, and is associated with 12.5 percent premium relative to Intensive public transportation zone. In Fringe zone premium is estimated to be 9.3 percent, in Suburban center zone 2.7 percent, and in Private car zone 2.1 percent relative to Intensive public transportation zone. While, housing units located in Public transportation zone with weaker public transportation connections than in Intensive public transportation zone sell at 2.3 percent lower prices.

The coefficient for *Distance to bus stop* does not differ from zero, indicating that proximity to bus stop does not have an impact on housing values. However, the price impact is not likely to be linear resulting in that the continuous variable may not tell the whole truth. To further investigate the price impact of proximity to a bus stop another specification of the model was estimated. The second specification of the model takes the following form:

$$\begin{aligned}\ln(\textit{Price}) = {} & \beta_0 + \beta_1 \cdot \ln(\textit{Property age}) + \beta_2 \cdot \ln(\textit{Unit size}) + \beta_3 \cdot \ln(\textit{Time on market}) \\ & + \beta_4 \cdot \ln(\textit{Number of rooms}) + \beta_5 \cdot \ln(\textit{Maintenance dues}) + \beta_6 \cdot \textit{Floor number} \\ & + \beta_7 \cdot I\{\textit{Type: Single family}\} + \beta_8 \cdot I\{\textit{Type: Townhouse}\} + \beta_9 \cdot \{\textit{Type: Duplex}\} \\ & + \beta_{10} \cdot I\{\textit{Sauna}\} + \beta_{11} \cdot I\{\textit{Elevator}\} + \beta_{12} \cdot \ln(\textit{Income}) + \beta_{13} \cdot I\{\textit{Condition: Acceptable}\} \\ & + \beta_{14} \cdot I\{\textit{Condition: Poor}\} + \beta_{15} \cdot I\{\textit{Condition: Unavailable}\} + \beta_{16} \cdot \text{Distance to CBD} \\ & + \beta_{17} \cdot I\{\textit{Pedestrian zone}\} + \beta_{18} \cdot I\{\textit{Fringe zone}\} + \beta_{19} \cdot I\{\textit{Public transportation zone}\} \\ & + \beta_{20} \cdot I\{\textit{Private car zone}\} + \beta_{21} \cdot I\{\textit{Suburban center zone}\} + \beta_{22} \cdot I\{\textit{Not in the zone}\} \\ & + \beta_{23} \cdot I\{\textit{Bus stop close}\} + \textstyle\sum_{i=1}^{4} \beta_{i+23} \cdot I\{\textit{Year}_i\} + \sum_{j=1}^{31} \beta_{j+27} \cdot I\{\textit{Submarket}_j\} + \varepsilon. \qquad (2)\end{aligned}$$

The second specification is consistent with Equation (1) with the difference that the continuous variable *Distance to bus stop* is replaced with an indicator variable *I{Bus stop close}*. To understand the price impact of proximity to a bus stop, four separate variations of the model were estimated. All four estimated models are consistent with Equation (2), and the difference is that each one has unique definition for a proximate bus stop. The following radii for proximity are estimated: 50 m, 100 m, 150 m, and 300 m.

Results from the estimation of Equation (2) for the 50 m, 100 m, 150 m, and 300 m radii are presented in Table 3. In the interest of brevity, only estimates for I{*Bus stop close*} are reported in Table 3 as the remainder of coefficient estimates is consistent with the results in Table 2. Testing various radii for proximity reveals that better accessibility to public transportation commands a premium which diminishes relatively fast with distance. Housing units located within 50 meters from a bus stop sell at 1.1 percent higher prices, but statistical significance seems to disappear already beyond 50 meters. Interestingly, the coefficient for 300 m radius indicates that transactions within 300 m radius from a bus stop are discounted 1.4 percent relative to observations that are located farther away. At this point it is important to notice that only 5 percent of the housing transactions are not located within 300 meters from a bus stop, potentially resulting in a bias. Thus, it is likely that the estimated negative price impact cannot directly be associated with proximity to a bus stop, but rather captures price impact from other factors.

Table 3: Estimated price impact, Equation (2)

Radius for close proximity:	**50 m**			**100 m**		**150 m**		**300 m**		
Variable	*Coefficient*		*(t-stat)*	*Coefficient*	*(t-stat)*	*Coefficient*	*(t-stat)*	*Coefficient*		*(t-stat)*
I{Bus stop close}	0.011	***	(3.0)	0.000	(0.2)	0.004	(1.3)	-0.014	**	(-2.1)
Year indicators:	Included (4 variables)									
Sub-market indicators:	Included (31 variables)									
Adjusted R^2:	90.98%			90.97%		90.97%		90.97%		
Observations:	12,449			12,449		12,449		12,449		

Notes: This table presents results from the least squares estimation of Equation (1) for the 50 m, 100 m, 150 m and 300 m radii. The dependent variable is Price, logged. The coefficient for I{*Bus stop close*} indicator variable indicates the estimated price impact of proximity to a bus stop. T-statistics corresponding to the coefficients are reported in parentheses. *** and ** designate statistical significance for the estimated coefficients at the 1% and 5% levels, respectively.

It is reasonable to assume that price impact from proximity to a bus stop may vary between different locations. Thus, to investigate interactions between distance to a bus stop and location in different traffic related zones of urban form, the third and fourth specifications of the hedonic model were estimated. The third specification is consistent with Equation (1) with the difference that six interaction terms are included to capture the joint impact of each traffic related zone and distance to bus stop. Also interaction term *Dist to bus stop**Dist to CBD* is included to capture if the price impact from the distance to a bus stop differs with the distance to Tampere Central Square. The fourth estimated specification of the hedonic model is consistent with Equation (2), but with the difference that six interactions terms are included to capture the joint impact of each included zone indicator and the indicator variable for a proximate bus stop. Results from the estimations of the third and fourth model specifications suggest that price impact may vary between traffic related zones, but due to inconsistencies drawing reliable conclusions based on the results is difficult. The issue behind the inconsistent results is likely to derive from that the third and fourth model specifications divide the full data sample into several subgroups. This results in too small and unevenly distributed subsamples, potentially introducing a bias in the results.

4. Conclusions and Discussion

Although economic consequences are an essential dimension in decision making, yet little is known about the impact of accessibility to bus transportation on housing values. In this study, the void in knowledge was addressed investigating the bus transportation related housing price impact in Tampere, Finland. An empirical strategy utilizing fixed-effect hedonic pricing models was applied.

Results from the estimations indicated that there are statistically significant valuation differences between traffic related zones. The analysis was performed relative to *Intensive public transportation zone*, and estimates revealed that housing prices are relatively highest in the Pedestrian zone, usually indicating location in downtown areas. In Pedestrian zone, housing prices were estimated to be 12.5 percent higher than in Intensive public transportation zone. In Fringe zone, usually located in close proximity to downtown areas, the premium was estimated to be 9.3 percent, in Suburban center zone 2.7 percent, and in Private car zone 2.1 percent relative to Intensive public transportation zone. While, housing units located in Public transportation zone with weaker public transportation connections than in Intensive public transportation zone sell at 2.3 percent lower prices. In an attempt to capture the price impact of distance to the closest bus stop with a continuous *Distance to bus stop* variable, no statistically significant price difference was found. However, testing another model specification utilizing indicator variables, a premium of 1.1 percent was found for housing units located no farther than 50 meters from a bus stop. *Distance to CBD* (Tampere Central Square) was estimated to be an important determinant for housing prices as one kilometer increase in distance results commands 4 percent depreciation in housing values.

The estimation results are in line with assumptions, given that Tampere is a relatively monocentric city with notably extensive bus transportation network; almost every bus line passing through the city center, and 95 percent of the housing transactions being located no farther than 300 meters from the closest bus stop. Due to the great coverage and service frequency of public bus transportation, the CBD is relatively easy to access from anywhere within the city limits. Thus, in Tampere, the distance to CBD seems to be a more important determinant in terms of accessibility than location of the closest bus stop. Valuation of traffic related zones is also mainly consistent with the assumptions as housing units located in zones with more diverse amenities and better bus connections are higher appreciated, with the exception that housing units in Private car zone sell at higher prices than units in Intensive public transportation zone. However, this observation is logical as Private car zone can be associated with comfortable and secure suburban neighborhoods where owner-occupied single-family houses are the predominant form of housing. In this kind of neighborhoods, bus transportation is of less importance as wealthier suburban residents often choose to use their own cars.

This study is the first of its kind investigating the impact of accessibility to bus transportation on housing values in the largest city outside the capital region of Finland. The results do not provide any big surprises but rather confirm authors' presumptions. However, as there are significant differences between cities, some limiting factors should be taken into account when interpreting the results. Price impact on residential property values was studied only in Tampere, Finland, and it is important to notice that the city structure, extensive coverage of the bus network, local market conditions, and other potential differences between cities may have a notable impact on the outcomes. Thus, more studies are needed before the results may be generalized across other geographical locations. In this study, the price impact was studied using Euclidean distance between the housing unit and bus stop. However, in reality, the accessibility to a bus stop is a much more complicated phenomenon than distance measured as the crow flies (Kang, 2015).

To improve the analysis, it might be useful to use a more advanced approach to define accessibility in further research. For example, accessibility could be defined more precisely taking into consideration the actual characteristics of the surrounding neighborhood. The analysis could also be extended to cover more detailed information on which bus lines serve the proximate bus stop, how often the busses arrive, which areas can directly be accessed via the bus stop, and what is the average driving time to the destination. Adding these above mentioned dimensions in the analysis would allow better understanding of the actual accessibility and its impact on housing values. Also alternative empirical strategies, such as geographically weighted regression (GWR) or combining matched sample methodologies with the hedonic regression, could be applied in an attempt to improve the analysis.

The evidence gained in this study can be utilized when striving for more viable and sustainable cities. Understanding the influence of accessibility to bus transportation on housing values should be of interest to a wide range of city planners, policymakers, and community stakeholders.

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Towards an Integrated Value Adding Management Model for FM and CREM

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Abstract

Purpose: To present an integrated process model of adding value by Facilities Management (FM) and Corporate Real Estate Management (CREM) that is a generalisation of existing conceptual frameworks and aims to be a basis for management of added value in practice.
Background: The growing research on the added value of FM and CREM over the last decade has resulted in the development of several conceptual frameworks and the collection of much empirical data in practice. However, the practical application of current knowledge has shown to be limited and difficult. The reasons seem to be that the different frameworks are too complex and lack of common terminology and clear operationalisations of intervention-impact relationships.
Approach (Theory/Methodology): A generalised Value Adding Management process model is developed based on a common cause-effect model identified in existing conceptual frameworks combined with the basic process model of input → throughput → output. The proposed model consists of interventions as input, management of implementation as throughput and added value as output/outcome.
Results and practical implications: The Value Adding Management model provides a simple framework which aims at supporting the practical management and measurement of added value. A typology with six types of FM/CREM interventions is developed from earlier research. The concept of Value Adding Management is investigated and the 12 most important added value parameters are identified.
Research limitations: The process model still has to be tested on its empirical validity and practical applicability. This is being done and will be presented in a forthcoming book on how to manage and measure value adding by FM and CREM.
Originality/value: The Value Adding Management process model condensates research in an original and simple model with the potential to make value adding management more applicable in practice.

Keywords: Facilities Management, Corporate Real Estate Management, Interventions, Value Adding Management, Added Value.

1. Introduction

Facilities Management (FM) and Corporate Real Estate Management (CREM) are two closely related and relatively new management disciplines with developing professions worldwide and which attract increasing academic attention. Both disciplines have from the outset had a strong focus on controlling and reducing cost for property, work space and related services. In recent years there has been a change towards putting more focus on how FM/CREM can add value to the organisation. The growing research on the added value of FM and CREM has resulted in the development of several conceptual frameworks and collection of much empirical information. However, the practical application of this knowledge has shown to be limited and difficult. The reasons seem to be that the different frameworks are too complex and lack of common terminology and clear operationalisations of input-output/outcome relationships.

The purpose of this paper is to present an integrated process model of adding value by FM and CREM which builds onexisting conceptual frameworks and aims to be a basis for value adding management in practice. The paper is related to a forthcoming book, where the model is further explained and validated. It is the result of work in a EuroFM research group established in 2009. The paper is mostly conceptual, but it is based on a huge amount of research and empirical evidence.

2. Conceptual Model

2.1 Existing Conceptual Frameworks

When the research group began there were 3 conceptual frameworks that formed the starting point. One framework was the FM Value Map developed in Denmark by Jensen (2008 and 2010). The other frameworks were more related to CREM. One CREM framework was developed in Finland by Sarasoja – then Lindholm (Lindholm and Leväinen, 2006). The other was developed in the Netherlands by De Vries (De Vries et al., 2008). A fourth framework was later developed in the Netherlands by Den Heijer (2012) - partly based on the framework of De Vries, but redesigned in a different form and extended with various other value parameters.

The FM Value Map and the framework by De Vries both include a basic process model based on input → throughput → output, but in a different way. In the FM Value Map the process model refers to processes in FM and not in the core business, with input being FM resources, the throughput being FM processes and output being FM provisions. The logic of the FM Value Map is that the FM provisions as outputs can lead to different types of outcomes i.e. impacts on added value parameters related to core business and the surroundings and various stakeholders. The distinction between FM as a support function to a core business is a fundamental part of much theory on FM – although not undisputed. This distinction is even included in the definition of FM in the first European FM standard (CEN, 2006) using the term primary activities as representing the core business.

In the framework of De Vries the process model is related to the overall business organisation and business processes and various stakeholders as well; there is no distinction of a separate CREM process as such. The inputs are divided in 5 general business resources: Human Resources, Technology, Information, Capital, and Real Estate, referring to real estate as the fifth resource (Joroff et al., 1993). Embedded in the process model is a brief overview of real estate interventions that may lead to different types of influences (added values) on the business process and business outputs. The model can be seen as a cause-effect model similar to the outputs leading to impacts in the FM Value Map. The framework of Anna-Liisa Sarasoja does not in a similar way include a process model, but it is basically structured as a cause-effect model with real estate decisions and operation leading to different types of added values that cumulate into increased shareholder value.

2.2 The Value Adding Management Model

In the conceptual frameworks mentioned above a general process model can be recognized:

Input → Throughput → Output → Outcome → Impact = Added Value

We can also identify an underlying cause-effect model that is included in all the four conceptual models with different wordings as shown in Table 1.

Table 1: Cause-effect model in the 4 conceptual frameworks

Framework	***Cause***	***Effect***
FM Value Map	*Provisions / Output*	*Impact / Outcome*
Sarasoja	*Real estate decisions and operation*	*Added Value*
De Vries	*Real estate intervention*	*Influence / Added Value*
Den Heijer	*Real estate projects / Input*	*Added Value / Performance*

By combining the general process model with the cause-effect model and including value adding management as the intermediary between cause and effect we can define the generalised Value Adding Management process model: Intervention → Management → Added Value.

Intervention is used as the general term for cause and Added Value is used as the general term for effect. This model is very simple and combines essential aspects of the different conceptual frameworks supplemented with the management of implementing the intervention to ensure that the FM/CREM interventions lead to added value for the organisation. In relation to the general process model the focus in the generalised Value Adding Management process model is on how output by appropriate management can lead to outcome and added value.

This is equivalent to: Decision on type of change → Implementation → Outcome/Impact.

And also to: What → How → Why.

What is the kind of change and the improvement FM/CREM intends to make to add value; *how* is the way FM/CREM manages the change and implements the improvement and *why* is the benefit the core business organisation is expected to achieve i.e. the positive outcome of benefits versus sacrifices in terms of costs, time and risks.

The three elements in the Value Adding Management model as presented above can be seen as "black boxes". In the following section we will open each of these black boxes and reveal what they contain in a FM and CREM context.

3. Opening the Black Boxes

3.1 FM and CREM Interventions

This sub-section explains the first part of the generalised Value Adding Management model called "Intervention" or "Decision on type of change". It presents a typology of FM and CREM interventions based on earlier research consisting of the following six types of FM and CREM interventions:

1. Changing the physical environment (on different scale levels: portfolio, building, space)
2. Changing facilities services
3. Changing the interface with core business
4. Changing the supply chain
5. Changing the internal processes
6. Strategic advice and planning

Changing the Physical Environment

The physical environment is essential to both FM and CREM. It includes buildings, internal and external spaces, technical services (installations), indoor climate, fitting out, furniture, workplaces, technology, artwork and ambience. Typical examples of changing the physical environment include:

- Moving to another location (new or existing building)
- New building
- Rebuilding, refurbishment or adaptive re-use i.e. conversion to new functions
- Changing workplace layout, e.g. conversion of a cellular office with personal desks to an activity-based work setting with shared use of a variety of task-related workspaces
- Changing appearance, e.g. to support corporate branding

Changing Facilities Services

The facilities services are the operational FM activities. In the European standard on taxonomy for FM (CEN, 2011) the facilities services are divided in demand related to Space & Infrastructure and demand related to People & Organisation with both categories sub-divided in standardised facility products as shown in Table 2. The standardised facility products Space and Workplace in the table are partly overlapping with Changing the physical environment, but the physical environment basically concerns tangible artefacts, while the facilities services mostly concerns intangible service activities.

Table 2: FM taxonomy with standardised facility products (CEN, 2011)

Demand related to	***Standardised facility product***
Space & Infrastructure	*Space (Accommodation)*
	Outdoors
	Cleaning
	Workplace
	Primary activities specific
People & Organisation	*HSSE (Health, Safety, Security and Environment)*
	Hospitality
	ICT (Information and Communication Technology)
	Logistics
	Business Support (Management Support)
	Organisation specific

Changing the Interface with Core Business

When organisations reach a certain size and complexity, FM and CREM are typically established as separate functions or departments. The interface between the core business and FM/CREM is defined specifically in each organisation and is not static. If the FM/CREM function is successful, it will in many cases get the opportunity to increase its area of responsibility. This is often part of a centralisation of the responsibility from several parts of the core business organisation to the FM/CREM function, thereby creating opportunities for economies of scale.

Changing the Supply Chain

FM is in most cases organised as a mixture of an in-house FM-function and a number of external providers of facilities services, which constitutes a FM supply chain. The situation is to some degree similar for CREM, but the CREM supply chain is more project-related and mostly consists of consultants, designers and contractors. Changes in the supply chain are primarily changes in the delivery process, but they often also have consequences for the incentives for the different parties and the management of the mutual relationships between the parties. The number of external providers varies a lot depending on the type of company and the sourcing strategies. Outsourcing in FM has over the last decades been constantly increasing in most countries and is a common way to achieve cost reductions. Even though the general trend is towards more outsourcing in most countries, there are also many examples of insourcing of former outsourced services.

Changing the Internal Processes

What we deal with here is increasing the efficiency of operational processes within a specific organisation without necessarily changing, neither the product, nor the supply chain. The organisation can be in-house or an external provider. Within management theory and practice there are a number of concepts aimed at increasing productivity and process efficiency, for instance Total Quality Management, Business Process Re-engineering, Benchmarking and Lean Management. Typical elements in such concepts are eliminating waste, implementing new technological solutions and optimising the work flow. Many companies conduct projects by using such concepts and the FM function is often included in the project. Many provider companies also work systematically with developing process innovations. This is also the case for some of the larger in-house organisation.

Strategic Advice and Planning

Strategic advice and planning are essential elements in the strategic and tactical activities of FM and CREM. The areas for strategic advice and planning can cover many different aspects and they will typically change over time according to what is of strategic importance for the company. A typical area of strategic advice to top management concerns the development of a long-term strategy for the corporate property portfolio. This requires a profound and up to date understanding of the overall corporate strategy to identify the future demand for property and close dialogue with evaluation of options, scenarios and proposals concerning the future supply of property. Another typical area is investment planning and feasibility studies, which concerns decision support on choosing between alternative options for fulfilling a need for changes in the capacity of space or similar. This can for instance be whether the company should extend existing facilities, relocate, build new building, sell or buy property, rent or rent out space.

3.2 Value Adding Management

This sub-section explains the second part of the generalised Value Adding Management model called “Management” or “Implementation”.

The term “Value Adding Management” and related terms are widely used in business and management literature. In manufacturing related literature “Value Adding Management” or VAM is often used in a way close to Lean Management with a focus on eliminating non-value adding or “waste” activities. However, VAM is also seen as part of an overriding strategy, where the corporate mission is *what* and VAM is *how* (Anonymous, 2014). This resembles our generalised Value Adding Management model, but there is no mentioning of *why***,** except indirectly with including “value adding” in the term. The industrial consultant Carlo Scodanibbio even calls VAM the philosophy of the second industrial revolution and the guiding light for the year 2000 industries (Scodanibbio, 2014).

It relation to FM and CREM essential aspects of VAM are strategic alignment between FM/CREM and core business and stakeholder management and relationship management as part of the implementation of changes. Here we will solely focus on strategic alignment. Aligning, in an active sense, implies moving in the same direction, supporting a common purpose, being synchronized in timing and direction, being appropriate for the purpose and in a passive sense, the absence of conflict (Then et al., 2014).

Figure 1 connects the terms alignment and added value to show that corporate real estate only adds value when its supports the organisational objectives. It shows that alignment of the accommodation and building related facilities and services requires a thorough understanding of the organisational strategy and its structure, culture, primary processes and so on. When the FM/CREM department develops its mission, vision and strategy, this should be done in connection to the mission, vision and strategy of the organisation. FM/CREM interventions should not only be checked on its impact on FM/CREM performance and organisational performance, but also on its impact on attaining organisational goals. A better performance does not per definition deliver added value. For instance, if an FM intervention results in a higher ranking on "green buildings" but the organisation was fully satisfied with the original ranking, this higher ranking does not add any value to the organisation.

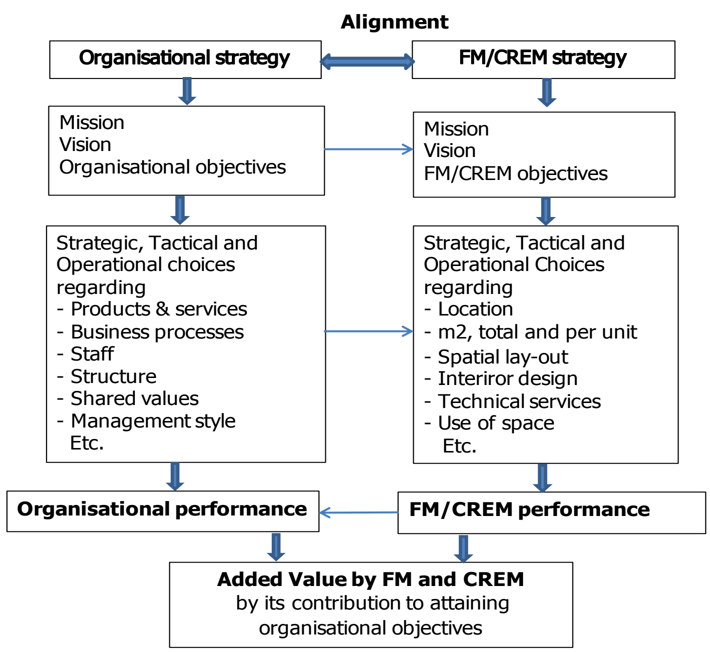

Figure 1: Connections between alignment and adding value (Van der Voordt, 2014)

3.3 Added Value Parameters

This sub-section explains the third part of the generalised Value Adding Management model called "Added Value". Table 3 presents an overview of the value parameters that were discussed in various studies and which have been classified in the six categories of performance measurement mentioned by Bradley (2002). With the division of the category Organisational development in 5 sub-groups table 3 provides 10 different value parameters with slightly different names. Remarkably the list of parameters by De Vries et al. (2008) is lacking in this list.

Table 4 presents a comparison of the 4 models mentioned in section 2. One difference is that it uses a more recent version of the model by Sarasoja, which includes Supporting environmental sustainability (Lindholm and Aaltonen, 2012). The different value parameters have been categorised under the four headings People, Process, Economy, and Surroundings.

Table 3: Different value parameters classified into the six categories (Riratanaphong and Van der Voordt, 2015)

Bradley (2002)	*Nourse and Roulac (1993)*	*De Jonge (1996)*	*Lindholm & Gibler (2005); Lindholm (2008)*	*Van Meel et al. (2010)*	*Den Heijer (2011)*	*Van der Zwart and Van der Voordt (2013)*	*Jensen et al. (2012)*
1.Stakeholder perception (employee satisfaction)	*Promoting HRM objectives*	-	*Increasing employee satisfaction*	*Attracting and retaining talented staff*	*Supporting user activities* *Increasing user satisfaction* *Improving quality of place*	*Increasing user satisfaction*	*Satisfaction*
2.Financial health	*Capturing real estate value creation of business*	*Increasing of value*	*Increasing the value of assets*	-	*Increasing real restate value*	*Improving finance position*	-
	Flexibility	*Increasing of flexibility*	*Increasing flexibility*	*Increasing flexibility*	*Increasing flexibility*	*Improving flexibility*	*Adaptation*
	Facilitating managerial process and knowledge work	*Changing culture*	-	*Encouraging interaction* *Supporting cultural change*	*Supporting culture* *Stimulating collaboration*	*Improving culture*	*Culture*
3.Organisational development	*Promoting marketing message Promoting sales & selling process*	*PR and marketing*	*Promoting marketing and sales*	*Expressing the brand*	*Supporting image*	*Supporting image*	-
	Facilitating and controlling production, operation and, service delivery	*Risk control*	-	-	*Controlling risk*	*Controlling risk*	*Reliability*
	-	-	*Increasing innovation*	*Stimulating creativity*	*Stimulating innovation*	*Increasing innovation*	-

Bradley (2002)	*Nourse and Roulac (1993)*	*De Jonge (1996)*	*Lindholm & Gibler (2005); Lindholm (2008)*	*Van Meel et al. (2010)*	*Den Heijer (2011)*	*Van der Zwart and Van der Voordt (2013)*	*Jensen et al. (2012)*
4.Productivity	-	*Increasing productivity*	*Increasing productivity*	*Enhancing productivity*	*Supporting user activities*	*Improving productivity*	*Productivity*
5.Environmental responsibility	-	-	-	*Reducing environmental impact*	*Reducing the footprint*	-	*Environmental*
6.Cost efficiency	*Occupancy cost minimization*	*Cost reduction*	*Reducing costs*	*Reducing costs*	*Decreasing costs*	*Reducing costs*	*Cost.*

Table 4: Comparison of added value parameters in four models

	A. Jensen et al., 2008	***B. Lindholm and Aaltonen, 2012***	***C. De Vries et al., 2008***	***D. Den Heijer, 2011***
Core business				
People	*Satisfaction* *Culture*	*Increase employee satisfaction*	*Image* *Culture* *Satisfaction*	*Increasing user satisfaction* *Supporting image* *Supporting culture*
Process	*Productivity* *Reliability* *Adaptability*	*Increase innovation* *Increase productivity* *Increase flexibility*	*Production* *Flexibility* *Innovation*	*Increasing flexibility* *Supporting user activities* *Improving quality of place* *Stimulating innovation* *Stimulating collaboration*
Economy	*Cost*	*Increase value of assets* *Promote marketing and sale* *Reduce cost*	*Cost* *Possibility to finance* *Risk control*	*Controlling risk* *Increasing real estate value* *Decreasing cost*
Surroundings	*Economic* *Social* *Spatial* *Environmental*	*Supporting environmental sustainability*		*Reducing the footprint*

The parameters related to People include (employee) satisfaction in all models. Model A also include “Culture”, while both model C and D include “Culture” as well as “Image”. Model B only includes “Increase employee satisfaction” under People. This model does as the only model include “Promote marketing and sale” placed under Economy. This parameter can be seen as an economical expression of “Image”, understood as brand. All four models include at least three parameters for Process with many overlaps. The differences can partly be seen as different degrees of sub-dividing. In relation to Economy, model A (the FM Value Map) only includes the parameter “Cost”, while the three other more CREM based models include parameters for “Value of real estate”, “Value of assets” or “Possibility to finance”. The parameter “Controlling risk” in model D is defined as related to financial goals, but it is also strongly related to the Process parameter "Reliability" in model A. In model C "Risk control" is included as well, partly related to reducing financial risks, but also to improving health and safety. Model A was the first model to include parameters related to Surroundings, including the "Environmental" parameter. The more recent CREM based models B and D also include a parameter for "Environmental sustainability" or "Reducing the footprint".

Based on the parameters in Table 3 and 4 we have decided to use the 12 value parameters listed in Table 5. All the parameters in Table 3 and 4 are more or less included, but the names of the parameters have been harmonised and Corporate Social Responsibility has been added. The parameters are like in Table 4 organised with four headings, but the heading Process has been changed to Process and Product.

Table 5: Added value parameters

Group	***Parameter***
People	*Satisfaction*
	Image
	Culture
	Health and Safety
Process and Product	*Productivity*
	Adaptability
	Innovation and Creativity
	Risk
Economy	*Cost*
	Value of Assets
Societal	*Sustainability*
	Corporate Social Responsibility

4. Discussion and Conclusion

Figure 2 shows the Value Adding Management model from section 2 with the 6 types of interventions from sub-section 3.1, the different aspects of VAM from sub-section 3.2 and the 12 added value parameters from sub-section 3.3. The model is seen as an integrated model for FM and CREM, which is generic for all kinds of businesses and for all types of property and facilities.

In order to be able to define the added value of an intervention by FM/CREM, it is important to measure the outcomes and impact of any intervention, ex-post and preferably also ex ante, as input to a business case (Van der Zwart and Van der Voordt, 2015). Clear performance indicators make it possible to assess how well people or facilities perform. The outcomes can provide the inspiration to achieve higher levels of effectiveness, efficiency, quality, and competitiveness. As such, performance measurement is an important aid for making judgments and decisions, which can help managers to answer five important questions: 1) where have we been; 2) where are we now; 3) where do we want to go; 4) how are we going to get there; and 5) how will we know that we got there (Lebas, 1995). Besides the need to operationalise the various value parameters in SMART performance indicators (Specific, Measurable, Assignable, Realistic and Time-related), performance measurement should be precise about the performance of *what*, e.g. people, facilities, or services.

Apart from clear performance indicators, it is also important to be able to define the causes of high or low performance, and to understand which changes are needed to improve what kind of performance. De Vries et al. (2008) concluded that cause-effect relationships are difficult to prove, due to the impact of many interrelated input factors, and the way interventions are implemented. It is our ambition in our further research to assess the 12 selected value parameters on what we know, what we still need to know, and what Key Performance Indicators could be applied to measure the different added values (Jensen and Van der Voordt, 2016).

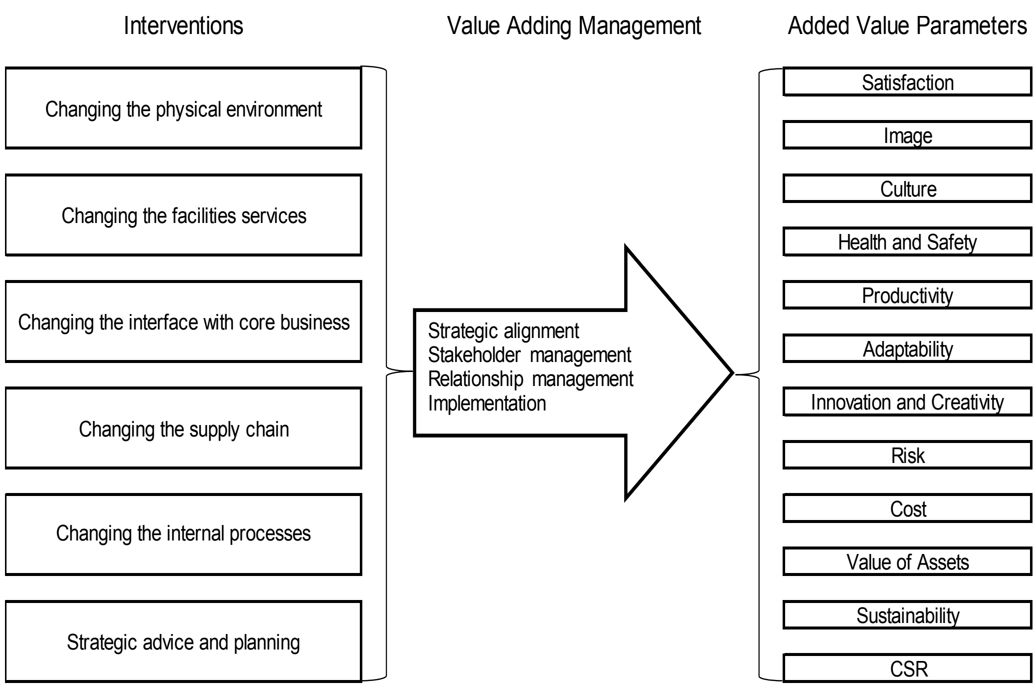

Figure 2: Added Value process model with types of interventions and added value parameters

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Managing Network Risks in Health Facilities

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Abstract

Health facilities play a crucial role in maintaining healthcare services to the community during an extreme weather event. Health facilities managers operate within a wider network of organisations which include emergency services, health resource suppliers, local authorities, external health agencies and governmental organisations. Their response to an extreme weather event depends significantly on their ability to manage the network risks which may arise between actors in this complex system. Yet existing research has tended to look at facilities managers in isolation. Through an in-depth case study of how health services in the State of New South Wales, Australia would respond to an extreme weather event, the interface risks between these various agencies are explored from a facilities management perspective. An analysis of 139 documentary sources which would dictate the inter-agency response shows that health facilities managers face numerous hidden risks arising from overlapping, complex and unresolved governance conflicts between the agencies on which they depend. It is concluded that these interface risks can be reduced if facilities managers employ a number of strategies. These include: mapping hospital dependency on other agencies; resolve overlapping operational boundaries with other agencies; undertaking proactive risk reduction for critical external support infrastructure; and better understanding potential conflicts with external agencies in responding to an extreme weather event.

Keywords: Facilities management, hospitals, risk, inter-agency, governance

1. Introduction

Using systems theory, Loosemore et al. (2012) provided empirical evidence to show that if healthcare facilities are to become more resilient to extreme weather events (EWEs), they cannot be treated in isolation from the wider systems in which they exist. EWEs are defined as weather patterns such as heatwaves, storms and floods that exceed a particular threshold and deviate significantly from mean climate conditions (Linnenluecke and Griffiths 2010). These interdependent systems include other organisations such as: the police, the army, the fire services; water, electricity and gas authorities; off-campus hospital suppliers; polyclinics; aged care facilities; and other critical service providers. Although the health facilities management literature acknowledges that the health system is complex, it provides little insight into the interface risks associated with the coordination and integration of all these organisations when the system is under stress. The ability of these various organisations to effectively coordinate with each other before, during and after an EWE can have a direct impact on a hospital's ability to cope. For example, records from the 1997 heat wave in Adelaide, South Australia, show that hospital computers overheated and failed and that outages occurred in water supply, air-conditioning and energy supply (Emergency Management Australia 1998). The 2005 Sydney heat waves had similar impacts and particularly affected the elderly and other vulnerable populations such as the obese and chronically ill, causing increased hospital admissions relating to heatstroke and cardio vascular diseases. This is not a problem unique to Australia. For example, in 2007 a tornado hit Greymouth in the South Island of New Zealand cutting electricity lines, damaging buildings and flooding access roads to many critical facilities (New Zealand Ministry of Civil Defence and Emergency 2007). Many other EWEs such as Hurricane Sandy in the USA in 2012 and the UK floods in 2007, have highlighted the vulnerability and inherent interconnectedness of critical infrastructure such as hospitals, power generation, water and transport networks, leading to calls for greater investment to make these systems more resilient to these emerging risks (Gardiner 2013, Committee on Climate Change 2014).

This intricate interdependency on other infrastructure systems indicates that health facilities managers have to operate within a complex system containing 'systemic risks' which propagate through numerous pathways, spreading quickly and rapidly, in non-linear and unpredictable ways (Koubatis and Schönberger 2005). Helbing (2013: 51) defines 'systemic risk' as "the risks of not just having statistically independent failures but interdependent so-called 'cascading' failures in a network of N interconnected system components". In other words, systemic risks result from looped connections between different system components (sub systems), leading to localised initial failures spreading and potentially inflicting unbounded damage. As White (1995), Jaafari (2001), Stahl, et al (2003) and Koubatis and Schönberger (2005) argue, complex systems are inherently unstable and characterised by multiple elements which are so interlinked that it is rarely possible to trace a risk event back to one singular event. This inherent instability arises from the important property of 'self-organization' (the ability of a system's connections and interdependencies to change, adapt and develop on their own without the influence of external managers). Systems researchers have shown that the property of self-organisation ensures that complex systems tend to settle at a 'critical edge' where a small change in the system can lead to catastrophic changes in the overall system through 'cascading interdependencies' which exist between different parts of a system. This property of systems is called 'self-organised criticality' and Kampmann (1999) argues that the world is made up of complex systems which may appear under control on the surface, but exist in a state self-organised criticality which makes sudden catastrophic collapses in response to external disturbances almost inevitable.

It is within this context that the paper aims to explore the systemic network risks which facilities managers face in the health sector. Responses to EWEs are studied as these events represent a real and growing threat to the health sector and address an important yet missing inter-organisational dimension in the facilities management and disaster management debate, which hitherto has been largely confined to intra-organisational issues.

2. Interface risks and extreme weather events

Numerous researchers such as Ansell and Gash (2008), have recognised the challenges of how multiple interdependent organisations mobilise, co-ordinate and control their actions and resources to respond to, cope with and recover from external threats such as an EWE. The earliest work in this field is attributed to Prince (1920), who derived a 'social theory' to explain human response to disaster. Later, Mileti et al. (1975) introduced the concept of the "disaster life cycle" and established the fundamental concepts of mitigation, preparedness, response and recovery used in most contemporary disaster management plans and facilities management literature. Drabek (1986) refined this work and introduced the concepts of emergent behaviour and human systems in disaster response, igniting the current debate over the validity of the centralised or bureaucratic model promoted in disaster management. Contemporary research into multi-agency responses to natural disasters (eg. Houghton et al. 2006; McMaster and Baber 2009) is concerned with the challenges faced by multi agencies in adapting their governance boundaries from standard operating procedures to accommodate the broader dynamic inter-agency interdependencies required in a disaster or crisis. During a threat such as an EWE, multiple agencies are required to change their modes of operation, to perform different functions and to work on multiple tasks simultaneously and under considerable time pressures. This requires path dependencies to be challenged and a certain degree of adaptive capacity to break with the 'normal' routines that are known to work when the system is not under threat.

From an interface risk management perspective, contemporary disaster management theory can be divided into two schools of thought. The first emphasises the importance of a centralised authority for a successful disaster response and the value of agreed, well-practiced operating procedures (Drabek and McEntire 2002). The second acknowledges emergent behaviours and is orientated towards decentralised or self-organising models operating on the basis of cooperation and collective problem solving (Mendonca et al. 2007). Recent research has also raised doubts about the effectiveness of the traditional command and control model (Mendonca et al. 2007, Kapucu and Arslan 2010). It is argued that while a central coordinating authority and pre-determined disaster management plans can be of value, it can also reduce the opportunity for improvisation and adaption to novel conditions which might typically arise during an EWE. Recent research is showing that the effectiveness of disaster response is highly dependent on pre-existing relationships between responding agencies established prior to the event (McMaster and Baber 2008; 2009, Department of Homeland Security 2012). The body of research outlined above indicates the importance of facilities managers establishing and maintaining relationships well in advance of an EWE event, yet Heng and Loosemore's (2011) research shows that this can be problematic because facilities managers are often seen as trivial and marginalised from central social networks in and around healthcare operations.

3. Methods

To investigate the interface challenges that hospital facilities management might face in managing this network of interactions, we conducted an in-depth analysis of the complex inter-agency governance structure responsible for managing healthcare delivery in the state of New South Wales, Australia. Australia comprises six states and two internal territories. All states and internal territories have their own parliaments and administer themselves, working in partnership with the Federal Commonwealth Government. Each state also retains the power to make their own laws over matters not controlled by the Commonwealth and have their own constitutions, as well as a structure of legislature, executive and judiciary. In terms of health services, the Federal Commonwealth Government provides leadership, financing, research and national information management around health policy while the states and territories are largely responsible for the delivery of public health care services and the management of healthcare workers in the public and private sectors. The states and territories deliver public acute and psychiatric hospital services including school and child health programs. Residential aged care is financed and regulated by the Federal Commonwealth Government and is outsourced mainly to the non-government sector (religious, charitable and for-profit providers). The Commonwealth, states and territories jointly fund and administer community care (such as delivered meals, home help and transport).

The state of New South Wales (NSW) provided an ideal context in which to study interface risks in this system. It is Australia's most populous state, with a population of about 7.5 million people served by about 230 public hospitals over an area of 809,444 km² which provide a wide range of other connecting services including emergency care, elective and emergency surgery, medical treatment, maternity services and rehabilitation programs. In addition to the Ministry of Health, the NSW Health service structure includes Local Health Districts, statutory health corporations and affiliated health organisations. New South Wales public health services include public hospitals, community, family and children's health centres, ambulance services and an extensive range of specialty services including mental health, dental, allied health, public health, Aboriginal health and multicultural health services. There are 15 Local Health Districts that are responsible for providing health services in a wide range of settings, from primary care posts in the remote outback to metropolitan tertiary health centres. The Ambulance Service of NSW is responsible for providing responsive, high quality clinical care in emergency situations, including pre-hospital care, rescue, retrieval and patient transport services.

Data about the interagency response boundaries and interactions revolving around healthcare facilities issues were collected using 139 documentary sources which would dictate the inter-agency response to an EWE. These documents included:

- Published governance structures for operating and maintaining public hospitals in New South Wales;
- Hospital, agency and community disaster management plans; government policy and legislation;
- Building control and standards guidance; published agency and government analysis of past EWE disaster responses;
- Annual reports of responding agencies; government inquiries into EWE responses; internal discussion papers;
- Disaster and emergency agency websites.

This data was analysed by cross-tabulating the responsibilities of the various agencies' names in these documents. The focus was to look for gaps and overlaps in their response mechanisms which could compromise the business continuity of a hospital in delivering health care services to communities during and after an EWE. A single case study approach of NSW (albeit with multiple internal dimensions), like any approach, has well-recognised limitations, particularly around representativeness and generalizability (Yin 2009). However, as discussed in the literature reviewed above, the number of potential agencies potentially involved in the response to an EWE and the complexity of interactions requires an in-depth approach to properly understand. Furthermore, in response to potential criticisms around generalizability, Flyvbjerg (2011: 301) argues that "while it is correct that the case study is a detailed examination of a single example, it is not true that a case study cannot provide reliable information about the broader class". Therefore, while the advantage of large samples might be breadth and representativeness, the advantage of case studies is depth and validity.

4. Analysis of interface risks

Our analysis indicated seven critical governance risks that can potentially impact a hospital facilities manager's ability to respond effectively to an EWE. These are:

- Inter-agency cooperation;
- Surge capacity;
- Preparation time;
- Gaining access to and from the disaster field;
- Resolving overlapping operational boundaries;
- Coordinating with agencies external to the health system;
- Resolving potential conflicts between external agencies.

Each of these risks is discussed in more detail below:

4.1 Inter-agency cooperation

In NSW, responsibility for the formulation and maintenance of disaster plans is delegated to 152 local governments which develop individual whole-of-community plans coordinated across the 11 Emergency Management Districts. Responsibility for disaster management of individual hospitals (both public and private) is allocated to 17 Local Health Districts (LHDs) with a different set of operational boundaries. Not only does this complex and overlapping governance landscape create potential coordination problems for facilities managers in preparing and responding to an EWE, it also creates the risk for disaster planning for hospitals to be undertaken in isolation from the whole-of-community disaster plans that are coordinated by Local Government officials.

4.2 Surge capacity

Our analysis indicated that surge capacity is a recurrent problem in hospitals and while financial constraints are often blamed for this, other issues identified in post disaster reports include fragmented governance of surge resources, offsite storage of resources, over-loaded supply chains and poor communication about overflow management.

4.3 Preparation time

Post disaster reports show that hospitals need preparation time to deploy a response team, be sufficiently resourced to receive mass casualties, as well as to assist with the health response during the community's recovery period. It also depends on careful planning to provide sufficient temporary additional treatment space through a range of measures including cancelling elective surgery, diverting emergencies not related to the disaster to other hospitals, and potentially transferring patients.

4.4 Access to and from the disaster field

There is an assumption that access to and from the disaster field will be possible during the course of a disaster response and recovery period. Not only does this assumption rely on surrounding infrastructure remaining operational (for example, roads, helipads or airports), it also relies on transport vehicles and equipment being capable of handing the conditions within the disaster field. However, our analysis indicated that dependency on other overloaded agencies to supply transport and the inability of the available responders to negotiate flooded roadways or rough terrain can significantly affect the effectiveness of hospital responses.

4.5 Overlapping operational boundaries

Our analysis shows that EWEs typically affect a wide catchment area and are likely to be covered by more than one local disaster plan, and in severe cases potentially even some regional or district-based disaster plans. This requires hospitals to be familiar with the procedures and arrangements contained within multiple disaster plans, and also to build operational relationships with a wide range of stakeholders and responding agencies.

4.6 Funding of asset development

In Australia, the state government will typically own a hospital's physical assets including the site, and through its various agencies, oversee and fund its upgrade or renewal. Individual hospital facilities managers and regional health boards tend to have funding and delegated responsibility to manage the operation including routine maintenance of individual sites and supporting built infrastructure. There are two obvious problems with this arrangement: firstly, the people on the ground with the responsibility for preparing for and responding to an EWE have limited influence over decisions to upgrade or renew their hospital which could affect their ability to respond. Secondly, at a state level, decisions regarding capital expenditure on the upgrade or renewal of assets within an individual site are typically prioritised, with reference to the entire hospital portfolio. What may be of high priority to an individual hospital in its disaster planning may not necessarily be considered so by government at the state level.

4.7 Coordination with agencies external to the health system

Although most health systems attempt to ensure independence through backup systems such as the installation of generators, our analysis showed that hospitals inevitably have to rely on interactions with agencies outside the health sector when an EWE strikes. LHDs have limited influence over the centralised procurement from warehousing facilities supplying support services such as linen, catering, IT or consumable medical supplies within their districts. In the same way, during an EWE, LHDs will have little influence in mobilizing other agency resources. Given that hospitals are not geared to provide their own disaster transport, they are highly dependent on other emergency service agencies to assist with the deployment of medical teams and supplies into the disaster field and also to transfer casualties from the field for treatment in hospital. Therefore, the quality and timeliness of the ‘health’ response is dependent on the cooperation of other agencies.

4.8 Potential conflict between external agencies and hospital objectives

One major problem for a facilities manager in dealing with an EWE is that external agencies may have conflicting objectives to those of the hospital. For example, records show that local aged care facilities often lack a disaster plan and tend to evacuate their patients and residents to tertiary hospitals during an event such as a flood, to prevent them being cut-off. Not only could patients become stranded en-route, but the arrival of additional vulnerable elderly persons into a hospital at a time when it is already under stress puts undue strain on the response effort.

5. Discussion

Past research on facilities risk management governance issues has taken an intra-organisational focus and the aim of this study was to balance this with inter-organisational insights. The findings add further qualitative evidence to Loosemore et al's (2012) research which argued that hospital facilities management is best conceptualised using a systems perspective that recognises the wider system in which hospitals are placed. The findings also support McMaster and Baber's (2008) and Uhr's (2009) contention that effective inter-agency coordinating is highly dependent on pre-existing relationships between responding agencies established prior to the event. In doing so it has also exposed the potential problems of 'sequential single agency response' highlighted by McMaster and Baber (2009). From a contemporary disaster management theory perspective, our results question the efficacy of the centralised governance school of thought which argues that a successful disaster response depends on the development of agreed, well-practiced operating procedures (Drabek and McEntire 2002). However, our findings also showed that the boundaries defining what each agency will tackle are often confused and are unlikely to adequately consider the dynamic inter-agency interdependencies required to ensure an effective response to an EWE. Furthermore, our research shows that while hospital facilities managers are responsible for managing critical assets during an EWE, they are unlikely to be an integral part of a common operational picture or a shared situational awareness which disaster management researchers like Wickens (2008) advocate. Our research suggests that during an EWE people will need to move outside these procedures and that it is therefore important to acknowledge emergent informal systems and behaviours, and the need for decentralised or self-organising models operating on the basis of cooperation and collective problem solving (Mendonca et al. 2007). In terms of future research, our findings therefore suggest that there is a need to more deeply explore the interaction between formal and informal systems and procedures in disaster response and in particular, how informal processes and procedures can act to support the formal systems that central policy-makers have put in place.

6. Conclusions

The aim of this paper was to explore the systemic network risks which facilities managers face in the health sector. Theoretically, these findings add to the facilities management literature by highlighting the importance of power for facilities managers as determined by their position in the social networks that are defined by disaster management plans. They also highlight the need to develop brokerage and relationship-building skills which are largely ignored in the facilities management literature. While interviews with key stakeholders would provide further valuable insights and while further research is clearly needed into the inter-agency challenges of the facilities management function, the value of this research is that it reveals a set of issues and skills which are not typically covered in facilities management research literature. In particular, it highlights the importance of: adopting a systems perspective in understanding the health system as a whole; understanding the power, politics and economics of governance; stakeholder management; inter-agency relationship building; and understanding the objectives, plans and constraints of other organisational functions (external and internal) which the facilities manager depends on. As evident from our findings, it is important that any future analysis of these issues should take care not to neglect the social networks in which facilities managers are imbedded and of their power relationships with other disaster management stakeholders.

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Operating Cost Estimation: A Comparison of Methods

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Abstract

Operating costs represent a significant amount of the overall expenditures over the life-cycle of buildings. Therefore, it is a crucial task for all participants involved in the planning process to determine operating costs as early as possible. Accordingly, cost-benefit analyses can be developed and planning alternatives can be evaluated economically. Likewise, costs incurring during the operation of buildings can be monitored and controlled in an iterative process. Consequently, methods for an accurate estimation of operating costs are essential and can serve as a foundation for decision-making and budgeting.

The current approach focuses on the comparison of statistical methods for the estimation of operating costs using empirical data as a basis. Therefore, a sample consisting of 206 occupied facilities located in Germany is employed. The data was gathered in the years 2008 to 2014 from 25 project partners and contains 11 different facility types. Linear and nonlinear regression models and artificial neural network models are developed, specified, and validated. Additionally, categorised cost indicators for the estimation of operating costs are introduced, using the results of the developed statistical models as a basis. All statistical methods are evaluated for their accuracy employing an independent, randomly selected, and representative test sample.

The results show the best estimation accuracy for the nonlinear regression model and the artificial neural network model with mean absolute percentage errors of 15.4% and 16.6% respectively. The minor differences of the measures of performance and quality for both models utilising the same 7 predictor variables indicate correctly specified models. The procedure of model development and the evaluation of the results are presented in detail and may serve as a basis for further research on the estimation of operating costs and the identification of significant predictor variables. The extension of the data sample, the consideration of further facility types, and the implementation of additional statistical methods may be considered by future approaches to improve the accuracy of operating cost estimation.

Keywords: Operating costs, estimation, statistical methods, regression analysis, artificial neural networks

1. Introduction

A significant amount of the financial expenditures over a building's life-cycle are represented by operating costs. Various studies illustrate the financial relevance of these costs and point out the substantial potential of cost savings for property owners and leaseholders. For instance, operating costs for school facilities of between 27.93 and 35.44 Euro/m²*a (per m² usable floor area) are published by Beusker (2003). Accordingly, it is an increasingly important task to determine operating costs as early as possible in the process of planning. This is the only way to develop cost-benefit analyses and evaluate planning alternatives holistically. Likewise, costs incurring during the operation of buildings can be monitored and controlled in an iterative process.

Consequently, methods for the estimation of operating costs under consideration of significant influential variables are essential and can serve as foundation for decision-making and budgeting. Though various statistical methods for the estimation of construction costs and corresponding influential variables are extensively examined and evaluated, there are currently only the studies of Stoy and Kytzia (2006) (office facilities) and Beusker (2013) (school facilities) introducing statistical methods for the estimation of operating costs and evaluating the quality and performance of the developed models.

The current approach develops and evaluates several statistical methods (regression, artificial neural networks, and cost indicators) for the estimation of operating costs. Based on a wide range of possible predictor variables and a data sample of 206 occupied facilities, the procedure of model development is presented in detail including specifications and parameters of the best-fitting model. Significant variables influencing operating costs are identified and validated. Categorised cost indicators for the estimation of operating costs are introduced using the results of model development as a basis. All statistical methods are assessed according to their estimation accuracy employing an independent, randomly selected, and representative test sample. The main objectives of the current study are:

- Development and specification of linear and nonlinear regression models and artificial neural network models.
- Identification of significant variables influencing operating costs.
- Introduction of categorised cost indicators.
- Evaluation of the estimation accuracy of the presented statistical methods.

Chapter 2 gives an overview of the statistical methods that are employed to conduct the current approach and defines operating costs as the response variable of the study. Chapter 3 contains a description of the data sample and includes descriptive statistics of variables serving as basis for the statistical analysis. The development of the statistical models and indicators for cost estimation is presented in Chapter 4. The best-fitting statistical model is specified in detail including relevant parameters. The estimation accuracy of the statistical methods is evaluated by an independent test sample. Before concluding the study in Chapter 6, a summary of the results including a discussion is given in Chapter 5.

2. Methodology

Statistical models are designed to capture and represent the reality as close and accurate as possible in practice and may be used for investigation or prediction (Fellows and Liu, 2008). Regression analysis is a method to determine functional relationships among variables and can be employed for description, model building, estimation, prediction, and for control aims (Chatterjee and Hadi, 2006). In multiple regression the attributes of one response variable depending on several predictor variables are explained by the following generalised relationship (Backhaus, Erichson, and Weiber, 2013):

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_i X_i + \varepsilon$$

where Y is the response variable, β_0 is the constant and β_i are the coefficients, X_i are the predictor variables, and ε is the error term of the regression. The unknown model parameters β_0 and β_i are to be determined from the data as accurate as possible by the so called ordinary least squares (OLS) method. Therefore, the mean squared error term ε (difference between observed and estimated value) for all observations is kept as small as possible.

Regression models for the estimation of costs in the field of construction are utilised since the 1970s. The current study introduces linear and nonlinear regression models to estimate operating costs. The nonlinear model includes transformation of predictor and response variables for correcting non-normality in the distribution of the data by application of the Box-Cox-Plot (Box and Cox, 1964). Therefore, an improvement of the model in terms of quality and performance is expected (Schmidt, 2009). Consequently, the term nonlinear does not indicate a nonlinear relationship between predictor and response variables.

In contrast to regression models, artificial neural network (ANN) models are able to represent nonlinear relationships between response and predictor variables. Inspired by the operation of the nervous system of humans and animals, ANNs are capable of learning and generalising from experience. They are considered as tools for construction since the 1990s (Moselhi, Hegazy, and Fazio, 1991) and are utilised for the estimation of construction costs in various studies.

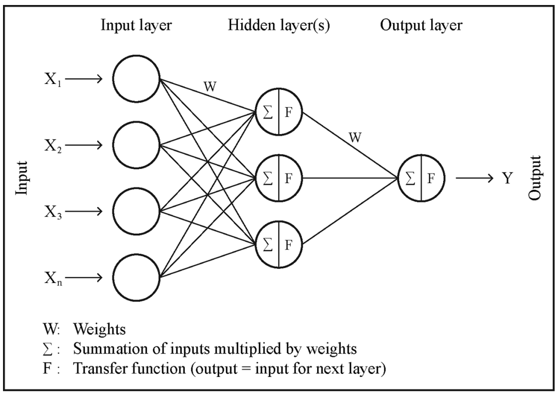

Figure 1: Typical architecture of a MLP neural network

For the estimation and identification of cause-effect relationships, the neural network architecture of multi-layer perceptrons (MLP) is most suitable (Backhaus et al., 2013) and therefore employed as a statistical method in the current study. MLPs typically consist of multiple layers of neurons as illustrated in Figure 1. Values of the predictor variables X_i are fed to neurons in the input layer, weighted and transferred to neurons of the first hidden layer. The inputs are summed up and then processed to the neurons of the next layer (or output layer) if the requirements of a transfer function are fulfilled. The output error is kept as small as possible by continuous comparison of the estimated and observed values and adjustment of the connection weights.

Based on the results of the regression and ANN models, cost indicators as a further method for the estimation of operating costs are developed and evaluated in the current study. Therefore, a suitable reference quantity is determined and cost indicators categorised according to identified predictor variables are presented.

The estimation quality and performance of the regression and ANN models can be determined by the accuracy of estimation compared to the underlying empirical data by the coefficient of determination R^2 as goodness-of-fit-index. The adjusted R^2 additionally takes the degree of freedom into account and consequently serves as a more reliable measure not depending on the number of predictor variables included in the model. Furthermore, the normalised root-mean-square error (CV)RMSE is used as an indicator to measure the standard deviation of the distance between observed and estimated values for evaluation of the statistical models.

The mean absolute percentage error (MAPE) is not only utilised as a measure of quality and performance to determine the goodness-of-fit of the statistical models, but also to measure the estimation performance under independent and unbiased conditions employing a test sample. The MAPE is defined as follows:

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{O_i - E_i}{O_i}\right| * 100\%$$

where O_i is the observed value, E_i is the estimated value, and n is the size of the sample.

To conduct statistical analysis based on empirical data, potential variables predicting the response variable have to be selected by the review of literature, by interviews, or by surveys (Fellow and Liu, 2008). Based on a selection by review of literature, a wide range of variables potentially influencing the operating costs (cf. Chapter 3) are considered for model development in the current study.

The response variable of the statistical models is defined as operating costs per year (Euro/a) according to German standard DIN 18960 (2008). Operating costs basically include supply of water, heating energy, electricity, disposal of water and waste, and costs for cleaning and care of indoor and outdoor facilities. Furthermore, costs for operation, inspection, and maintenance of building structures and technical installations as well as costs for security, surveillance, and statutory charges are included.

3. Data sample

The empirical approach of the current study employs a data sample consisting of 206 occupied facilities. The data collection was conducted in the years 2008 until 2014 in Germany and includes data provided by 25 project partners. The data were complemented on-site the facilities, using a standardised questionnaire. Among operating cost data, the sample contains possible predictor variables, e.g. quantities, information about utilisation and location, and evaluations of the condition of building structures and technical installations.

Table 1: Available qualitative variables

Variable	Characteristic	No. obs.	Percentage[a]
Thermal mass	Heavy thermal mass	176	85.4%
	Light thermal mass	30	14.6%
Standard of building automation	High standard	82	39.8%
	Low standard	124	60.2%
Standard of technical installations	High standard	153	74.3%
	Low standard	53	25.7%
Cleaning services	External contractor	189	91.7%
	Internal cleaning services	17	8.3%
Type of heating energy source	District heating	70	34.0%
	Electricity	11	5.3%
	Gas	110	53.4%
	Oil	15	7.3%
Type of facility	Care retirement home	13	6.3%
	Church building	11	5.3%
	Community hall	5	2.4%
	Fire department	5	2.4%
	Kindergarten	102	49.5%
	Library	4	1.9%
	Municipal building	8	3.9%
	Research/teaching	10	4.9%
	School facility	22	10.7%
	Sport facility	19	9.2%
	Town hall	7	3.4%
Kitchen	Kitchen/canteen	115	55.8%
	Tea kitchen	35	17.0%
	None	56	27.2%

[a] Total sample size is 206.

Potentially relevant qualitative variables are presented in Table 1 including their characteristics, their particular number of observations, and their percentage of the total sample. All available quantitative variables employed in the statistical investigation are described in Table 2. Operating costs as analysed response variable are adjusted to 2nd quarter 2015 prices including German VAT. Cost data were monitored over at least 1 up to 5 years, depending on the availability of data from the particular project partner. Cost indicators are created employing the gross external floor area (GEFA) defined by CEEC (2008) as reference quantity (cf. Chapter 4.1).

For an unbiased validation of the examined statistical methods, the total sample of 206 observations is divided into two subsamples. The training sample consists of 186 observations

(90% of the total sample) and serves as a basis for the development of the statistical models and cost indicators. The test sample includes 20 observations (10% of the total sample) and is used to measure the estimation performance of the developed models and cost indicators. The test sample is selected randomly and shall be representative of the training sample.

Table 2: Available quantitative variables

Variable	Type[a]	Mean	Standard deviation	Min.	Lower quartile	Median	Upper quartile	Max.
Absolute operating costs (Euro/a)[b]	RE	97,481	124,719	7,000	20,288	44,419	126,546	702,644
Operating cost indicators (Euro/m² GEFA*a)[b]	RE	39.13	15.21	10.21	28.37	37.81	47.78	79.76
Gross external floor area GEFA (m²)	CN	2,873	3,774	160	578	1,276	3,438	22,272
Share of usable floor area UFA on GEFA (%)	CN	0.54	0.12	0.25	0.46	0.54	0.62	0.81
Share of heatable GEFA (%)	CN	0.88	0.12	0.39	0.82	0.91	0.96	1.00
Share of ventilated and air-conditioned GEFA (%)	CN	0.09	0.15	0.00	0.00	0.02	0.12	0.76
Share of regularly cleaned usable floor area UFA (%)	CN	0.78	0.13	0.21	0.72	0.83	0.88	0.94
Share of sanitary area on GEFA (%)	CN	0.05	0.03	0.00	0.03	0.05	0.06	0.17
Average floor size (m²)	CN	695	628	87	292	496	878	3,954
Average storey height (m)	CN	3.95	1.50	2.50	3.10	3.50	4.26	14.08
Number of floors	DN	3.52	2.22	1	2	3	5	14
Number of elevator stops	DN	1.23	2.16	0	0	0	2	12
Number of sanitary facilities	DN	8.66	14.98	0	2	4	8	122
Share of glass surfaces on above-grade exterior walls (%)	CN	0.27	0.12	0.06	0.18	0.26	0.34	0.62
Share of double or triple glazing on ext. glass surfaces (%)	CN	0.91	0.27	0.00	1.00	1.00	1.00	1.00
Share of defective building construction (%)	CN	0.14	0.14	0.00	0.03	0.11	0.19	0.81
Share of defective technical installations (%)	CN	0.12	0.15	0.00	0.00	0.06	0.17	0.77

Number of observations for all quantitative predictor variables: 206.
[a] RE stands for response variables, CN stands for continuous numeric variables and DN stands for discrete numeric variables.
[b] Costs and cost indicators are adjusted to 2nd quarter 2015 prices including VAT.

4. Statistical investigation

4.1 Model development

Based on the pre-analysis presented in Chapter 3, statistical models are stepwise developed employing a training sample of 186 observations. Describing the causal interrelations between the response and the predictor variables, the main objective of the models is set to be the estimation of operating costs. Besides a linear regression model, a nonlinear regression model with transformed variables for the correction of non-normality of the underlying data is presented. Furthermore, an artificial neural network (ANN) model is developed. The models are summarised in Table 3 including measures of quality and performance.

Table 3: Comparison of relevant statistical models for estimation of operating costs

Model		No. variables	R²	R² (adj.)	MAPE	CV(RMSE)	Outliers	No. obs
Response variable: Operating cost indicators (Euro/m² GEFA*a)								
OP_1	Linear regression model	5	63.2%	59.7%	20.4%	23.8%	9 (4.8%)	186
OP_2	Nonlinear regression model	7	77.3%	74.9%	16.5%	21.4%	6 (3.2%)	186
OP_3	Artificial neural network (MLP)	7	*	70.3%	16.8%	21.6%	12 (6.5%)	186

It can be assumed that the estimation of cost indicators has more practical relevance for a variety of reasons, e.g. the comparability of indicators for benchmarking or long-term monitoring of performance. Based on the evaluation of models estimating absolute costs and cost indicators, the gross external floor area (GEFA) is identified as most suitable reference quantity. Therefore, only models estimating operating cost indicators (Euro/m² GEFA*a) are presented in the current study. Comparing the developed models, the nonlinear regression model OP_2 offers the best quality and performance in terms of accuracy with a R^2 of 77.3% and an adjusted R^2 of 74.9%. Furthermore, the MAPE of model OP_2 indicates the best accuracy with the lowest value of 16.5% compared with nonlinear regression model OP_1 and ANN model OP_3.

4.2 Specifications and parameters of the best-fitting model

As presented in Chapter 4.1, various statistical models for the estimation of operating cost indicators are developed. In the current chapter, the best-fitting nonlinear regression model OP_2 is specified and relevant parameters are presented in detail. Table 4 gives a description of the included predictor variables and their coefficients.

Table 4: Description of coefficients for nonlinear regression model OP_2

Response variable (Y)		Transf. (λ)	R²	R² (adj.)	MAPE	CV(RMSE)	p-value	No. obs.
Operating cost indicators (Euro/m² GEFA*a)		0 (LN)	77.3%	74.9%	16.5%	21.4%	0.000	186
Predictor variable (X)		**Transf. (λ)**	**Coefficient (β)**	**Coefficient Std. Error**	**Standardised Coefficient**	**t-value**	**p-value**	**VIF**
β_0	Constant	*	3.995	0.245	0.000	16.33	0.000	*
X_1	Share of heatable GEFA (%)	2 (SQ)	0.586	0.116	0.260	5.05	0.000	1.93
X_2	Share of regularly cleaned UFA (%)	2 (SQ)	0.521	0.136	0.217	3.84	0.000	2.42
X_3	Average floor size (m²)	0 (LN)	-0.125	0.031	-0.219	-4.03	0.000	2.19
X_4	Share of defective tech. installations (%)	0.5 (SQR)	0.239	0.080	0.121	2.97	0.003	1.25
X_5	Cleaning services	*	*	*	0.332	*	0.000	*
	External contractor	*	0.000	0.000	*	*	*	*
	Internal cleaning services	*	-0.517	0.063	*	-8.16	0.000	1.22
X_6	Type of heating energy source	*	*	*	0.175	*	0.000	*
	District heating	*	0.000	0.000	*	*	*	*
	Electricity	*	0.238	0.083	*	2.85	0.005	1.31
	Gas	*	0.124	0.042	*	2.98	0.003	1.78
	Oil	*	-0.037	0.072	*	-0.51	0.609	1.56
X_7	Type of facility	*	*	*	0.539	*	0.000	*
	Care retirement home	*	0.000	0.000	*	*	*	*
	Church building	*	-1.189	0.108	*	-11.03	0.000	2.42
	Community hall	*	-1.015	0.124	*	-8.20	0.000	1.65
	Fire department	*	-0.683	0.129	*	-5.31	0.000	1.77
	Kindergarten	*	-0.474	0.082	*	-5.80	0.000	4.73
	Library	*	-0.717	0.129	*	-5.55	0.000	1.44
	Municipal building	*	-0.654	0.112	*	-5.84	0.000	1.86
	Research/teaching	*	-0.534	0.105	*	-5.08	0.000	2.09
	School facility	*	-0.507	0.093	*	-5.46	0.000	3.24
	Sport facility	*	-0.438	0.093	*	-4.69	0.000	2.96
	Town hall	*	-0.477	0.115	*	-4.14	0.000	1.70

Following equation describes the nonlinear regression model OP_2:

$$Y = e^{\beta_0} * e^{\beta_1 X_1{}^2} * e^{\beta_2 X_2{}^2} * x_3{}^{\beta_3} * e^{\beta_4 \sqrt{X_4}} * e^{\beta_5 X_5} * e^{\beta_6 X_6} * e^{\beta_7 X_7}$$

Transformations of both response and predictor variables are presented with their respective lambda (λ) as determined by Box-Cox transformation. The coefficients (β) for the regressions constant and variables are complemented by the standard error displaying the standard deviation of the coefficient's estimate for the sample. The standardised coefficients indicate the effect of the predictors even if they are measured on different scales. The standardised coefficients for categorical predictor variables are determined by re-calculating the regression including composite variables as established by Eisinga, Scheepers, and van Snippenburg (1991).

According to the t-values exceeding a value of 1.972 (significance level alpha set to 0.05), a generalised significance is indicated for all predictor variables included in model OP_2. The 4 quantitative and 3 qualitative variables are tested on their empirical significance complying with the threshold of the p-value on an α-level of 0.05. Since the present study is not conducted on an experimental level where variables can be observed isolated, multi-collinearity of the predictor variables exists to an extent (Chatterjee and Hadi, 2006). Nonetheless, values of the variance inflation factor VIF fall below the determined threshold of 5 for all predictor variables.

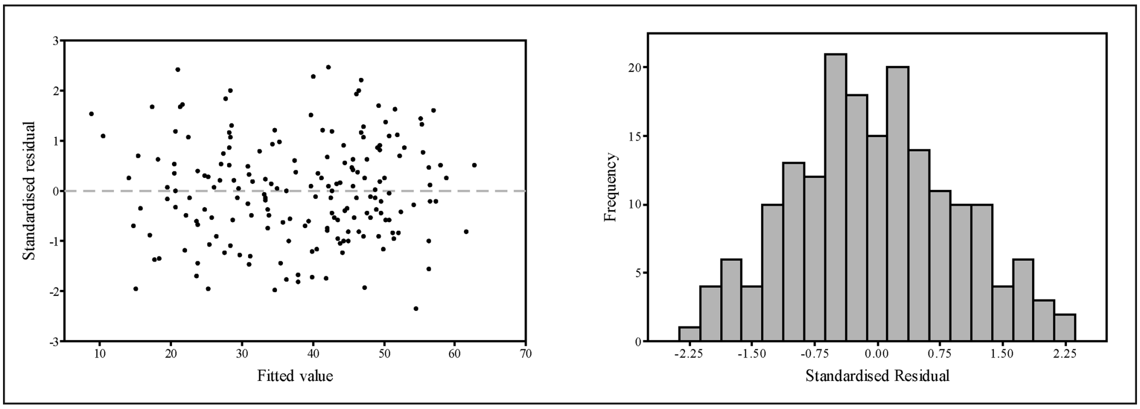

Figure 2: Residuals versus fitted values and histogram of residuals for model OP_2

As illustrated in the scatterplot and histogram in Figure 2, the variance of the residuals (difference between observed and estimated values) appears to be independent, randomly scattered, and heteroscedastic. Therefore, a correctly specified regression model OP_2 with no missing terms, extreme outliers, or influential points is indicated.

4.3 Cost indicators

The statistical methods compared in the current study include the estimation of operating costs employing cost indicators. As specified in Chapter 4.1, the best results in terms of quality and performance can be achieved for models including the gross external floor area GEFA. Therefore, the GEFA is determined as reference quantity for the generated cost indicators (Euro/m² GEFA*a). According to the standardised coefficient, the type of facility is identified as predictor variable with the greatest effect on operating costs in nonlinear regression model OP_2 (cf. Table 4). Based on the training sample including 186 observations, cost indicators with a categorical distinction according to the type of facility are presented in Table 5. In addition, corresponding boxplots are illustrated in the Appendix of the current study.

Table 5: Utility supply cost indicators

Type of facility	Lower quartile[a]	Median[a]	Upper quartile[a]	No. obs.
Care retirement home	30.11	45.64	67.48	12
Church building	12.56	14.49	19.93	10
Community hall	16.07	20.86	22.86	5
Fire department	15.27	22.07	34.14	5
Kindergarten	35.6	43.37	54.03	92
Library	22.23	27.80	30.85	4
Municipal building	21.02	26.39	31.16	7
Research/teaching	22.76	27.80	38.38	9
School facility	29.66	33.74	35.31	19
Sport facility	38.81	42.44	49.04	17
Town hall	25.01	26.28	32.69	6

[a] Operating cost indicators (Euro/m² GEFA*a), costs are adjusted to 2nd quarter 2015 prices including VAT.

4.4 Evaluation of performance and quality

The validation of the statistical methods is performed employing a test sample of 20 observations not included in the development of the statistical models and cost indicators. Therefore, unbiased and independent inferences about the estimation accuracy are expected. Observed and estimated values for the statistical models and the estimation by cost indicators are presented in Table 6. The estimated values are calculated by applying the observed predictor variables into the models (OP_1, OP_2, and OP_3) or selected according to the respective type of facility (indicators).

Table 6: Comparison of observed and estimated values for the test sample

No.	Type of facility	Obs.[a]	Linear regr. (OP_1) Est.[a]	Linear regr. (OP_1) APE[b]	Nonlin. Regr. (OP_2) Est.[a]	Nonlin. Regr. (OP_2) APE[b]	ANN (OP_3) Est.[a]	ANN (OP_3) APE[b]	Indicators (Median) Est.[a]	Indicators (Median) APE[b]	Pref.
4	Sport facility	45.20	44.23	2.1%	50.14	10.9%	47.35	4.7%	42.44	6.1%	Lin.
7	School facility	38.95	42.15	8.2%	37.45	3.8%	34.06	12.5%	33.74	13.4%	Nonl.
17	School facility	38.43	34.92	9.1%	38.72	0.7%	37.89	1.4%	33.74	12.2%	Nonl.
57	Kindergarten	77.50	56.95	26.5%	53.77	30.6%	65.41	15.6%	43.37	44.0%	ANN
59	Research/teaching	29.47	33.17	12.6%	28.40	3.6%	28.25	4.1%	27.80	5.7%	Nonl.
65	Kindergarten	45.68	46.03	0.8%	41.80	8.5%	44.66	2.2%	43.37	5.1%	Lin.
88	Kindergarten	42.34	42.26	0.2%	46.65	10.2%	36.14	14.7%	43.37	2.4%	Lin.
94	Church building	27.03	23.08	14.6%	22.36	17.3%	28.47	5.3%	14.49	46.4%	ANN
97	Kindergarten	69.67	50.29	27.8%	51.80	25.7%	53.97	22.5%	43.37	37.8%	ANN
115	Kindergarten	47.52	42.74	10.1%	43.36	8.8%	41.28	13.1%	43.37	8.7%	Ind.
122	Care retirem. home	28.84	37.32	29.4%	35.08	21.6%	35.59	23.4%	45.64	58.3%	Nonl.
123	Municipal building	36.60	29.43	19.6%	27.09	26.0%	31.63	13.6%	26.39	27.9%	ANN
133	Kindergarten	65.34	51.19	21.6%	56.10	14.1%	55.55	15.0%	43.37	33.6%	Nonl.
149	Kindergarten	16.88	25.30	49.9%	23.98	42.1%	27.43	62.5%	43.37	56.9%	Nonl.
161	Kindergarten	43.17	49.16	13.9%	48.35	12.0%	52.13	20.7%	43.37	0.5%	Ind.
168	Town hall	45.85	39.87	13.0%	42.15	8.1%	38.86	15.2%	26.28	42.7%	Nonl.
170	Sport facility	32.99	28.22	14.5%	26.57	19.5%	27.90	15.5%	42.44	28.6%	Lin.
189	Kindergarten	38.47	44.97	16.9%	38.78	0.8%	37.20	3.3%	43.37	12.7%	Nonl.
193	Kindergarten	35.21	46.80	32.9%	42.99	22.1%	45.97	30.5%	43.37	23.2%	Nonl.
203	School facility	31.68	39.85	25.8%	38.30	20.9%	42.97	35.6%	33.74	6.5%	Ind.
Total (MAPE)				17.5%		15.4%		16.6%		28.6%	

[a] Observed and estimated values: Operating cost indicators (Euro/m² GEFA*a), costs are adjusted to 2nd quarter 2015 prices including VAT.
[b] Absolute percentage error.

The absolute percentage error (APE) quantifies the accuracy of the estimated values for all 20 observations of the test sample. Furthermore, the preference for a statistical method according to the estimation accuracy is presented. With a preference of 9 out of 20 observations, values of the APE ranging between 0.7% and 42.1%, and a mean absolute percentage error (MAPE) of 15.4%, the most accurate estimation is indicated for nonlinear regression model OP_2.

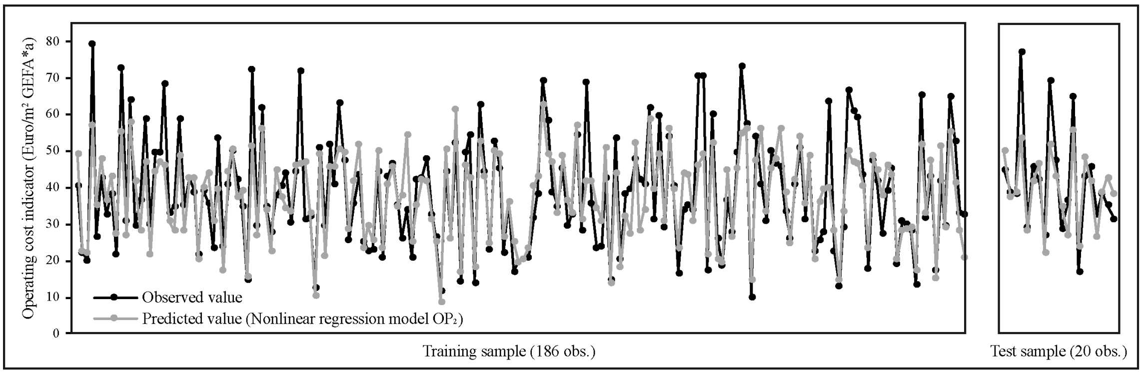

Figure 3: Comparison of observed values and values estimated by model OP_2

A comparison of the observed values and the values estimated by nonlinear regression model OP_2 is illustrated for both training sample and test sample in Figure 3. The graph reveals relatively consistent and small residuals for both training and test samples and indicates a good estimation accuracy for the statistical model.

5. Results and discussion

Comparing statistical methods for the estimation of operating costs employing an independent and representative test sample of 20 observations, a mean absolute percentage error (MAPE) of between 15.4% and 28.6% can be achieved as summarised in Table 7. The adjusted R^2 of the developed linear and nonlinear regression and artificial neural network models ranges between 74.9% and 59.7% with a CV(RMSE) of between 21.4% and 23.8%. The most accurate estimation of operating costs is provided by the nonlinear regression model OP_2 employing the gross external floor area GEFA as reference quantity. The model offers an adjusted R^2 of 74.9%, a CV(RMSE) of 21.4% and a MAPE of 16.5% (training sample) and 15.4% (test sample).

Table 7: Summary of statistical methods estimating operating costs

Sample	Linear regression (OP_1)		Nonlin. regression (OP_2)		ANN (OP_3)		Indicators (Median)		
	R^2 (adj.)	CV(RMSE)	R^2 (adj.)	CV(RMSE)	R^2 (adj.)	CV(RMSE)	R^2 (adj.)	CV(RMSE)	No. obs.
Training sample	59.7%	23.8%	74.9%	21.4%	70.3%	21.6%	*	*	186
	MAPE	No. pref.	MAPE	No. pref.	MAPE	No. pref.	MAPE	No. pref.	No. obs.
Training sample	20.4%	27 (14.5%)	16.5%	81 (43.5%)	16.8%	42 (22.6%)	25.3%	33 (17.7%)	186
Test sample	17.5%	4 (20.0%)	15.4%	9 (45.0%)	16.6%	4 (20.0%)	28.6%	3 (15.0%)	20
Total	20.1%	31 (15.0%)	16.4%	90 (43.7%)	16.8%	46 (22.3%)	25.6%	36 (17.5%)	206

With a significance level of alpha (α) determined as 0.05 for the current study, 7 significant predictor variables influencing operating cost indicators are identified for model OP_2 (ordered descending by the size of effect determined by the standardised coefficient of the regression):

- Type of facility
- Cleaning services

- Share of heatable gross external floor area
- Average floor size
- Share of regularly cleaned usable floor area
- Type of heating energy source
- Share of defective technical installations

The developed statistical models show better results in terms of accuracy comparing them to cost indicators employed for the estimation of operating costs. Due to a relatively small data sample, cost indicators with a categorical distinction according to only one predictor variable can be presented and evaluated. Therefore, the accuracy of the estimation by the regression and ANN models including between 5 and 7 significant predictor variables is expected to be more accurate. The correction of existent non-normality in the distribution of the data results in a better performance of the nonlinear regression model compared with the linear model. Though the nonlinear regression model performs slightly better, nonlinear relationships between the response variable and the predictor variables are indicated by the results achieved by the ANN model.

6. Conclusion

The current study examines multiple statistical methods for the estimation of operating costs on the basis of a data sample of 206 occupied facilities. Therefore, linear and nonlinear regression models and artificial neural network models are developed, specified, and evaluated in terms of their estimation accuracy. Significant variables influencing the operating costs are identified and presented. Based on the results of the developed statistical models, categorised cost indicators for the estimation of operating costs are introduced. All statistical methods are evaluated for their performance and quality employing an independent and randomly selected test sample.

The results show the best estimation accuracy for the nonlinear regression model and the artificial neural network model. The minor differences of the measures of performance and quality for both models utilising the same predictor variables indicate correctly specified models. The procedures of model development and the evaluation of the results are presented in detail and may serve as a basis for further research on the estimation of operating costs and the identification of significant predictor variables.

Future research may improve its results considering the limitations of the current study. Due to a limited number of observations of some types of facilities, the accuracy of the presented statistical methods could be improved by extension of the data sample. Moreover, future approaches may consider further types of facilities for the development of cost estimation methods (e.g. health service facilities, industrial facilities, laboratories). The data sample employed in the current study includes solely properties owned and operated by public-sector institutions. For the identification of the influence of strategies on operating costs (e.g. energy contracting, outsourcing, public-private partnership, maintenance strategies), further research may include data from properties owned and operated by private institutions.

Though operating costs represent a substantial amount of the life-cycle costs of facilities, further approaches may extend their focus on cost types such as the maintenance and the repair of facilities. Likewise, the implementation of additional statistical methods for the estimation of costs may be considered and evaluated (e.g. decision tree analysis). Ultimate objective should be the development of standardised cost models and applicable tools for the holistic estimation of life-cycle costs of facilities including planning, construction, operation, maintenance, repair, and reuse or demolition.

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Appendix

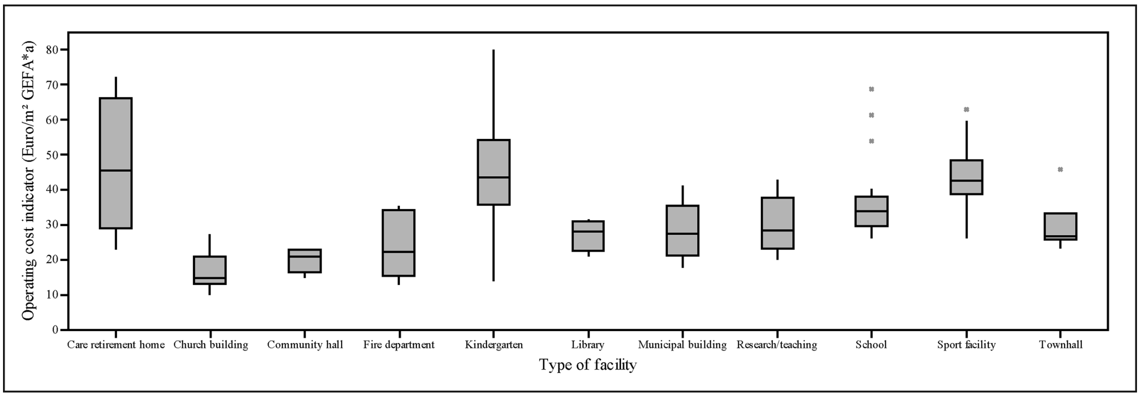

Figure A1: Boxplots of operating cost indicators categorised according to the type of facility

DEVELOPING BUDGET REFERENCE SYSTEMS: TWO CASE STUDIES

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Abstract

This paper presents two case studies about developing budget reference systems. One of them was created to support contractors decisions related to construction costs in a private company. The other one is an ongoing job where "Caixa Econômica Federal", the main public institution dealing with financial support to construction in Brazil, intends to improve its skills to estimate construction costs. In order to improve managers demands, this paper shows how to develop a reference system, based on data site collection and analysis. This empirical procedure gives more confidence to the proposed figures.

Keywords: Budget, productivity, construction costs

1. Introduction

Construction cost estimation is always an important theme to be discussed. Contractors and public and private developers often debate about the correct value to be adressed to a specific project (BAKHSHI; TOURAN, 2014; LAI et al, 2008; OZTAS; OKMEN, 2003; SHEHU et al, 2014; WILMOT; CHENG, 2003). Cost understanding allows several managers decisions: from the project´s viability to the cost control during the building production (JIBOURI, 2003). But it is very accepted that construction costs may vary in a large range accordingly to several features of the project being produced (CHENG, 2014; MAHAMID, 2013; POLAT et al, 2014; WILLIAMS; GONG, 2014).

In order to help decisions based on cost understanding, estimates reference systems are available to support cost estimation. Private and public companies dealing with construction base their cost estimation on a process that uses Cost Data Books. In this context it is important these books contain widespread and reliable information.

In Brazil exists a public database of cost construction which is a reference to finance several kinds of building construction by the Brazilian Government. It's called National System of Costs Survey and Indexes of Construction (SINAPI), which is indicated in the Brazilian Law. The system is maintained by the Brazilian government's financing agent Caixa Econômica Federal. The SINAPI is being updating by a pool of universities in order to represent the different used construction all over the country, as well to comprehend new technologies not contemplated in the previous versions.

Based on author´s previous research experiences, this paper presents both guidelines for the development and some parts of two cost estimation systems developed by them recently for a private and a public companies.

2. Cost construction reference system

Cost estimation can be discussed under several points of view including: monetary versus physical resources approach; global versus partial costs; type of project; contents and context of a project; developer versus contractor; etc.

Based on the literature, the authors see the process of estimating the building construction cost, in terms of direct costs [1],as composed by the following steps (Figure 1): 1) the breakdown of the final product into smaller parts; 2) the quantity estimation of each part (surveying); 3) the

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[1] DIRECT COSTS – *"Costs of completing work that are directly attributable to its performance and are necessary for its completion. 1) In construction, the cost of installed equipment, material, labor and supervision directly or immediately involved in the physical construction of the permanent facility. 2) In manufacturing, service, and other non-construction industries: the portion of operating costs that is readily assignable to a specific product or process area"*. (AACE; 2015)

forecast of the effort (in terms of the items labor, material and equipment) associated to one unit for each part of the product; 4) the evaluation of unit costs for each item; 5) defining global cost.

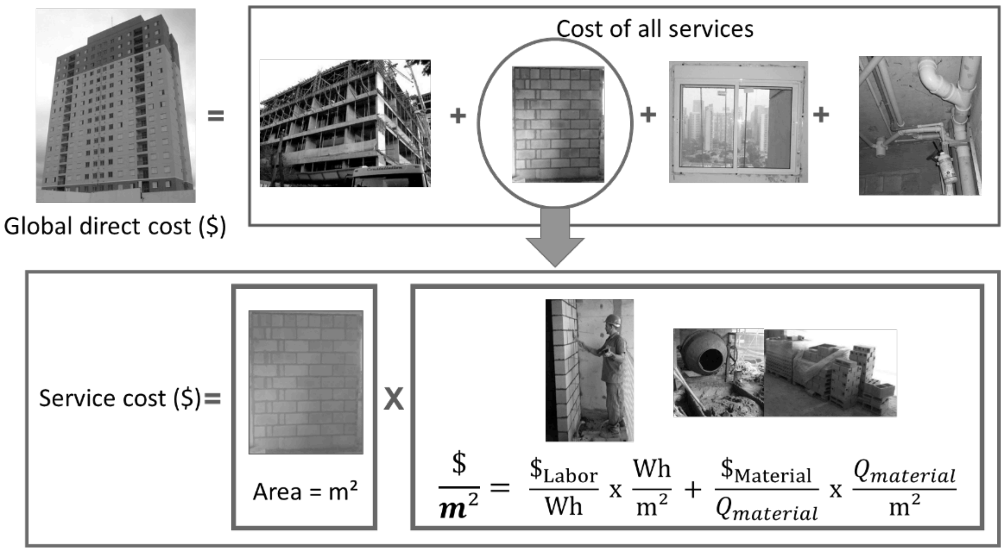

Figure 1: – Estimating building construction cost (Wh = workhours, Q material = quantify of materials)

2.1 Product breaking down

Several approaches are presented in the literature to help divide the whole product into smaller parts (ISO TR 14177:1994; ISO/ DIS 12006-2, 1998; RS Means, 2008; Cho et all , 2013). This paper considers the approach suggested by Marchiori (2009) as the direction to be followed. Breakdown (Figures 2 and 3) is based both on the division for the product but also in terms of the process to be adopted.

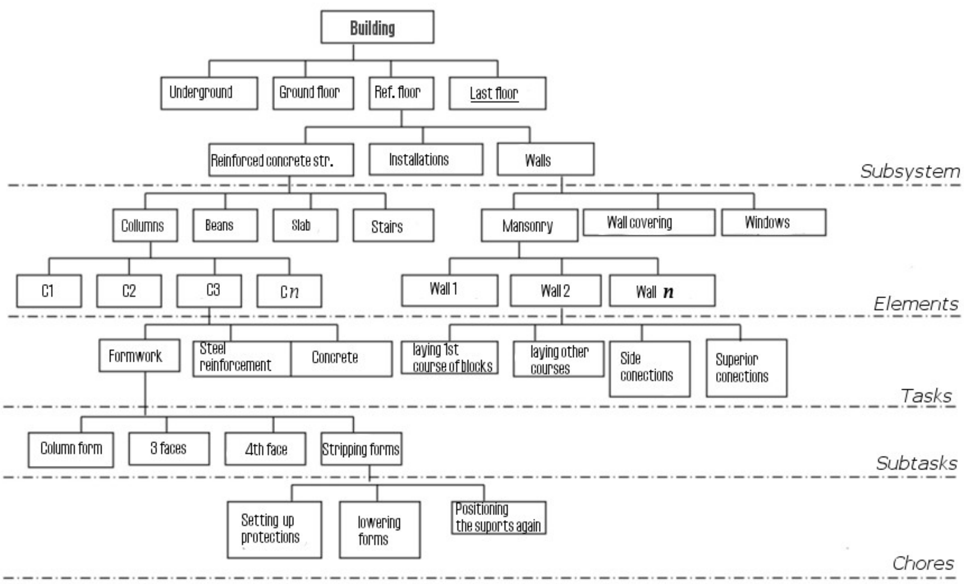

Figure 2: Division of the product (Marchiori, 2009)

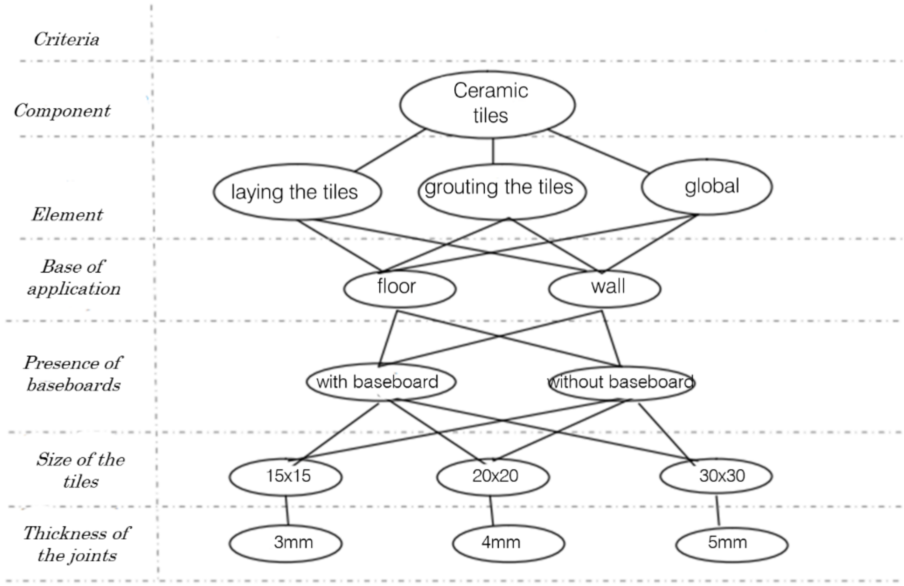

Figure 3: Division in terms of the process (Marchiori, 2009)

The structure proposed by Marchiori (2009) represents better the found conditions in the building sites than the previous structure of information in the Brazilian construction cost databases, once it contemplates what is being done, by who and where, allowing to use of this structure for the integration of information systems, for example to control costs and time in the level of detail that anyyou wants to analyze. This structure was used in both case studies.

2.2 Surveying

Once the "parts" are defined, one have to measure each part extension. Two different approaches are normally found in the literature: measuring the effective extension (BANSAL; PAL, 2007; JADID; IDREES, 2007; SHEN, ISSA 2010) versus take into consideration specificities of the product to define "equivalent" amounts to be produced. See Figure 4 as an example of the two alternatives.

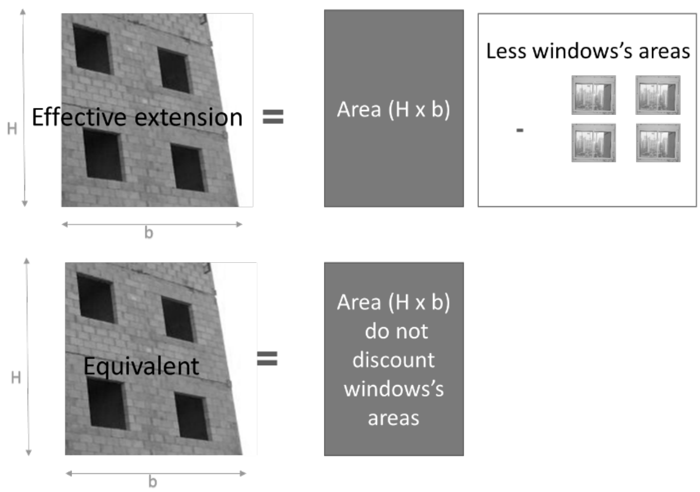

Figure 4: Measuring blockwork.

The authors consider the effective amount of a job has to be considered in order to avoid mistakes in defining what is quantity and relative difficulty.

2.3 Unit Efforts

Different approaches can be used to express the needed "efforts" to produce an amount of certain product. For example, RSMeans define a team with equipments and indicates the job quantity this team makes in one hour (see Figure 5 as an example of RSMeans approach).

22 11 Facility Water Distribution
22 11 13.74 - Facility Water Distribution Piping

22 11 13.75 Pipe, Plastic

		Crew	Daily Outputs	Labor-Hours	Unit
1930	3" diameter	Q1	53	0,302	L.F.

Crew Q-1
1 Plumber
1 Plumber Apprentice

Figure 5: Unit demands accordingly to RSMeans (2008)

The authors consider the most appropriate way to define effort associated to a product production is expressing the amount of each resource demanded to produce 1 unit of the addressed product. Figure 6 show an example accordingly to TCPO.

Plumbing installations
Plumbing - PVC pipe

13.007.000096.SER PVC pipe for adhesive jointing ø 75 mm - unit

Code	Components	Unit	Average Consumption
01.001.000005.MOD	Plumber Apprentice	h	0,406
01.001.000001.MOD	Plumber	h	0,406
14.001.000471.MAT	Cleaning solution for PVC	l	0,001
14.001.000511.MAT	Brown PVC pipe for adhesive jointing (75 mm diameter)	m	1,05
14.001.000564.MAT	jointing adhesive for PVC	kg	0,002

Figure 6: Unit demands accordingly to TCPO (2014)

Unit efforts can be seen as the efficiency in processing the resources. As far as the demanded resources are labor, materials and equipment, the estimator has to deal respectively with labor productivity, material consumption and equipment efficiency.

This paper considers efficiency rates should be defined based on the Factor Model approach (see Thomas et al (1990) for additional information). Figure 7 shows the indicator to be used in a budget is calculated adding a potential unit rate (pUR) to a value considering the usual lack of efficiency (dUR). Both pUR and dUR can be defined based on the statistical analysis of a real database collected in projects of the company defining its budget reference system.

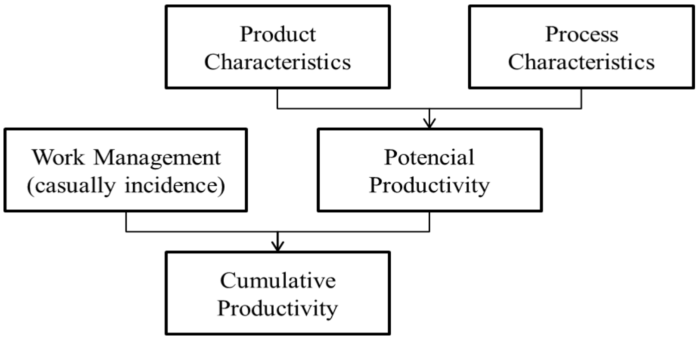

Figure 7: Factor Model as basis to define efficiency unit rates (SOUZA et al, 2014)

2.4 Unit Costs Definition

Each resource has to be evaluated in terms of its cost. The process of evaluating unit costs can also follow several directions. It can be based on price lists, available in specialized magazines, or it can result from a unit cost search.

Both in contractors and in developers many times one can find a department responsible by collecting local prices to support local projects cost estimation. It is also usual to consider the minimum value coming from the search to be adopted to compose the budget.

Once the reference system has to be used in a larger area (for example a country), unit prices can vary accordingly to regional features. In this case, search have to take into account this variability; the subareas to be represented can be larger or smaller as a function of the reliability to be given to the reference system.

2.5 Global Cost

Once the product is divided into parts, each part is measured, unit resources demand is adopted and unit prices are considered, global direct cost is easily determined (accordingly to Figure 1 previously described).

3. Proposed Budget Reference Systems

This item describes some parts of two budget reference systems the authors have the opportunity to help improve. One of it belongs to a private multi story building developer; and the other is still being improved for the largest public funding company in Brazil.

3.1 Case Studies

3.1.1 Private multi story building developer (company A)

Company A is a large Brazilian construction company that works both with developing and producing its projects. Built area in 2015 was more than 16 million m². The goal was to improve building structures cost estimation for multi story buildings in the São Paulo city area.

3.1.2 Public funding (company B)

Financial institution that is the largest public bank in Latin America. This institution operates the application of funds from the Brazilian Federal Budget and operates in the financing of public and private works, mainly focused on basic sanitation, infrastructure and housing (OLIVEIRA et al, 2015).

This bank is also the sponsor of SINAPI – National System of Costs Survey and Indexes of Construction. According to the decree 7.983/2013, directs costs of a public construction must be based on the service compositions of an official system, as the SINAPI (OLIVEIRA et al, 2015).

This System, created in 1969, is the main source of free public construction costs in the country. Every month, the SINAPI web publishes costs references for housing, infrastructure and sanitation works carried out in an urban environment for the Brazil's 27 state capitals (OLIVEIRA et al, 2015).

The goal is to improve the existing budget reference system, dealing with more than 5.000 resources unit rates table providing support to better define unit costs.

3.2 Adopted Aproach

In both cases the goal was to define unit rates for each resource demanded for a certain construction part. In order to get to these indicators, real values were collect in the field.

For company A, the number of case studies for each part was the case studies available at that moment. Due to the high number of ongoing contracts, the sample was ever bigger than B. For company B it was defined a minimum sample sample of 10 contruction sites for any study.

Based on the collected data, the authors processed and analysed than in order to define the unit rate values. For company A, the results were expressed as a range of values associated to the reasons for better or worse performances. For company B, an unique value is associated to specific job description due to the public use of the figures. Figure 8 shows the main steps in developing the reference systems.

Figure 8: Main steps in developing the reference systems

One usual question is about how to take into account the job quality. It is important to state that data collection is related just to the production in accordance to the public and private standards.

3.3 Results

Here some relevant points are present, and not the complete performed job.

3.3.1 Company A

Concrete reinforced structure is one of the most important systems composing the multistory buildings of company A. Then, it was important to improve cost estimation for it. Once the structure conception vary significantly from one building to another, one of the most strong innovation in this reference system was to use the concept of variable productivity.

Figure 9 shows the process to define labor unit rate for column formwork. One can see the labor productivity can vary 90% from the easiest to the hardest conditions to produce one square meter of formwork.

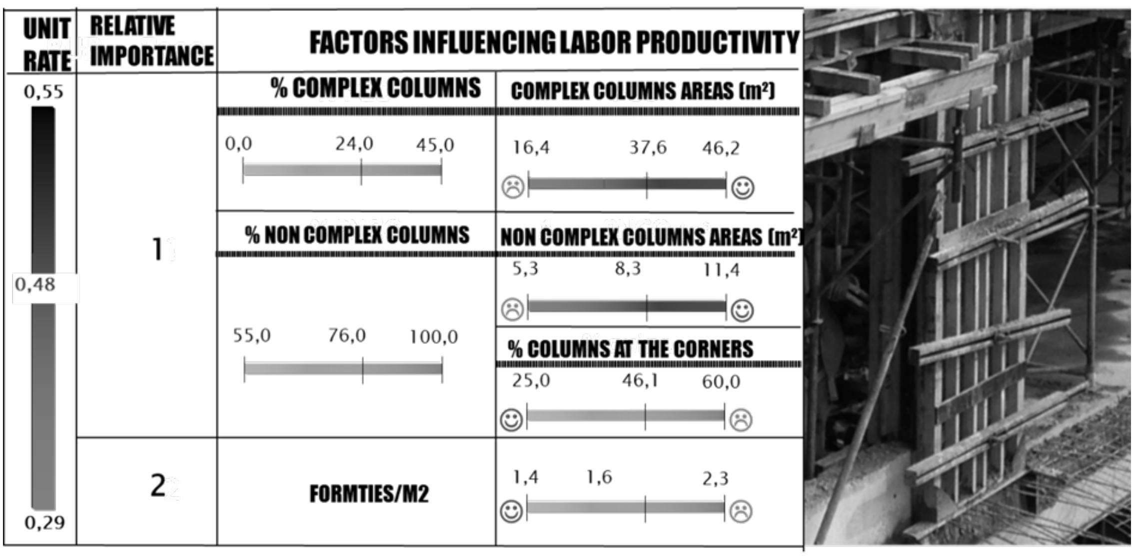

Figure 9: Results of Company A: Labor unit rate for column formwork

3.3.2 Company B

This still ongoing research job is being produced by a team with about 60 people and includes site data collection in 11 cities representing 3 areas of Brazil (see Figure 10)

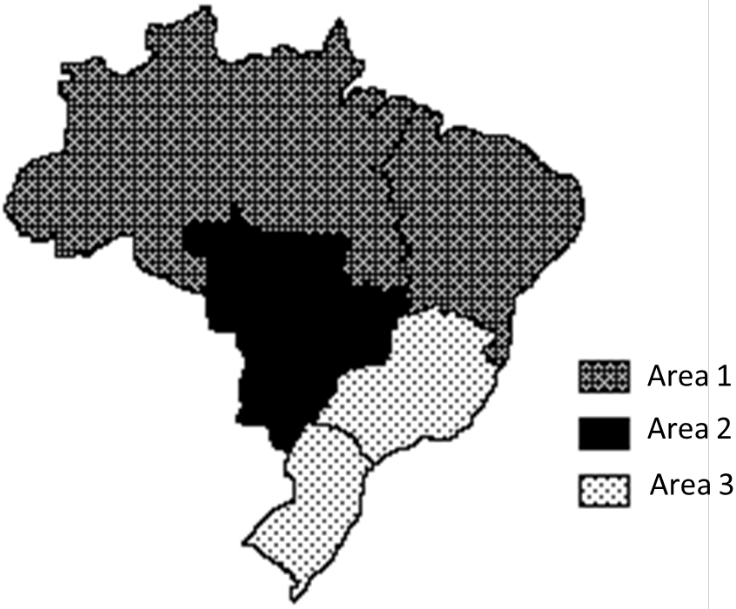

Figure 10: Represented areas in Brazil

Figure 11 shows an example of adopted “product breakdown” for one part of the building (screed). Notice that instead of having just one resources unit rates table for the job, figure 11 shows an extense bunch of alternatives to represent it.

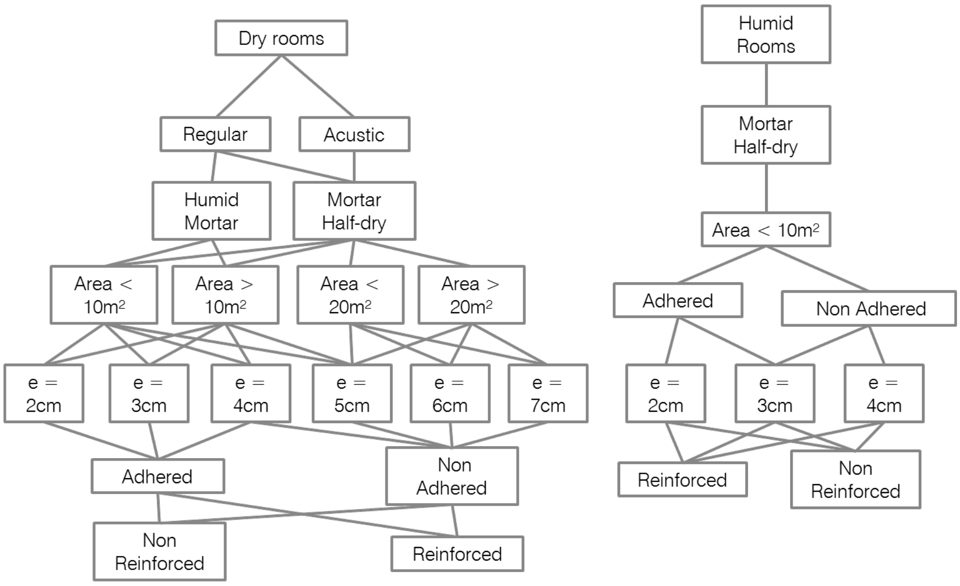

Figure 11: Breakdown of screed

Table 1 summarizes resources unit rates table defined to represent the same job. Here, instead of defining ranges of variation for each resource, a group of resources unit rates table tries to represent all the different features one can face to perform the job. Notice the labor unit rates described varies 200%; and the materials unit consumption includes losses that vary from 0,031m³/m² to 0,076 m³/m².

Table 1: Breakdown of screed

nº	Local	Area	Type	Adhered	thickness (cm)	Reinforced	laborers (h/m²)	Helpers (h/m²)	Mortar (m³/m²)
1	Dry rooms	Area < 10 m²	Regular	Yes	2,00	Yes	0,32	0,16	0,0310
2	Dry rooms	Area < 10 m²	Regular	Yes	2,00	No	0,29	0,15	0,0310
3	Dry rooms	Area < 10 m²	Regular	Yes	3,00	Yes	0,35	0,18	0,0431
4	Dry rooms	Area < 10 m²	Regular	Yes	3,00	No	0,33	0,16	0,0431
5	Dry rooms	Area < 10 m²	Regular	Yes	4,00	Yes	0,38	0,19	0,0530
6	Dry rooms	Area < 10 m²	Regular	Yes	4,00	No	0,36	0,18	0,0530
7	Dry rooms	Area > 10 m²	Regular	Yes	2,00	Yes	0,27	0,13	0,0310
8	Dry rooms	Area > 10 m²	Regular	Yes	2,00	No	0,24	0,12	0,0310
9	Dry rooms	Area > 10 m²	Regular	Yes	3,00	Yes	0,30	0,15	0,0431
10	Dry rooms	Area > 10 m²	Regular	Yes	3,00	No	0,27	0,14	0,0431
11	Dry rooms	Area > 10 m²	Regular	Yes	4,00	Yes	0,33	0,17	0,0530
12	Dry rooms	Area > 10 m²	Regular	Yes	4,00	No	0,30	0,15	0,0530
13	Dry rooms	Area < 10 m²	Regular	No	4,00	Yes	0,32	0,16	0,0530
14	Dry rooms	Area < 10 m²	Regular	No	4,00	No	0,29	0,15	0,0530
15	Dry rooms	Area < 10 m²	Regular	No	5,00	Yes	0,38	0,19	0,0607
16	Dry rooms	Area < 10 m²	Regular	No	5,00	No	0,35	0,18	0,0607
17	Dry rooms	Area < 10 m²	Regular	No	6,00	Yes	0,39	0,20	0,0661
18	Dry rooms	Area < 10 m²	Regular	No	6,00	No	0,37	0,18	0,0661
19	Dry rooms	Area > 10 m²	Regular	No	4,00	Yes	0,28	0,14	0,0530
20	Dry rooms	Area > 10 m²	Regular	No	4,00	No	0,25	0,12	0,0530
21	Dry rooms	Area > 10 m²	Regular	No	5,00	Yes	0,33	0,16	0,0607
22	Dry rooms	Area > 10 m²	Regular	No	5,00	No	0,30	0,15	0,0607
23	Dry rooms	Area > 10 m²	Regular	No	6,00	Yes	0,34	0,17	0,0661
24	Dry rooms	Area > 10 m²	Regular	No	6,00	No	0,32	0,16	0,0661

nº	Local	Area	Type	Adhered	thickness (cm)	Reinforced	laborers (h/m²)	Helpers (h/m²)	Mortar (m³/m²)
25	Humid rooms	Area < 10 m²	Regular	Yes	2,00	No	0,59	0,29	0,0310
26	Humid rooms	Area < 10 m²	Regular	Yes	2,00	Yes	0,62	0,31	0,0310
27	Humid rooms	Area < 10 m²	Regular	Yes	3,00	No	0,63	0,31	0,0431
28	Humid rooms	Area < 10 m²	Regular	Yes	3,00	Yes	0,65	0,33	0,0431
29	Humid rooms	Area < 10 m²	Regular	No	3,00	No	0,66	0,33	0,0431
30	Humid rooms	Area < 10 m²	Regular	No	3,00	Yes	0,68	0,34	0,0431
31	Humid rooms	Area < 10 m²	Regular	No	4,00	No	0,69	0,34	0,0530
32	Humid rooms	Area < 10 m²	Regular	No	4,00	Yes	0,71	0,36	0,0530
33	Dry rooms	Area < 20 m²	Acustic	No	5,00	Yes	0,40	0,20	0,0607
34	Dry rooms	Area < 20 m²	Acustic	No	5,00	No	0,37	0,19	0,0607
35	Dry rooms	Area < 20 m²	Acustic	No	6,00	Yes	0,41	0,21	0,0661
36	Dry rooms	Area < 20 m²	Acustic	No	6,00	No	0,38	0,19	0,0661
37	Dry rooms	Area < 20 m²	Acustic	No	7,00	Yes	0,43	0,21	0,0760
38	Dry rooms	Area < 20 m²	Acustic	No	7,00	No	0,40	0,20	0,0760
39	Dry rooms	Area > 20 m²	Acustic	No	5,00	Yes	0,35	0,17	0,0607
40	Dry rooms	Area > 20 m²	Acustic	No	5,00	No	0,32	0,16	0,0607
41	Dry rooms	Area > 20 m²	Acustic	No	6,00	Yes	0,35	0,18	0,0661
42	Dry rooms	Area > 20 m²	Acustic	No	6,00	No	0,33	0,16	0,0661
43	Dry rooms	Area > 20 m²	Acustic	No	7,00	Yes	0,37	0,19	0,0760
44	Dry rooms	Area > 20 m²	Acustic	No	7,00	No	0,34	0,17	0,0760

4. Conclusions

The authors have a large experience in dealing with efficiency in construction and also are often questioned about misunderstandings about construction costs. They believe construction efficiency can widely vary but the variation can be in a large part understood. Cost reference systems can be a very strong tool to discuss costs once they are carefully composed and represent nowadays technology and efficiency. In both presented cases, the users of the improved reference systems describe they can not only improve the figures resulting from its use but they can more easily discuss cost with other agents dealing with construction projects.

In both cases the produced reference system became an important tool to take decisions. Company A use it to discuss new buildings from the conception stage to the site decisions. And Company B is using its reference system to base all decision regarding to funding Brazilian construction.

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An Energy Expedition

Experiences of a Dutch collective of house owners aiming for energy neutrality

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Abstract

The municipality of Apeldoorn had polled the interest among its private home-owners to turn their homes energy neutral. Based on the enthusiastic response, Apeldoorn saw the launch of the Energy Apeldoorn (#ENEXAP) in 2011. Its goal was to convert to it technically and financially possible for privately owned homes to be refurbished and to energy neutral, taking the residential needs and wishes from occupants as the starting point. The project was called an Expedition, because although the goal was clear, the road to get there wasn't. The Expedition team comprised businesses, civil-society organisations, the local university of applied sciences, the municipality of Apeldoorn, and of course, residents in a central role. The project was supported by Platform31, as part of the Dutch government's Energy Leap programme. The #ENEXAP involved 38 homes, spread out through Apeldoorn and surrounding villages. Even though the houses were very diverse, the group of residents was quite similar: mostly middle-aged, affluent people who highly value the environment and sustainability. An important aspect of the project was the independent and active role residents played. In collaboration with businesses and professionals, through meetings, excursions, workshops and by filling in a step-by-step plan on the website, the residents gathered information about their personal situation, the energy performance of their home and the possibilities available for them to save and generate energy themselves. Businesses were encouraged to develop an integrated approach for home-owners, and consortia were set up by businesses to develop the strategy, products and services needed to meet this demand. On top of making minimal twenty from the thirty-eight houses in the project energy neutral, the ultimate goal was to boost the local demand for energy-neutral refurbishment and encourage an appropriate supply of services, opening up the (local) market for energy neutral refurbishment. This paper will reflect on the outcomes of this collective in the period 2011-2015.

Keywords: Energiesprong, #ENEXAP, LALOG, energy efficiency, local energy initiative, co-design

1. Introduction

As a result of the ongoing trend of individualisation, people are eager to actively influence and shape their own environment (Oostra, 2013). This paper will describe a case study in which owner-occupants did just that, no longer waiting until professionals were ready to deliver the kind of services and offers they wanted. The case study described in this paper was a recent Dutch project, part of Energy Leap (Energiesprong), an innovation programme commissioned by the Dutch Ministry of the Interior and operated by Platform31. The programme ran until the end of 2014, although parts were later extended to the end of 2015. The aim was to make various types of buildings energy-neutral and to boost large-scale initiatives. In the sub-programme LALOG (Lokaal Alle Lichten Op Groen) the owner-occupants themselves were looking for ways to challenge professionals to make their homes energy-neutral. The LALOG sub-programme provided support to groups of owner-occupants in six municipalities: Apeldoorn, Wageningen, Den Bosch, Hoorn, Amsterdam and Amersfoort. Goal was to convert at least 20 homes in each of these municipalities to energy neutral. It was a process of learning by doing by residents, builders, municipal officers, installation contractors, appraisers and other professionals. In this paper we will focus on the experiences of the Energy Expedition in Apeldoorn, also known as #ENEXAP.

2. Theoretical framework

There are basically two main bodies of knowledge relevant as theoretical framework. One is the literature on innovation management in which innovation is seen as a combined technological and economical phenomenon looking at companies (e.g. Von Hippel 1986, Chesbrough, 2006), entire supply chains (e.g. Vrijhoef, 2011) or the industry as a whole (e.g. Lundvall, 2008). Most relevant in the context of the case study are the theories focussed at upscaling from an innovative technological niche towards uptaking in the current regime (Strategic Niche Management (SNM)). The other body of knowledge relevant for this paper is the world of grassroots innovations and community action directed at fundamentally rethinking all aspects of our current society in order to build an intrinsic sustainable way of living. These two knowledge domains not only represent two different scientific communities, they represent fundamentally different groups of people with distinct discourses and practices in real life as well.

2.1 Innovation management

For innovation at the level of (a part of) an industry, the term transition is generally used. The perspective of social-technical transitions has emerged from evolutionary economics (Nelson & Winter, 1977; Dosi, 1982). From studies of former mayor changes in society e.g. the transition from horse carriage to rail and steam trains, from cottage industry to mass fabrication, insights have emerged regarding the importance of experimentation, multi stakeholder learning, coevolution of technologies, new ways of organisation, rules & regulations and financial systems. This resulted in theories of Strategic Niche Management and Multi Level Perspective (Geels & Kemp, 2007; Loorbach & Rotmans, 2006), which can be used to analyse current innovations. The rationale in these theories is that innovations start in specific niches, but their further development is highly dependent on other changes in the different societal levels (micro, meso and macro). SNM describes emerging innovative niches becoming mainstream in combined dynamic social and technological systems.

The innovation management perspective focuses on the formation of niches in which innovations can flourish. In this perspective, residents would learn to use their purchasing power to get the innovations they want, in order to be able to improve the energy performance of their homes towards energy neutral. According to Strategic Niche Management, three additional processes are important when developing a successful technological niche (Kemp et al., 1998):

- The articulation of expectations and visions that would provide direction to the learning process of parties involved. The expression of visions and expectations would also help to attract attention from the necessary stakeholders and legitimate their involvement and support.
- Construction of social networks. Interaction between different stakeholders is needed to collect the required resources (time, expertise and money) and commitment.
- Learning on multiple aspects: (1) Technical aspects and design specifications, (2) Market and user preferences, (3) Cultural and symbolic meaning, (4) Infrastructure and maintenance networks, (5) Industry and production networks, (6) Regulations and government policy and (7) Societal and environmental effects.

2.2 Grassroots innovations & community action

Until recently, the attention for innovation from the voluntary sector and local communities was not really taken into consideration despite decades of initiatives at local level. As a result, little is known about the success factors and the way these grassroots innovations take place. The innovation in these bottom-up initiatives consists mainly of social innovation. Seyfang and Smith (2007) define grassroots innovation as follows:

> *"Grassroots innovations are networks of activists and organisations generating novel bottom-up solutions for sustainable development and sustainable consumption: solutions that respond to the local situation and the interests and values of the communities involved." (Seyfang & Smith, 2007, p.585)*

Local initiatives usually construct alternative systems in which production, distribution, marketing, retail and consumption are connected in a novel way. Since the publication of the Limits to Growth report (Meadows et al., 1972) environmental movements emerged that experimented with different ways to minimize their ecological footprint. Inspired by Schumacher's 'Small is Beautiful' (1973) pioneers also addressed housing with appropriate technology, i.e. adopting a scale and complexity of technology appropriate to its setting. Seyfang and others translated the conclusions of their academic work in ten important statements directed at policymakers in relation to local energy initiatives, aiming to support innovation from these local initiatives. Community Energy is (grassrootsinnovations.org):

1. Critically important for sustainable (energy) transitions (Hielscher et al., 2013)
2. A diverse, growing, grassroots-led movement (Seyfang et al., 2013b)
3. About more than just sustainable energy (Hargreaves, 2012)
4. Thrives on local enthusiasm, but can't rely on goodwill alone (Hielscher, 2013)
5. As much about soft skills as well as hard technology (Seyfang et al., 2013)
6. Not yet being taken seriously enough by government (Seyfang et al., 2013)
7. Connected to community and sustainability networks (Seyfang et al., 2013)
8. Benefits from strong support networks and organisations (Hargreaves et al., 2013)
9. Reaches parts of society the private sector alone cannot reach (Martiskainen et al., 2013)
10. Demands flexible and tailored policy support at all levels (Hargreaves et al., 2013)

2.3 Integrated framework for analysis

The two frameworks of innovation management and grassroots community action were integrated into one integrated framework to analyse #ENEXAP:

- Articulation of expectations and visions
- Construction of social networks: (1) Diversity of actors, institutional forms and activities (2) Social capital (networks of support), human capital (skills), organisational capital (know how), financial capital (3) Contacts on local, regional and national levels an (4) Sector support infrastructure
- Learning on multiple aspects: (1) Technical aspects and design specifications (2) Market and user preferences (3) Has different meaning to the people involved (4) Infrastructure and maintenance networks (5) Industry and production networks (6) Regulations and government policy, and (7) Learning by doing, face-to-face support and mentoring.

3. Purpose & methodology

This paper will reflect on the outcomes of the collective in Apeldoorn. The subsidized #ENEXAP project ran in the period 2012 - December 2014. The period that is described in the paper is October 2013 until June 2015. The description of #ENEXAP case is based on the authors' experience as part of the initiative. Oostra was member of the #ENEXAP board from November 2013 until April 2015, Been was secretary and resident advisor for #ENEXAP from March 2013 until June 2015. The material on which the analysis is based derives from action research, board meetings, occupant meetings, meetings with Energy Leap, study meetings for the companies and conversations with people related to #ENEXAP. First a general description of the case study will be made. The next sections will be dedicated to the description of the results and the analysis of the results before ending with the summary.

4. Case description of Energy Expedition Apeldoorn

In 2011, Apeldoorn saw the launch of the Energy Expedition Apeldoorn (#ENEXAP). The municipality of Apeldoorn was curious to find out how many of its residents were interested in making their homes energy neutral, and placed an announcement in the local newspaper, 'Stadsblad'. A large group of owner-occupants came to the meeting. This resulted in a group of 33 households that started as part of the Expedition in May 2011, growing to 38 households during the process. The Expedition was supported with a LALOG subsidy from 2012 until December 2014. LALOG's direct goal was to refurbish a minimum of 20 homes making them energy neutral, taking as starting point the input from occupants. The overall ambition was to make it technically and financially feasible for owner-occupants to retrofit their home, starting with this small group and from there on boosting the local demand for energy-neutral refurbishment and encourage an appropriate supply of services. The #ENEXAP team comprised of local residents, businesses, civil-society organizations, the municipality of Apeldoorn and the local University of Applied Sciences, Saxion. These different groups al played a constructive role in carrying out the Expedition. Owners fuelled professionals with their ideas and wishes; professionals helped owners to make their wishes achievable. In the next paragraphs, the roles of the key players in the Expedition are described.

Table 1: Roles of the different stakeholders in #ENEXAP

Stakeholder	Role
Owner-occupants	*(1) The occupant-owners played an active and vital role in shaping the process. The board of #ENEXAP consisted merely of residents. After the founding of the Expedition, residents formed working groups, which were started to address different relevant issues. (2) Residents actively monitored the energy consumption in their own homes. They put a lot of effort in making their residential wishes explicit. They were guided in this by a course and a specially developed step-by-step plan. (3) Residents were actively involved in the development of solutions by professionals.*
Advisers	*(1) Several professionals brought in their knowledge on sustainability by presenting on one of the meetings for occupants or by giving a tour. Because of the innovative character of the initiative they were often willing to do so for free. (2) Additionally professional support was hired for organisational issues, but also for communication strategy and the development of a magazine. Professional support was also hired for executing three EPA Super Luxurious analyses, matching financial advice and support for the Board.*
University of Applied Sciences	*The university was asked to develop and organize two courses to the residents as well as the consortia. The first course was intended to help the occupants to articulate their requirements, how to formulate these to professionals and how to weigh different solutions e.g. financially with the principles of Total Cost of Ownership. During the course for professionals the focus was on how to deliver an integrated offer to this specific group of clients. A second course for professionals was directed at how to make an energy fingerprint of a dwelling, how to respond to a wide range of demands from clients by using principles of mass-customization and what is involved in providing a warranty on energy performance after a retrofit. The university was also part of the Board.*
Companies & consortia	*At first large contractors were linked to #ENEXAP. They dropped out because their primary interest in larger building assignments, e.g. block by block retrofitting of terraced houses with a high level of standardization. In the Expedition however, the houses are of varying types, spread around Apeldoorn. The companies that remained linked were local SME's. They made integral plans for energy neutral refurbishments, which was highly challenging for them, because of a lack of knowledge necessary for these assignments. #ENEXAP handed the SME's knowledge through courses and contact with a group of interested clients.*
Energy coaches	*The energy director helped residents to make a choice for the consortium that fitted their requirements best and helped owner-occupants in requesting quotes and the evaluations of these bids. The energy director was meant to be the intermediary between owner-occupant and companies. An auditor was appointed as supervisor to offer extra safety for the participants, by providing an extra check on the plans. In practice the roles of energy director and auditor were combined. For the residents group coached by a specific energy director the other functioned as auditor, and vice versa. Instead of 'energy director' and 'auditor' the name of 'energy coach' was therefore more appropriate.*
Municipality	*(1) The municipality proved to be an important party since they took the initiative for the start of the*

	Expedition. They decided to make an inventory of residents interested in energy neutrality. (2) They were also the party that applied for a LALOG grant (€ 285.000) that was combined with money from SLOK (€ 33.265) and money from the municipality's budget (€ 6.000). Also money from the EU project ACE was available for product development and feasibility studies (€ 84.500) (Apeldoorn, 2012). (3) The municipality was part of the Board of #ENEXAP and (4) formed the link to the national energy programme.
Energy Leap	*(1) Energy Leap organised several meetings to exchange information between the stakeholders in the municipalities involved in the LALOG programme. (2) Energy Leap also made links to other parts or parties in the Energy Leap programme that were of interest for #ENEXAP. For example the expertise was shared, that was being developed around the topic of energy performance guarantees (e.g. the standard contract) in Rapids, another sub-programme directed at dwellings. (3) Experts were invited to give presentations at either one of the occupants meetings, as part of the course made available to the local SME's or for special sessions. #ENEXAP was asked by Energy Leap to host one of the field trips for appraisers. In this field trip appraisers from around the country were asked to make an estimate of the dwelling before and after the retrofit in order to establish how an improvement in energy performance would translate in additional financial value of the dwelling.*

5. Results

The overall result of the Apeldoorn Energy Expedition was that in June 2015, after being roughly four years en route, five houses were well on their way towards becoming energy neutral. Three consortia of local SME's were formed, and residents had started to save considerably on energy.

Table 3: Goals of the LALOG program vs. results of #ENEXAP

Goals of LALOG	**Results of #ENEXAP**	**Remarks**
To put owner-occupants central in the development program	*Owner-occupants were in the lead.*	*This worked very well for focussing on the topics relevant for owner-occupants. It proved to be a hindrance for the continuation of the program after the end of the LALOG subsidy.*
De-burden occupant-owners in their search of energy neutrality	*The formation of a new consortium of companies focussed at the retrofitting of owner-occupant housing, training of 3 local consortia and the development of an approach that would fit both clients and entrepreneurs.*	*Proved to be difficult since the innovation leap required was very steep for the companies involved. These companies operated in a context were business and investment money was scarce. For them it proved to be very difficult to commit to the required product and process innovations.*
20 dwellings energy neutral	*June 2015 5 #ENEXAP houses were energy neutral or were in the process of becoming energy neutral.*	*It was not easy to reach this goal. There was only one other LALOG municipality that succeeded in realizing 5 energy neutral dwellings (Energiesprong, 2014).*
Secondary – To integrate higher comfort level, healthier indoor climate and an increase of functionality with a considerable reduction of the energy bill	*A combination with other requirements of the clients proved to be key during the program. Important additional requirements were: additional space, conversion of bathroom and/or kitchen and future proofing of the home.*	*It turned out, that the secondary goals of the LALOG program were essential to the occupant-owners. In case the consortia tried to eliminate an important secondary requirement of the client, the process came to a halt.*
Secondary - Promote the use of environmentally friendly products	*Attention was given to environmentally friendly products in presentations given at occupants meetings, in excursions and it was the expertise of one of the energy directors in #ENEXAP.*	*This was regarded as a matter of taste within #ENEXAP. To some of the occupant-owners this proved to be important, mainly because environmentally friendly products are associated with a healthy indoor environment.*
Secondary - Increase of the value of the dwelling	*This topic was not so much addressed in the sessions between occupants and companies since they themselves were not able to answer questions on this topic. Neither was the local broker.*	*This knowledge had to be developed. Energy Leap understood the importance of this question and organised two field trips of appraisers. One was hosted by #ENEXAP.*
To draw a business case for the companies to allow for continuation of energy neutral retrofitting after the duration of	*The following was developed in order to smoothen energy neutral retrofitting:* • *Step-by-step plan for the occupant-owners as a*	*The companies were focussed on making money from the start, as this is the way they are used to do business. They were not accustomed to heavily invest in the*

#ENEXAP	*means to aggregate all the information necessary about their homes and current energy consumption.* • *A financial check and a website to structure and exchange of all the information gathered.* • *Courses to help occupants to make their requirements explicit and for companies to be able to develop an integrated approach and matching offers.* • *A one-stop-shopping approach towards clients, which includes scrum-sessions at the kitchen table with all disciplines present to draw up quickly a tailor-made solution.* • *A coaching approach to support companies during their first assignments with clients.*	*development of a new (industrialised) market approach, while #ENEXAP was trying to focus on opening a bigger market on the long term for which new retrofitting concepts and approaches needed to be developed. For Energy Leap the experiences from the LALOG programme were a reason to design new subsidy programmes: Rapids Rental and Rapids Purchase.*

6. Analysis & discussion

In this paragraph we analyse the case study by confronting process and results with the integrated framework introduced in paragraph 2.3.

ARTICULATION OF EXPECTATIONS & VISIONS

The structure of the experiment was designed to support residents: the course, the interactions during kitchen table conversations, but also the discussions that emerged around presentations and excursions all helped to articulate expectations and visions. This stimulated the owners to aim high and ask for innovative solutions, be fitting their situation and demands, thereby stretching the abilities of the consortia. So the group of owners demanded innovation, but on the other hand they requested warranties on energy performance. This combination was hard on the consortia to achieve, however, the group would not let go of this high ambition.

CONSTRUCTION OF SOCIAL NETWORKS

Diversity of actors, institutional forms and activities - In a period of three years, different groups of residents, professionals and intermediaries were brought together to work on the goals set: zero energy houses and fulfilled residents wishes, while at the same time paving the road for a widespread of retrofitting in the nearby future. This required bridging the gap between residents and professionals, which both speak a different language because of different knowledge levels, perspectives and goals. During the course of several meetings, workshops and excursions residents and professionals acquired knowledge, both technical and about the perspective of the other group, and learned how to fill in their role. In the mean time, several products were developed, from which the most important one is the step-by-step plan. In working groups, residents and professionals with different expertise worked together on specific themes. There were several working groups for technical issues, EPA Super Luxurious, finances and communication. The communication group made a website to monitor progress and to serve as a discussion platform. Courses were held to support both residents and professionals in finding their way. Outcomes were that residents could better articulate their wishes and needs, a new consortium was formed and approaches were developed for the professionals to be able to make multi-disciplinary offers.

Social capital (networks of support), human capital (skills), organisational capital (know how), financial capital - There was a network of similar initiatives like #ENEXAP with initiatives in Amsterdam, Amersfoort, Wageningen, Den Bosch and Hoorn, that met once in a while. Also there were discussions with the Energy Leap programme. This provided a network to exchange ideas and inspiration. It also helped to see that others were also struggling to meet the goals set at the beginning by the Energy Leap programme. Because of the diversity of actors involved, people willing to give lectures and advise, and money from the programme to hire missing expertise, knowledge and skills needed in development were available.

Learning by doing, face-to-face support and mentoring - The goal was clear but the road to get there wasn't. This fostered learning by doing. The pilot EPA Super Luxurious e.g. turned out not to work as it was intended. The contractors did not directly translate the reports written by energy advisors into matching offers. Instead these companies either presented alternatives to the solutions proposed, or just started the work all over again. Because of the community feeling, people remained focused on the goals, although it was sometimes hard to find the right course. The social network helped to keep the parties involved on track when confronted with setbacks. The local setting, the organized activities and the energy coaches made regular face-to-face support available for both residents and companies. The energy coaches were mentoring both residents and companies on how to formulate interesting offers.

Contacts on local, regional and national level - Local contacts were organised within the Expedition and by reaching out to the expertise required. Energy Leap, the municipality, Saxion and professionals involved provided contacts on regional and national level when necessary.

Sector support infrastructure – Additionally, the municipality made hours available from a civil servant. And of course there were as well hours available from the different (professional) volunteers. This made it possible to erect an infrastructure to support interested owner-occupants in converting their own dwellings to energy neutral as well as to support local companies interested in exploring this new emerging market. Most of this supporting infrastructure is already described above.

LEARNING AT MULTIPLE ASPECTS

Technical aspects and design specifications - Technical aspects received a lot of attention in presentations at meetings, excursions and kitchen table conservations between consortia and owner-occupants. The kitchen table conversations and the first course helped in making the requirements from the occupants explicit. This formed the basis for the design specifications.

The Plugwise system was used to measure the consumption of electricity. It helped to create awareness on energy consumption necessary to operate different appliances in the home. For most people it was a complete surprise to see what the usage of a specific appliance meant, e.g. the electric boiler in the kitchen, the tap with boiling water or the electrical floor heating. This insight was essential to take further steps, e.g. changing equipment or just switching devices off.

Market and user preferences - The experiment can be seen as a way of developing a new market. #ENEXAP was an experiment, a pioneer project. The market was, and still is, learning how to accommodate clients' wishes and requirements when retrofitting individual occupant-owned houses to energy neutral in an integral way. At the same time, user preferences within this project proved to be very specific, being influenced by specific housing types and lifestyles. Therefore, every solution had to be tailor-made. For the companies involved it proved to be very challenging to develop matching supply for energy neutrality in combination with the other requirements. In board meetings it was also discussed that the consortia should integrate the wish of several occupants to think about combinations of professional work and DIY. The majority of the board saw this as a risk to overburden the consortia and the idea was therefore put aside.

The initiative has a different meaning to the people involved - The Expedition was about being adventurous: developing unexpected roads together, while enhancing sustainability. Owner-occupants had various reasons to take part in #ENEXAP. During the experiment it became clear that the idea of a sustainable, environmental friendly home with a small ecological footprint was an important driving factor, but not for all. There were also people part of the programme that were technologically interested, or focussed at reducing operational costs of living. This underlines outcomes of other research about the profile of people interested in energy neutrality (e.g. Hensen & Westerhof, 2013). For a part of the group it became a sort of hobby: improving their house, replacing e.g. lighting and refrigerator or just switching off a close-in boiler or waterbed, and sharing experiences with co-participants. The financial investment made by occupant-owners didn't need to be earned back completely by lower monthly energy costs; also the feeling of being part of this new, sustainable movement and acquiring more comfort or other functionalities were rewarding for the people involved.

Infrastructure and maintenance networks – During the training attention was given to maintenance and performance guarantees. This appeared to be very challenging for the consortia. External expertise from the Energy Leap programme was made available. In the end this did not lead to concrete offerings including maintenance and performance guaranties.

Industry and production networks - The technical innovation expected from the Expedition did not materialize. The local SME's were not equipped to create specific innovative products or designs. The industry able to come up with innovative products was not part of the Expedition. LALOG turned out to be an important lesson for the Energy Leap programme that they needed to create a different framework in order to realise the change in industry required for cost effective implementation of retrofitting at a large scale. This finally resulted in a new sub-programme: Rapids.

Regulations and government policy - The local government took their citizens seriously, since they initiated the #ENEXAP in order to reach governmental goals. Nevertheless, policies on for example permits for refurbishing were not able to provide the flexibility required right away. The local government tried to work with the occupant-owners to make the process of permit acquisition as smooth as possible. And discussions were started around topics like whether trees should be taken down in neighbourhood streets that would be blocking sunrays to reach solar panels and about the conditions necessary to meet flora & fauna legislation.

Societal and environmental effects - In the Netherlands there are approximately 7.2 million dwellings, among which a lot of terraced houses build between 1946 and 1991. The municipality of Apeldoorn has 156.960 inhabitants and consist of 67.780 households (Stadindex, 2015). To give an indication of the amount of energy that can be saved: 1.04 PJ per year by retrofitting 10 % of the Dutch housing stock to zero-on-the-meter in a period of 10 years. The average energy consumption per dwelling in the Netherlands is 1440 M3 natural gas and 3440 kWh of electricity (Nibud, 2015). This is 53 GJ per dwelling. When 10 % of housing stock will be retrofitted to zero-on-the-meter in 10 years (19,650 a year) it will represent a saving of 1.04 PJ of fossil energy per year. In the Netherlands, the gross revenue per employee per year was 310,000 Euro in 2013 (EIB, 2013). By linking the above gross turnover of 8.8 billion per year and the gross turnover per employee in the Netherlands, it will result in 28,000 jobs per year. For Apeldoorn only, the effects will be scaled to ratio of course.

Is as much about soft skills as well as hard technology - This experiment shows that technical knowledge alone was not enough to reach the goals of this experiment. The courses and the energy coaches had to guide the process and translate between both clients and companies. The road to success was not easy, mainly because next to goodwill, also knowledge both technical and process related, was needed to guide all the parties in the right direction. Also the process by which the clients were approached by the consortia, the so-called customer journey, had to be addressed by the energy coaches. Scrum sessions were introduced to speed up the process and to diminish the time needed by the companies to formulate a tailor made offer.

7. Summary & concluding remarks

The developments in the Energy Expedition addressed aspects of both views mentioned in the theoretical framework: innovation management and grass roots innovations. Both emphasize the construction of a new community, or niche, focussed at a mutual goal and room for learning. In the integrated framework this was translated in the backbone of the three pillars of the integrated framework constructed in section 2.3: goal articulation, social networks and learning. All three have played an important role in the functioning and results of the Expedition.

Starting point was the articulation of the ambition of energy neutrality. The Expedition stimulated owner-occupants to articulate their specific expectations and demands. Their high ambition level stimulated the consortia to give their best. They started developing one-stop-shop formulas and integrating existing products into customized solutions.

The programme in itself formed a coalition of occupant-owners, companies and facilitating parties. This coalition shared experiences and expectations for a period of three years e.g. during meetings, excursions and courses. This social network was the carrier and basis for the meetings, working groups and other interactions. Furthermore, the network helped to survive setbacks and to maintain drive and enthusiasm.

The new and dynamic network that was constructed around #ENEXAP provided the necessary conditions for learning. Learning was not so much on technical aspects as on social innovation, like market and user preferences, speeding up of the offer preparation process and soft skills. In relation to market preferences, it was learned that owner-occupants demanded tailor-made solutions based on their specific situation. An important lesson from this initiative is that for consortia focussing on the market of retrofitting owner-occupant owned dwellings it is essential to look at all requirements: energy performance, comfort level, future proofing of the home and other additional requirements, and to do this in an integrated way. Moreover, the owner-occupants want a warranty on energy performance. Soft skills proved to be key to bridge different knowledge levels, perspectives and goals. Finally, it can be concluded that the combination of expertise and roles necessary to upscale the retrofitting of occupant-owned dwellings requires even more integrated value chains. It also became clear in #ENEXAP, as in LALOG that disruptive product innovations are key to arrive at affordable energy retrofitting solutions necessary to realise large scale retrofitting of owner-occupant owned dwellings. New sub-programmes, Rapids Rental and Rapids Purchase were initiated to accomplish just that.

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The energy concept of a post-2020 housing development zone – economic assessment

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Abstract

This paper presents a housing development project in Tampere. Part of the construction of the zone will take place after 2020. The buildings constructed after that in the zone must be so-called 'nearly zero' buildings. Another significant constraint is the location in cold climate.

The project examined several different energy solutions. They differed from each other in the way heat and electricity was produced for the area. In these solutions, heat was either transferred to the area via traditional district heating, produced using heat pumps or solar thermal collectors. The electricity solution, on the other hand, was either concentrated, i.e. a power grid, or self-produced using photovoltaic panels.

Energy consumption was calculated using dynamic IDA-ICE simulation software, which used as input data hourly consumption profiles of an adjacent zone. The structures of future houses are in compliance with the energy efficiency targets set for the period in the National Energy Path. Primary energy and greenhouse gas emissions were calculated using local coefficients. The economic review covered the calculation of the payback period, the internal rate of return and the total cost.

Geothermal energy as a source for heating and electricity supplied by the network turned out to be the competitive alternative compared to traditional system, whether the decision was based on primary energy consumption, greenhouse gas emissions or economy.

Keywords: nzeb, RES, heating, electricity, economy

1. Introduction

The target area is located in Tampere. According to Köppen's climate classification, Tampere as well as Finland wholly belongs to the temperate zone with cold, wet winters with sunlight marginally. The mean temperature of the warmest month is no lower than 10°C and that of the coldest month no higher than -3°C.

The area in question is an abandoned industrial area that will be rebuild to residential use. The industrial area was sold to a property developer who has planned the area in cooperation with the city. A neighbourhood construction cooperation model known as "collaborative urban planning" (Nykänen et al., 2007) has been applied to the planning process. In the model, the planning of the residential area and town planning are carried out jointly by the construction company and the planning organisation of the city. This procedure is suitable for projects where special objectives have been set for an area, such as energy efficiency or higher-than-usual quality.

In the target area, such objectives had been set precisely for energy efficiency and customer orientation. Communications with the neighbourhood and potential residents have already been close during the town planning stage. The planning is otherwise proceeding normally with regard to background investigations and hearings that have also caused changes to the plan. Among other things, the final floor area (218 000 m^2) is lower than the first proposal.

The floor area of the residential buildings is large compared to the local housing market. For this reason, the construction is distributed over a period of ten years. This means that some of the buildings will not be completed until after year 2020, when all construction in the Member States of the European Union must be nearly zero energy buildings. A nearly zero energy building refers to an energy-efficient building as defined in the Energy Performance of Buildings Directive (2010). The required amount of energy that is nearly non-existent or extremely small should be covered to a large extent with energy from renewable sources, including renewable energy generated on-site or in the vicinity of the building.

2. Project goal

The main goal of the project has been to find a suitable energy system for the new residential area comprising near zero energy buildings. The suitability has been examined from several different perspectives. These make up the project's sub-goals or examinations from 1) the technical perspective (energy production), 2) the environmental perspective (greenhouse gas emissions) and 3) the financial perspective (investments and expenses during service life). This conference paper concentrates on sub-goal three, or financial examinations. Sub-goals one and two are discussed only to the extent to which they affect sub-goal three. It should be noted that the issue in question is the selection of a district-level energy system. Building-level solutions have been excluded, although the district systems might require their modification.

3. Research method

The energy consumption of the buildings in the area has been assumed to comply with the currently valid regulations until the year 2020, after which consumption is at the zero energy level. The hourly energy consumption profiles have been adopted from the neighbouring area, where new apartment blocks have been built over the last couple of years. The availability of light and warmth from the sun is similar in these two residential areas. It is also likely that the area will attract households of a similar type as the previously built area.

Several solutions for satisfying the need for energy have been investigated, taking into consideration the aim to increase the share of renewable energy in the buildings' energy consumption. Information on renewable energy yields has been received from both the industry and studies by our own research organisation.

3.1 Evaluation of solutions

The first financial examinations focused to the alternative decentralised solutions that use different forms of renewable energy. These calculations were done using a calculation model developed in the Renewable Energy Multitechnology Mix -project (REmix www-pages). The tool uses the basic key indicators of investment calculations (the payback period, the internal rate of return (IRR), and the net present value (NPV)). The calculation model also supports taking into consideration synergies resulting from the parallel development of several different forms of energy already from the planning stage. The model was developed to support the decision-making of, in particular, the municipal sector, so indirect effects can also be included in the calculation.

The basic idea of the model is to compare (at least to a certain extent) the solution implemented using renewable forms of energy to a "business as usual" solution comprising district heating and grid electricity. This assumption is extremely well suited to investments for replacements, where the current solution is based on district heating and grid electricity. The assumption can also be justifiably used as a comparison alternative in new construction areas, where district heating and grid electricity would be easily obtainable.

The payback period is the most commonly used investment calculation method, as it is simple to use and easy to understand. In this case the investments are made in equal parts over a period of ten years. The assumption is that the price of energy will increase and the price of technology decrease, each part of the investment will be made in a slightly different price environment.

The internal rate of return, in turn, indicates the discount rate at which the net present value of the investment is zero. The investment can, thus, be considered to be profitable if the internal rate of return is higher than the required rate of return for the capital or discount rate used by the operator.

3.2 Total cost comparison

The second calculation focused to the investment and the operating costs of all alternatives. These total costs have been calculated over a period of 25 years applying methodology framework for calculating cost-optimal levels (2012/244/EU). To be noted that the evaluations are done from the perspective of the Limited Liability Housing Companies.

4. Energy solutions and calculation assumptions

4.1 Alternative heat carriers for an energy system

Geothermal heat (GTH) is energy absorbed into the ground and water, mostly originating from the sun. GTH can be utilised with a heat pump regardless of the time of year (Lauttamäki et al., 2013). The pump collects heat from a drilled heat well that is typically around 200 m deep, or from a heat collection field installed either to the ground (depth one metre) or bottom the lake (depth two metres). The pump consumes electricity during the process, and the amount of heating energy it produces is typically around three times the amount of electricity it consumes.

Solar energy can be collected directly with **solar thermal collectors (STH)** or **photovoltaic panels (SE).** In Northern Europe, the problem in their utilisation is that the heat and electricity are generated at a different time than when they are used. Solar energy is most abundant during the summer, when its only application is heating household water (Pesonen et al., 2012). Both solar thermal collectors and PV are used as a secondary system. In order to maximise the power from the panels, they should be positioned facing south. Solar electricity is most cost effective when utilised right away. Storing electricity is not yet economically profitable due to the high price of batteries. The panels have an efficiency of around 10 to 20 per cent, which means that around 100 to 200 kWh/m^2 of the annual solar radiation energy (1,000 kWh/m^2) can be converted into electricity.

A district heating (DH) network comprises power plants and pipelines going into the heating stations of the buildings. Heat is transferred from the warm water entering the heating stations to the buildings' own heating systems. District heat can be produced most energy-efficiently in Combined Heat and Power (CHP) plants producing electricity and, as a side product, heat that is then fed into the district heating network. District heating can also utilise incinerated waste and industrial waste heat (District heating –site).

Electricity network (NE) is a basic service. The task of the electricity network is to transmit the electricity produced in power plants to electricity users.

4.2 Examined alternatives

Of the alternatives described above, five different combinations were chosen for further examination (table 1; figure 1).

1 BAU: District heating and electricity from the national network.

2A GTH, NE, STH & SE: Geothermal heat (50 per cent of the peak power requirement) and network electricity complemented with solar heat (ten per cent of the roof area) and solar electricity (an optimal amount)

2B GTH & NE: Geothermal heat (50 per cent of the peak power requirement) and network electricity

3A GTH, DH, NE & SE: Geothermal heat (35 per cent of the peak power requirement is fulfilled by collector field) complemented with district heating, grid electricity and solar power (an optimal amount)

3B GTH, DH & NE: Geothermal heat (35 per cent of the peak power requirement) complemented with district heating and network electricity

Table 1. The input of energy carriers by examined solutions.

	BAU	2A	2B	3A	3B
District heating	56 %			28 %	28 %
Geothermal heat		40 %	46 %	22 %	22 %
Solar heat		7 %			
Network electricity	44 %	43 %	54 %	44 %	50 %
Solar electricity		10 %		6 %	

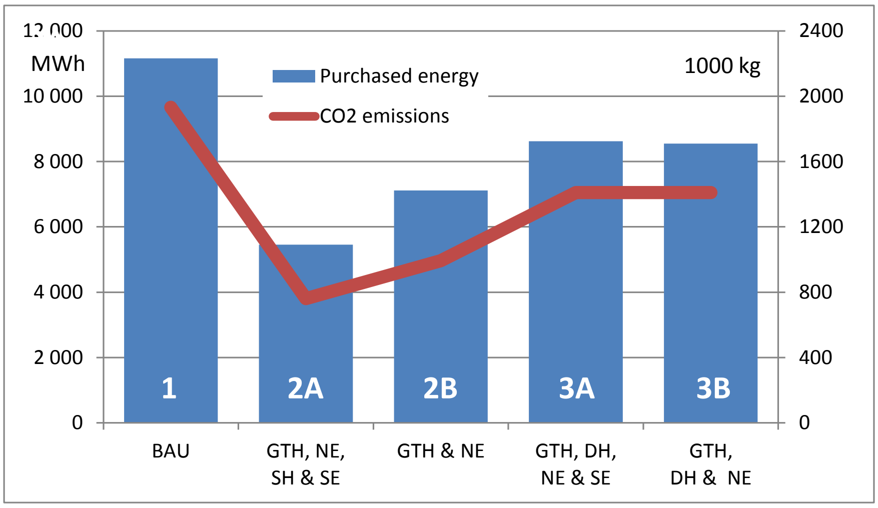

Figure 1. Purchased energy and greenhouse gas emissions of examined solutions.

Connecting the buildings to the local district heating network and the national electricity network (alternative 1) is the "business as usual" alternative. In alternatives 2A and 3A, the aim is to increase the share of renewable energy through nearby energy production. Harvesting solar energy has been eliminated from alternatives 2B and 3B.

Geothermal heat (2A, 2B, 3A, 3B) covers most of the need for heat, but their power is not enough for heating the buildings during the coldest weather during the winter. These peak consumption periods are covered by support heating. In the 2A and 2B alternatives, the support heating is produced through electricity network, and in the 3A and 3B with district heating. The primary energy consumption of the alternatives is presented in Figure 1.

The energy consumption of the buildings is identical in all alternatives. The differences in the consumption of purchased energy (figure 1) are a result of the efficiency of the energy production and how much free energy and renewable energy can be used.

4.3 Calculation assumptions

In this project, the basic assumptions and the price change scenarios were decided jointly with the research group and project's steering group. The key calculation assumptions:

- Price of district heat EUR 80/MWh including energy + monthly fees + VAT 24 % (Energy prices -site)
- Price of grid electricity EUR 120/MWh includes energy + transmission + monthly fees VAT 24 % (Energy prices -site)
- Energy price development 2 % per year and 4 % per year
- Renewable energy technology -2 % per year except solar power technology -5 % per year
- Operating and connection costs development 2 % per year
- The surplus energy produced is either wasted or used free of charge.
- Time horizon 25 years
- The residual value of the investment is EUR 0

The moderate energy price, operating and connection costs scenario (2 %) is in line with the general development of consumer prices in the near history. In the alternate scenario (4 %), the price of energy is assumed to increase faster than the general consumer prices.

Forecasting the development of energy price over a 25-year period is very challenging as it is affected by so many different factors (taxation, energy policy, state of the global economy, etc.). A 50-year horizon could also have been used, but energy price development forecasts reaching just 25 years into the future already include a great deal of uncertainty, making an even longer time period difficult to justify. Furthermore, investments usually have to pay for themselves and show profitability after a significantly shorter time period than 25 years.

A 25-year horizon is so far away that the low residual value at the end of the period does not have much impact on the calculations. Additionally, determining the residual value 25 years into the future is very challenging, as technological solutions are rapidly developing.

In the future nearby production surplus energy can naturally have its use, if selling it into the network becomes possible and/or advancements are made in energy storage technologies (e.g. batteries). In its part, this would improve the profitability of renewable energy investments.

The price trend of renewable energy solutions has been downward in the 2000s, particularly in the case of solar power. This development has been assumed to continue for the next five to ten years in the calculations.

In alternatives 2A and 2B, all investments are made in parts over a period of ten years in accordance with the demand for energy (it is assumed that construction takes place at an even pace over ten years). In reality, the construction will probably not take place at an even pace, but this assumption was made in order to make the calculation clearer.

In alternatives 3A and 3B, the geothermal system is built as a one-time investment, and the district heat and solar electricity investment (in alternative 3A) within five years in accordance with demand (it is assumed that construction takes place at an even pace). Alternatives 3A and 3B have options for starting the implementation either immediately or after five years. The solution can be deployed either in the half of the area that is completed first or the half completed last. The price environments between these options are different to such a degree that it must be taken into consideration in the calculations, too.

5. Results of examinations

5.1 Is it worth invest earlier than later?

Figure 2 depicts the payback period for the different solutions of alternative 2 for the part investments made during the first and tenth years. The payback periods of the first and last part investment differ very significantly from each other. The payback period of the investment as a whole is somewhere between these extreme values. It can also be stated in the 2B solutions, the payback period is shorter than in the 2A solutions, i.e. the solution with just geothermal heat leads to a better end result in the economic sense than when it is combined with solar heat and electricity.

According figure 2 the payback period is shorter the larger the annual increase in energy price is. Correspondingly, a part investment made in the tenth year leads to a shorter payback period than the part investment made in the first year. This is explained both by the increase in the price of energy and the decrease in the price of technology. The figure also shows that the time of the part investment (first vs. tenth year) has a clearly larger impact on the payback period than the increase in the price of energy (2% vs. 4%). The price environment is naturally most favourable with a tenth year part investment and a 4% assumed increase in the price of energy.

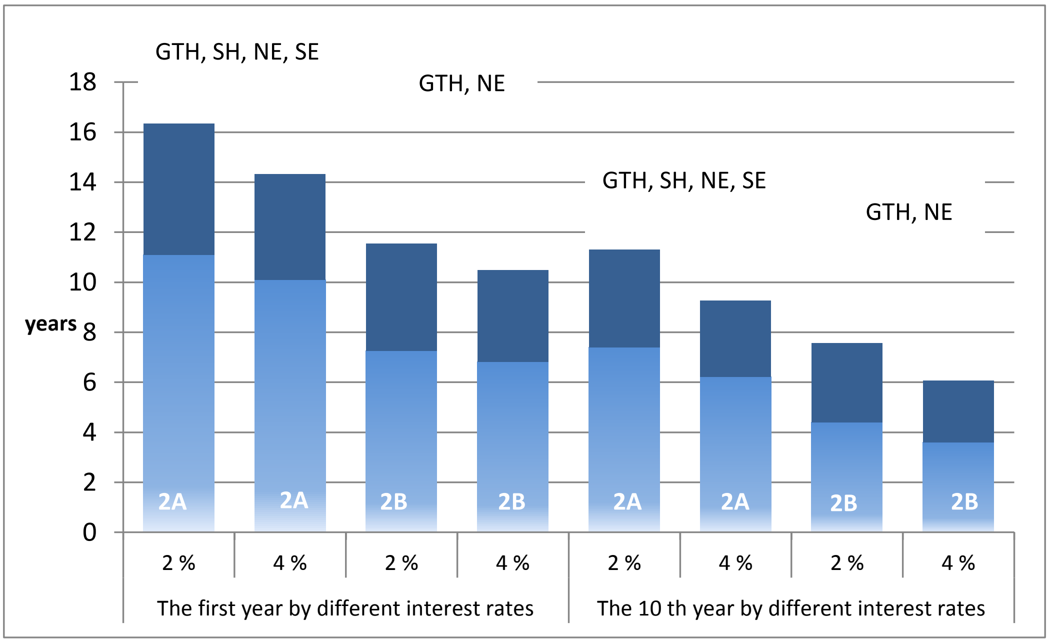

Figure 2. Payback period (years) is shorter without solar energy both in the first year's and the 10th year's investment even the price erosion has been taken account. Price range is ± 20 % (dark part of columns).

It can be seen in Figure 3 that the internal rate of return is higher the larger is the annual increase in the price of energy. The column on the right (price increase 4 %) is thus always higher than the one on the left (price increase 2 %).

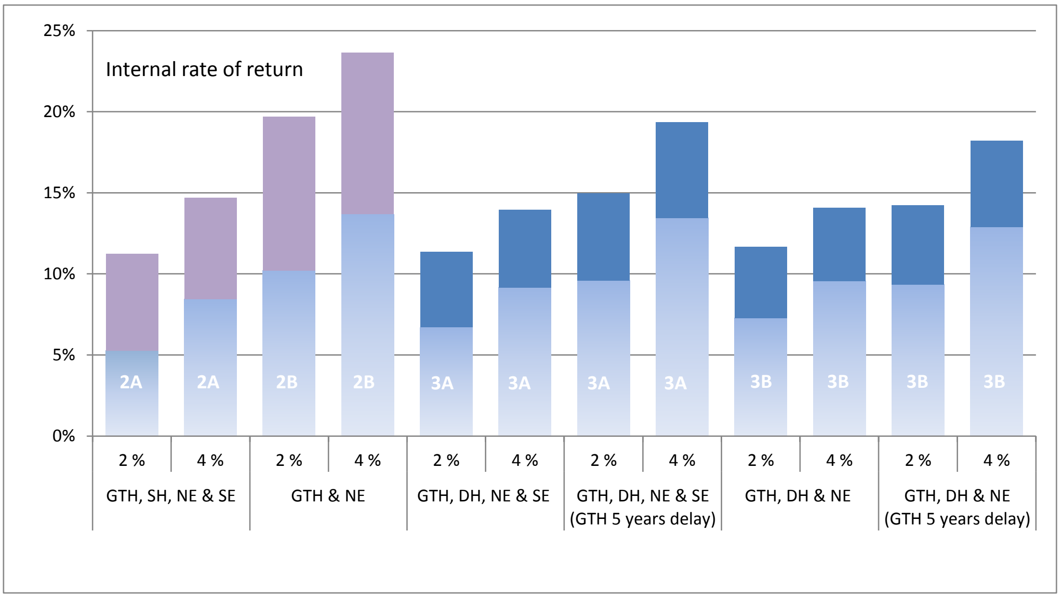

Figure 3. Internal rate of return in the different alternatives. Alternatives 2 and 3 cannot be compared with each other due for example, to different division of investments (for this reason, columns of different colours are also used in the figure). Price range is ± 20 % (dark part of columns).

The figure also shows that, in alternatives 3A and 3B, the solution implemented after five years leads to a higher internal rate of return. This is explained by both the assumed increase in the price of energy and the assumed decrease in investment costs. In other words, the investment can be made in a more favourable price environment. Thus, the difference between investments made at the present time and after five years is at its largest with the higher assumed increase in the price of energy (4%).

Extending the horizon from 25 years to 50 years will not have a significant impact on the results. There is no impact at all on the payback period, because even the longest payback period is only somewhat over 16 years. The possible residual value (e.g. 50% of the initial investment) as a rule has only a minor impact on the results, because even a 25-year horizon is so far in the future that the net present value is usually very low with these internal rates of return.

5.2 Is it worth choose centralized, decentralized solution or parallel solution?

In figure 4 we can see the total cost comparison. As could be presumed, parallel system is an expensive solution as it is in this case with the 3A and 3B, where district heating is uses as complementary system to geothermal heat. The network electricity however, is the overall cost effective complimentary energy source.

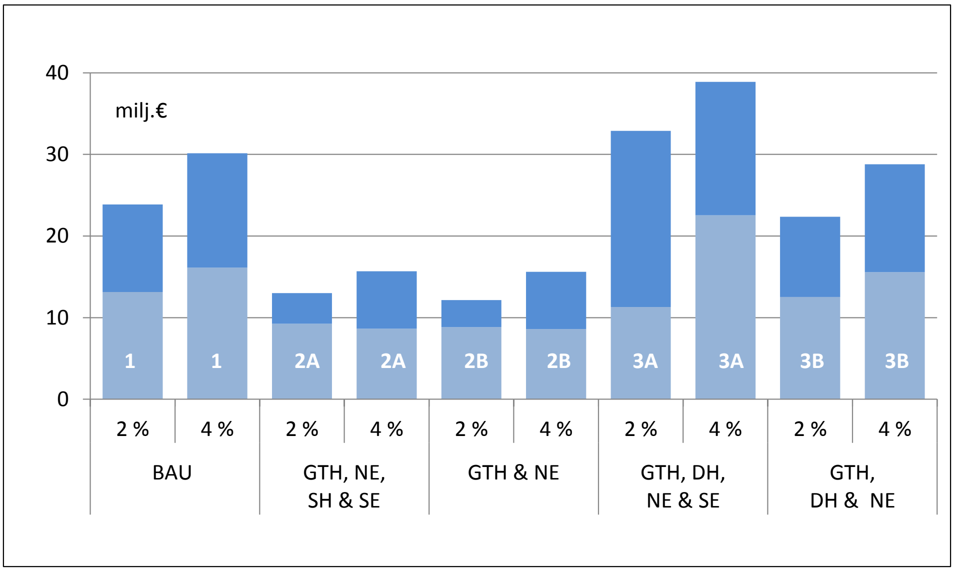

Figure 4. Total costs of energy system alternatives. Reason to high costs of 3A and 3B are a district heating system as complimentary system. Price range is ± 20 % (dark part of columns).

The calculated payback periods, internal rates of return and total costs are at such a level that solutions based on geothermal heat and network electricity (2A and 2B) would appear to be competitive alternatives. This is in line with other research results made in a similar business environment (Häkämies et al., 2015). In particular, the option 2A but also the option 2B is surveyed less GHG emissions productive when emissions are calculated by the local factors (figure 1).

Naturally, decisions depend entirely on each operator's required rate of return on the capital and the required payback period. It should be emphasised that these kinds of calculations are very dependent on several different initial assumptions, and even small changes in these assumptions can have a significant impact on the end results. Calculations should, thus, be made using several different parameters, observing their effect on the end results.

The prices and assumptions used in the calculations are largely based on the views of the research scientists and the project participants. No actual offers for these solutions have been requested. The actual prices may differ significantly, particularly due to the conditions in the area, scalability and time of implementation. Conditions in the area in this context refer, for example, to the actual price of geothermal heat depending on the geological conditions in the area. Scalability in this context refers, for example, to there being clearly more information on and estimates for geothermal heat solutions for individual apartment blocks than for an entire residential area. The prices of the technologies are also in a constant flux, and the actual price thus depends on the time of implementation.

6. Discussion

The energy system alternatives appear differently to society, the developers and the future residents of the area. In this case, society is represented by **the city**, ultimately responsible for the built environment and planning as a whole. Energy and climate objectives place binding demands on the city, among other things, in the form of agreements voluntarily made with the state (Energy Efficiency Agreement –site), and image-wise in the form of joint mayoral proclamations. Accolades received in the past also create an obligation. Indeed, from the city's point of view, the best alternative would be the one with the lowest consumption of primary energy and generation of greenhouse gases. The choice would thus be the alternative with as much renewable energy as possible (alternative 2A or 3A). On the other hand, the city owns the district heating company, so it also has grounds for adopting the traditional alternative (1). The traditional alternative is also supported by the fact that renewable energy sources can be utilised in the production of district heat. The utilisation of the existing network and production capacity saves in investment costs and is material-efficient.

It is in the **construction company**'s interest to generate profits and avoid risks, as it is bound by a ten-year guarantee on the functionality of the building. By choosing the traditional alternative (1), its investment costs and risks remain lower. On the other hand, it could be in the construction company's interest to profile itself as a frontrunner with ecological values, so the choice could turn to the alternatives involving renewable energy. These alternatives require developing the concept of an apartment block as a product. The traditional concept is that a construction company erects the building; after its completion, the building is managed by a limited liability housing company, supported by energy services that have been centralised to a great extent.

Local energy production would need to be separately organised. This would go against the prevalent development (for example energy efficiency directive 2012/27/EU), as the trend in many technological fields has rather been the opposite, towards centralisation and the benefits of the economies of scale. Based on the Smart City agenda, virtual power plants have been theorised, with this kind of local energy production bundled together and with a common operator. This would be a major regime-level change compared to the current situation.

Living as affordably as possible is in the interests of the **residents**. In this context, self-produced, free energy sounds like a tempting alternative. Indeed, when it comes to the heating of single family houses, the choice is often a property-specific system, even partial generation of one's own electricity, although its life cycle costs are currently higher. This particularly applies to countries where small-scale production of electricity has no public subsidies.

The situation is different for apartment blocks already because in the building skin there is a little space for harvesting solar power. Their choices are not made by individual households, but by the limited liability housing companies made up of individual households. For new buildings, the decisions are made by the construction company for the housing company, because only some or none of the housing company shareholders are known at the time of the decision-making. Once the housing company formed from households has been established, it is too late to influence the solutions. In order to be able to benefit from the affordability of the local production, the housing company must assume some responsibility over the system. This responsibility is, however, often outsourced to a maintenance company and it spends the economic advantage of the households.

With hybrid energy systems, the responsibility refers to, for instance, remote monitoring and the investigation and correction of any deviations detected. At this point, things move from traditional maintenance company operations to digital control rooms, where the economies of scale rule and a new breed of business ecosystems thrive.

7. Summary

The subject of this conference paper is an apartment block area comprising near zero energy buildings. The goal was to study the best way to arrange energy services for the area. The area is transitioning from an industrial area to a high-efficiency residential area.

The alternatives that were studied comprised traditional, centralised energy service, and local energy production in the area, using geothermal heat, solar heat and solar electricity. The calculated payback periods, internal rates of return and total costs are at such a level that solutions based on geothermal heat and network electricity would appear to be competitive alternatives. The solutions are area-specific, and must always be studied on a case-by-case basis.

The decision-making is rife with uncertainties. With regard to new technologies and, in particular, hybrid systems, the question are about the optimal control of the operation of the systems either on building or area level. There are examples where attempts at saving primary energy have resulted in increased consumption due to the systems not functioning properly. Utilising the benefits in full may require the development of a new business ecosystem.

The choice is also influenced by the prior choices of the target area or the city, or so-called path-dependency, which may also be a positive factor. Keeping with the traditional solution allows benefiting from the prior investments. If the energy efficiency of the city's old building stock is improved, the district heating system will have enough capacity for new customers with minor additional investments. The new area will benefit from the centralised system's investments made in on energy efficiency, renewable energy sources, and fulfilment of customer needs, remote monitoring, and large-scale hybrid solutions, including the combined heating and cooling (CHC) -technology.

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An Indicator-based Approach to Neighbourhood Sustainability Assessment for Urban Renewal Decision-making

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Abstract

Urban renewal, as an opportunity of realizing sustainable development, can resolve numerous problems facing cities. Due to the linkage between sustainability and urban renewal, it is helpful to investigate sustainability in urban renewal context. Although there exists a consensus on the importance of sustainable development, this concept is still ambiguous, which may lead towards a deviated direction. In order to capture a better understanding on sustainability in urban renewal, thus making informed decision-making on sustainable urban renewal, some evaluation tools/methods have been proposed. However, most research focuses on a city scale or a renewal project. Sustainability assessment focusing on neighbourhood renewal is still a rarely touched area. With the aim of supporting decision-making in urban renewal, this paper proposed an indicator-based approach to neighbourhood sustainability assessment. Essential steps in this approach are introduced in detail. A case study on several neighbourhoods of Hong Kong is conducted to apply this indicator-based approach. This paper not only provides a better understanding on neighbourhood sustainability in urban renewal process, but also proposes a method of assessing sustainability of neighbourhood for supporting urban renewal.

Keywords: sustainability assessment, urban renewal, neighbourhood, decision-making

1. Introduction

Urban renewal is regarded as a two-fold sword. It can deliver a positive opportunity for realizing sustainable development and act as an antidote for urban problems (Zheng et al., 2014). There also exists some criticism including fading of local culture, destruction of social network, and segregation. Facing different voices on urban renewal, it is important to integrate the concept of sustainability into urban renewal practice. Although the concept of sustainable is accepted widely, its application in practice is not always favouring (Hunt et al., 2008). To better deliver sustainable urban renewal, it is necessary to conduct urban renewal evaluation, especially when it comes to decision-making. For example, a systematic approach with evaluation criteria on urban competitiveness quality and priority model for urban renewal projects was proposed to facilitate decision makers and developers in Taipei in reviewing urban renewal project selections (Juan et al., 2010). A model for measuring sustainability of urban regeneration at project level was proposed to assist decision-making (Peng et al., 2015). Urban regeneration performance was evaluated based on different categories (the economy and work, resource use, buildings and land use, transport an mobility, and community benefits) (Hemphill et al., 2004a; Hemphill et al., 2004b).

However, most studies on urban renewal evaluation focus on the impacts of urban renewal impacts, which are post-evaluation, minimizing the opportunities of promoting sustainability. It is more beneficial if pre-evaluation is included in urban renewal process. Pre-evaluation before urban renewal is crucial for regional policies (Greig et al., 2010). Only a few studies focusing on pre-assessment for urban renewal decision-making. For example, Ho et al. (2011) developed the Dilapidation Index under the context of Hong Kong to assess the building conditions for identifying potential renewal projects. But the Dilapidation Index only focuses on building conditions at building scale. The index of multiple deprivations, as a national matrix in the UK, is also for assessing the need for regeneration activities (Greig et al., 2010). This index is comparatively more comprehensive, yet its local context is in the UK.

Therefore, this research aims at proposing a universally indicator-based approach for sustainability assessment at neighbourhood scale for urban renewal decision-making. Four major steps are involved in the application of this approach. To better illustrate it, a case study on eight neighbourhoods of Hong Kong is employed to examine this indicator-based approach. The second section reviews previous work on neighborhood sustainability assessment and urban renewal assessment. The following section presents the conceptual framework of this approach. In further unravelling this approach, the fourth part shows the case study. The fifth section discusses limitations of this paper. And the final section concludes this paper.

2. Relevant Work

2.1 Neighborhood sustainability assessment

Sustainability has been an essential objective in city development. After it was firstly proposed in the Brundtland Report, it has been considered as a crucial issue for urban development. In order to transit to sustainable urban development, it is necessary to know where we are, what goals that we have met, and what to do next. This poses challenges and potentials on sustainability assessment. Devuyst et al. (2001) provided a definition of sustainability assessment: "a tool that can help decision-makers and policy-makers decide which actions they should or should not take in an attempt to make society more sustainable." Sustainability assessment is useful for decision-makers on determining which actions should or should not be taken for realizing sustainable development (Ness et al., 2007).

There are some internationally well-known tools for sustainability assessment for neighbourhood, including but not limited to the following ones: Building Research Establishment's Environmental Assessment Method Communities (BREEAM Communities), CASBEE for Urban Development, The Leadership in Energy and Environmental Design for Neighbourhood Development (LEED for Neighbourhood Development). Comprehensive Assessment System for Building Environmental Efficiency for Urban Development (CASBEE for Urban Development) addresses the assessment of urban areas by focusing on the phenomena of aggregation of buildings and the outdoor spaces (Haapio, 2012). BREEAM Communities focuses on the planning stage of the development process of large-scale project with the aim of making the project show their environmental, social and economic benefits to the local community (BREEAM, 2009). LEED for Neighbourhood Developments was established as a U.S. national standard for neighbourhood design which focuses on green building and smart growth. It aims at assessing the impacts of development projects based on its standards (USGBC, 2006). Although different tools have different emphases and criteria, themes applied by most tools are involved with several aspects: resources and environment, transportation, economic, location, site selection pattern and design, and innovation (Sharifi and Murayama, 2013). Through analysis of existing systems of neighbourhood sustainability assessment, locality (e.g. local culture and laws) is emphasized as a necessary aspect for adaptability of existing systems (Berardi, 2013).

2.2 Urban renewal evaluation

The importance of evaluating urban renewal/regeneration initiatives on monitoring current renewal/regeneration programs has been widely acknowledged (e.g. Peng et al., 2015; Kauko, 2012; Hemphill et al., 2004a; Hemphill et al., 2004b) . A large number of studies have been conducted in terms of urban renewal/regeneration impacts.

Some research only focuses on one certain aspect of impacts of urban renewal, like social or economic impact. For example, in order to identify social impacts of urban waterfront regeneration in Helsinki, four themes of social impacts (resources and identity, social status, access and activities and waterfront experience) were proposed (Sairinen and Kumpulainen, 2006). From economic perspective, the impacts of a public-sector-led urban renewal project on housing prices in Hong Kong were measured by a price gradient analysis (Lai et al., 2007). Some researchers explore several aspects together. Social and economic impacts of residential brownfield development in the most deprived urban neighbourhood were assessed in terms of changing housing market, residential density, population growth and economic deprivation (Bäing and Wong, 2012).

There are also studies comprehensively evaluating urban renewal initiatives. Impacts of urban renewal on socio-economic and spatial structure are often discussed together (e.g. Uzun, 2003; He and Wu, 2007; Wu and He, 2005), although different studies may use various indicators. Some scholars apply composite indicators to assess urban renewal comprehensively (Hemphill et al., 2004a; Hemphill et al., 2004b; Hunt et al., 2008; Pérez and Rey, 2013; Wedding and Crawford-Brown, 2007). To measure regeneration performance, a group of indicators under different categories (the economy and work, resource use, buildings and land use, transport an mobility, and community benefits) were proposed (Hemphill et al., 2004a; Hemphill et al., 2004b). While most studies assess urban renewal from the perspective of post-evaluation, only a few address pre-evaluation. To facilitate regeneration decision-making in Birmingham Eastside, Hunt et al. (2008) presented a series of indicators including social aspect (user comfort, form and space, access, amenity, inclusion), economic aspect (social benefits and cost, transport, employment, competition effects, viability), environmental aspect (air quality, land use, water, ecology and cultural heritage, design and operation, transport), and natural resources (materials, water, energy, land utilization, waste hierarchy).

3. Conceptual Framework

This research develops an indicator-based approach to neighbourhood sustainability assessment with the purpose of providing references for urban renewal decision-making. Figure 1 shows the conceptual framework. There are totally four steps, in which different methods could be applied. This section is to provide details in each step.

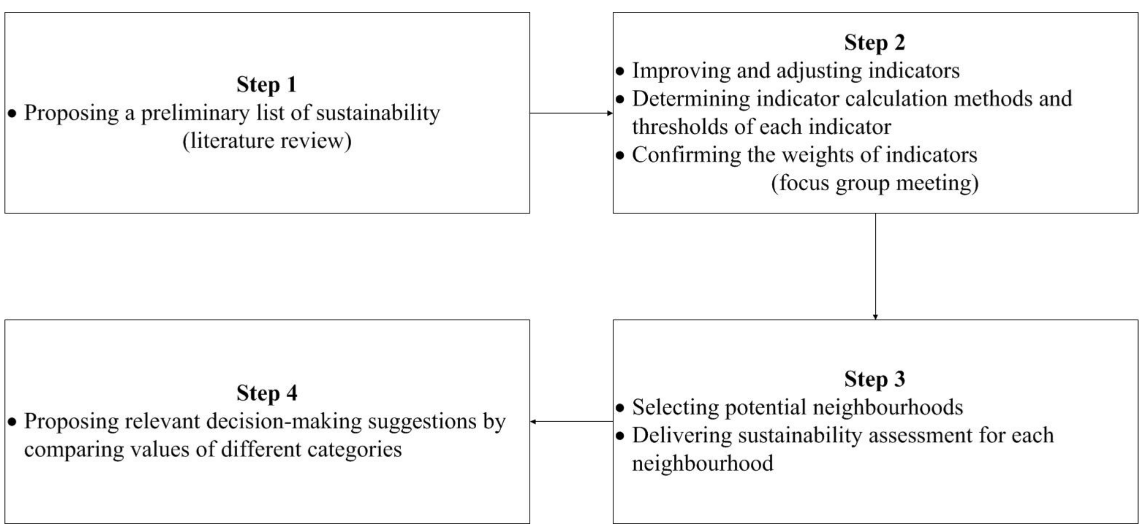

Figure 1: Major steps in the proposed approach

3.1 Step One

Various indicators have been applied in studies on sustainability assessment at neighbourhood scale. The existing tools or research can be useful resources for identifying initial indicators and their calculation methods. During this process, two other aspects need to be considered. One is the local condition. Another is what is crucial for urban renewal. In summary, the initial indicator list is a comprehensive indicator system which integrates sustainability consideration, urban renewal focus, and local conditions. Different indicators should be categorized into different themes. A hierarchy framework of indicators then can be drawn. Figure 2 shows the hierarchy framework of indicators.

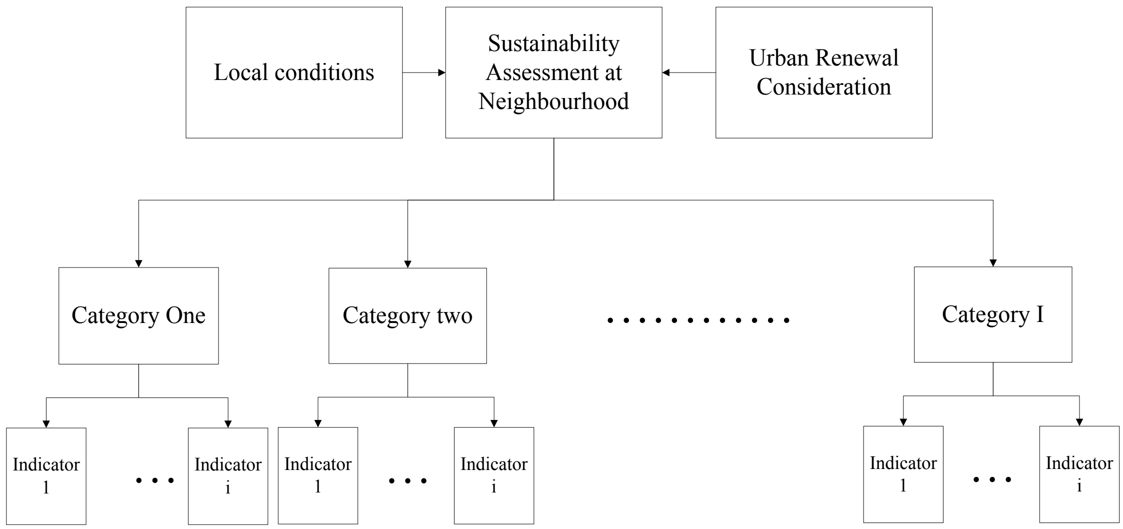

Figure 2: The hierarchy framework of indicators

3.2 Step Two

The selected indicators may be subjective, thus requiring adjustment of indicators. Focus group meeting is conducted to collect suggestions on existing indicators and to add ignored indicators selected during step one. After adjusting and improving the indicator list, it is necessary to determine calculation methods and thresholds of each indicator.

Under each category, weights of indicators is to be determined. There are different ways. For example, participants can pose specific weights for various indicators directly after discussion. Or participants judge the relative importance of each indicator, the results of which are then to be used for calculating weights by methods like analytic hierarchy process (AHP) and analytic network process (ANP). The sum of weights for indicators in each category should be 1.

3.3 Step Three

Potential neighbourhoods for renewal decision-making are to be determined during this step. Then relevant data is to be collected accordingly. The following actions include calculating values of each indicator and then obtaining the final value of each category.

Each indicator has its unique calculation method. The initial evaluation results of indicators are obtained by using different units and cannot be compared directly, thus requiring standardization before calculating values of different categories. Taking into account of the positive and negative effects of different indicators on sustainability, two formulas were applied for standardization (Pirrone et al., 2005).

Positive indicator: $y_{ij} = (x_{ij} - \min x_{ij}) / (\max x_{ij} - \min x_{ij}) (1 \le i \le m, 1 \le j \le n)$ (1)

Negative indicator: $y_{ij} = (\max x_{ij} - x_{ij}) / (\max x_{ij} - \min x_{ij}) \ (1 \le i \le m, 1 \le j \le n)$ (2)

The final value of each category is calculated by the formula below, in which S_I stands for the final value of category I, v_i represents value of indicator i, and w_i is the weight of indicator i.

$$S_I = \sum_{1}^{i} v_i w_i \quad (3)$$

3.4 Step Four

After obtaining values of various categories, relevant suggestions on urban renewal decisions can be proposed accordingly. This approach does not suggest calculating a total score of sustainability, but tends to compare each category among neighbourhoods, which can offer more detailed and specific strategies for neighbourhood renewal.

4. Case Study

4.1 Study Area and Data Preparation

Hong Kong is selected as the case study context because of its unique characteristics. Firstly, it is now facing serious urban decaying problems with approximate 4,000 buildings aged 50 years or above. Secondly, it is a typical high-density city in Asia, which experiences overcrowding and scarcity of land supply. Urban renewal can free some land for Hong Kong. Thirdly, various voices emerge in urban renewal process of Hong Kong, within which there are also some criticism such as profit-driven, fading of local culture and destruction of local network.

Eight tertiary planning units TPUs in Kowloon District of Hong Kong are selected in the case study to experiment the proposed approach (See figure 3). These TPUs, are applied by Planning Department of Hong Kong for planning purpose. A database for this research is prepared, in which both spatial and non-spatial data are included. Spatial data include land use map, road network map, the location of public facilities, and building distribution. Non-spatial data involves environmental and social aspects. The data is from different governmental departments, including Planning Department, Lands Department, Building department, Hong Kong Housing Society, Environmental Protection Department, and Census and Statistics Department. Data processing actions involve digitalizing land use map and integrating data from different sources in ArcGIS software package.

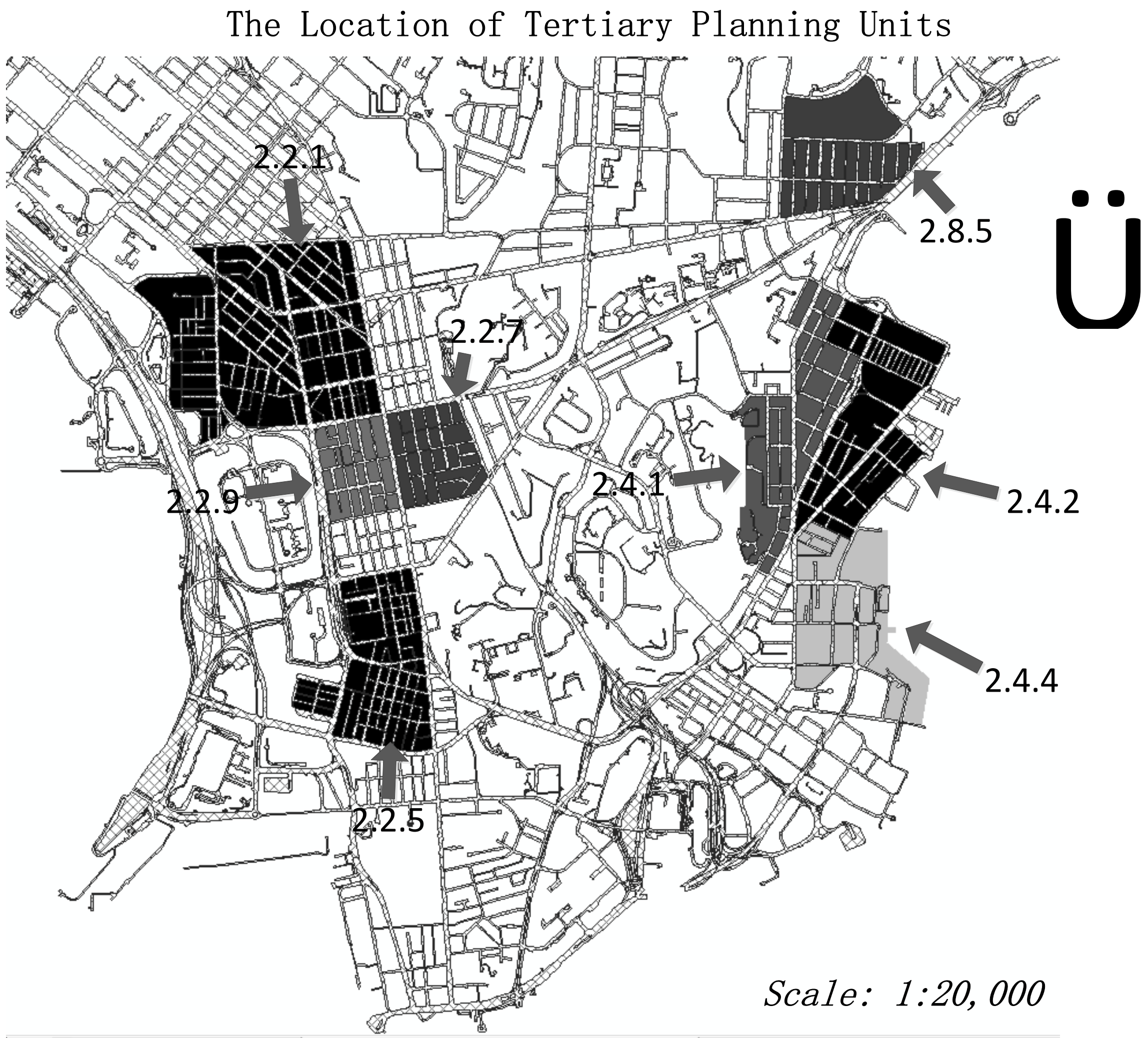

Figure 3: The location of tertiary planning units (TPUs)

4.2 Application of the proposed approach

Following the steps in the conceptual framework, the proposed approach was applied. Through literature review (e.g. Greig et al., 2010; Hemphill et al., 2004a; Hemphill et al., 2004b; Hunt et al., 2008; Boyko et al., 2012; Cheng and Lin, 2011), an initial list of indicators were proposed. This case categorized indicators into five themes, which are social aspect, environment and resources, economy and work, land use form and building conditions. Then in step two, two more indicators (Density of Small businesses with local characteristics and the fragment level of property rights) were added and calculation methods were confirmed for each indicator. To make it simple (because this study is a pilot one), each indicator is regarded contributing the same to the total value of each category; thus, the weights for indicators are the same. Several indicators were not included in the calculation because of lacking data at this scale. Additionally, this is a pilot study for illustrating this approach, it is acceptable that several indicators are not included. Table 1 presents an adjusted indicator list, which can also be referred by other contexts. Table 2 shows the final scores of different categories. Figure 2 can clearly show the comparing results in space.

Base on the results, performance of each neighbourhood can be compared directly. In terms of social aspect, TPU 2.2.1 performs the best while TPU 2.4.1 has the lowest value. As for economy and work, TPU 2.4.4 stands out with its highest value while other TPUs have similarly low values. TPU 2.2.7 obtains the highest value for the performance of environment and resources. TUP 2.2.9 shows the best result for land use form while land use form of TPU 2.2.1 presents the worst one. Building conditions in both TPU 2.2.1 and TPU 2.2.7 are satisfactory and TPU 2.8.5 presents the most serious building condition.

From these results, some issues could be found. Although some TPUs perform well in certain aspects, they may face some problems in other aspects. This phenomena reminds of a fact that values of some positive aspects may offset those negatives ones if we only refer to the overall value of sustainability. Therefore, calculating different categories respectively can avoid this dilemma in this approach. Based on the results, corresponding strategies can be proposed for each neighbourhood. For example, for TPU 2.8.5 with higher value in land use form and comparatively lower values in other categories, building rehabilitation initiatives are urgent. Then for some decaying area, comprehensive redevelopment may be an alternative for addressing various problems. It is essential to include both physical and socio-economic improvement during renewal.

Table 1: A summary of indicators and their measurement

Category	*Indicator*	*Measurement*	*Remarks*
Social aspect	*Human density*	*Population/Area of the planning unit*	*Results can be obtained through normal calculation*
Social aspect	*Age diversity*	$\frac{1}{cat}\sum_{i=1}^{cat}(1-\frac{n_{cat\_age\_i}}{n_{cat\_age\_i}^{obj}})^2$	cat *is the number of different age groups,* $n_{cat\_age\_i}$ *is the population belonging to age group* i*,* $n_{cat\_age\_i}^{obj}$ *refers to the objective population in age group* i
Social aspect	*Residential floor area per capita*	*Residential floor area/Population*	*Results can be obtained through normal calculation*
Social aspect	*Public transport diversity*	$\frac{1}{cat}\sum_{i=1}^{cat}(1-\frac{n_{cat\_trans\_i}}{n_{cat\_trans\_i}^{obj}})^2$	cat *means the number of public transportation types,* $n_{cat\_trans\_i}$ *is the number of transportation points (stops/stations) in type* i*,* $n_{cat\_trans\_i}^{obj}$ *is the objective number of transportation points in type* i*.*
Social aspect	*Facilities diversity*	$\frac{1}{cat}\sum_{i=1}^{cat}(1-\frac{n_{cat\_faci\_i}}{n_{cat\_faci\_i}^{obj}})^2$	cat *represents the number of facility types,* $n_{cat\_faci\_i}$ *is the number of facility* i*,* $n_{cat\_faci\_i}^{obj}$ *is the objective*

			number of facility i .
Economy and work	*Labor force participation rate*	*Labor force participation rate*	*Data can be obtained from statistical information*
Economy and work	*Disposable income per capita*	*Disposable income per capita*	*Data can be obtained from statistical information*
Economy and work	*Diversity of business activities*	$\frac{1}{cat}\sum_{i=1}^{cat}(1-\frac{n_{cat\_busi\_i}}{n_{cat\_busi\_i}^{obj}})^2$	cat *is the number of various business groups,* $n_{cat\_busi\_i}$ *is the population belonging to business category* i , $n_{cat\_busi\_i}^{obj}$ *refers to the objective population in business category* i
Economy and work	*Density of Small businesses with local characteristics*	*The trade of small business with local characteristics/the area of planning unit*	*Data cannot be obtained;* *This is a newly added indicator*
Resources and environment	*Waste generation*	*Total waste generation/population*	*Data can be estimated*
Resources and environment	*Waste recycling*	*Number of waste recycling facilities/area the planning unit*	*Data can be estimated*
Resources and environment	*Electricity consumption*	*Total electricity consumption/population*	*Data cannot be obtained*
Resources and environment	*Air quality*	*Air quality index*	*Data cannot be obtained*
Resources and environment	*Water consumption*	*Total water consumption/population*	*Data cannot be obtained*
Land use form	*Land use mix*	$-\sum_{i=1}^{n} l_i \ln l_i / \ln n$	l_i *is the area of land use type* i , n *means the number of land use types.*
Land use form	*Accessibility to cultural facilities*	*Number of cultural facilities within 300 meters*	*Results can be obtained through spatial analysis in GIS*
Land use form	*Accessibility to education services*	*Number of education facilities within 300 meters*	*Results can be obtained through spatial analysis in GIS*
Land use form	*Accessibility to health care services*	*Number of health care facilities within 300 meters*	*Results can be obtained through spatial analysis in GIS*
Land use form	*Accessibility to sport and leisure facilities*	*Number of sport and leisure facilities within 300 meters*	*Results can be obtained through spatial analysis in GIS*
Land use form	*Accessibility to other facilities*	*Number of other facilities within 300 meters*	*Results can be obtained through spatial analysis in GIS*

Land use form	*Accessibility to public transport*	*Number of public transport points within 300 meters*	*Results can be obtained through spatial analysis in GIS*
Land use form	*Open space coverage ratio*	*Area of open space/Area of the planning unit*	*Results can be obtained through spatial analysis in GIS*
Building condition	*Average building age*	$\sum_i^n age_i / n$	*Results can be obtained through normal calculation*
Building condition	*Number of buildings aged 50 years or above*	*Number of buildings aged above 50 years*	*Data can be obtained directly from statistics*
Building condition	*Building maintenance*	*Number of building repair cases/Number of buildings aged above 50 years*	*Data can be obtained through normal calculation*
Building condition	*Building density*	*Floor area/Area of the planning unit*	*Data can be obtained through normal calculation*
Building condition	*The fragment level of property rights*	*The fragment level of property rights*	*Data cannot be obtained; This is a newly added indicator*

Table 2: Values of neighbourhoods in different categories

	Social aspect	*Economy and work*	*Environment and resources*	*Land use form*	*Building condition*
2.2.1	*0.618491*	*0.261551*	*0.532039*	*0.231615*	*0.503037*
2.2.5	*0.38292*	*0.26032*	*0.537261*	*0.355585*	*0.353346*
2.2.7	*0.495204*	*0.175815*	*0.899771*	*0.513832*	*0.57359*
2.2.9	*0.569303*	*0.135118*	*0.720754*	*0.60348*	*0.496879*
2.4.1	*0.323248*	*0.236482*	*0.638122*	*0.268797*	*0.465472*
2.4.2	*0.419863*	*0.197809*	*0.590737*	*0.432339*	*0.306757*
2.4.4	*0.501843*	*0.600275*	*0.440865*	*0.505447*	*0.390898*
2.8.5	*0.387836*	*0.242227*	*0.396396*	*0.621737*	*0.286446*

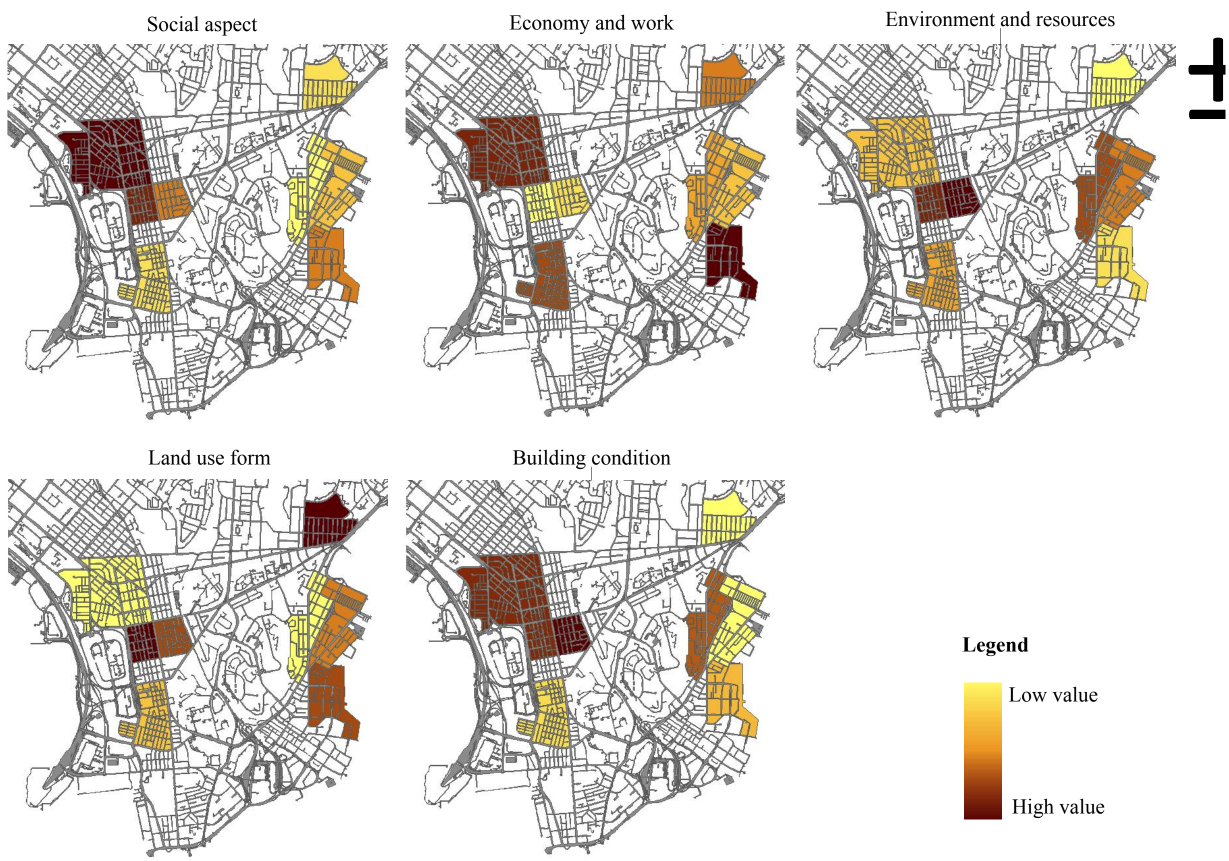

Figure 4: Comparison of values for different categories

5. Discussion

This paper proposed an indicator-based approach to assessing neigborhood sustainability for better urban renewal decision-making. Four steps are included in the assessment. Case study facilitates illustrating how to apply this approach in practice. This approach could be applied in different contexts but be adjusted based on specific conditions. The indicator list proposed on the basis of Hong Kong context can also be referred by other studies. Changes are suggested if necessary because different contexts face different challenges and issues in neighborhood renewal.

This research has some limitations. Due to data limitation, some calculation results are estimated, which may not be accurate. And data of several indicators cannot be obtained at this scale, thus ignoring their effects on the final results. Another limitation is that weights were not developed in step two. In order to further improve it, it is suggested to include as much data as possible. It would be of great use if the weights of various indicators were obtained in step two. This approach is not aiming at making decisions directly, but to provide useful references for decision-makers. Therefore, decision-makers should combine other information and approaches when applying this approach.

6. Conclusions

With the aim of supporting urban renewal decision-making at neighbourhood scale, this paper presents an indicator-based approach for neighbourhood sustainability assessment. This approach involves four essential steps, which are illustrated in the case study. It has several shining points. Firstly, unlike some studies on assessing urban renewal, it requires a more comprehensive perspective for indicator selection, which suggests sustainability, urban renewal and local context. Secondly, its focus is neighbourhood scale, which is a proper scale for initiating urban renewal activities. This scale is regarded as an important geographic and social unit for practicing planning activities (Rohe, 2009). Thirdly, with the fact that most studies on urban renewal evaluation focus on impacts of urban renewal (post-evaluation), the pre-assessment by this approach maximizes the opportunities of applying sustainability into renewal practice. The proposed approach can benefit both theory and practice.

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Institutional Development is the Key for Sustainable Water Services in the Built Environment

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Abstract

This paper explores the role of institutions in the development of water services – especially community water supply and wastewater. It is based on an extensive research programme on the evolution of water services in Finland that also compares our domestic development with international achievements since WWII.

The term *institution* is here used to mean the "rules of the game" while the term *organisation* is used to mean any of the "players". Institutions include both formal and informal rules, and often a large part of the latter are unseen. The paper deploys a wider view of technology development: (i) artefacts, (ii) processes, and (iii) knowledge how to apply (i) and (ii). It reminds of appropriate technology where we need a variety of criteria for technical, social, and economic appropriateness.

Water services are under continuous need of reassessment. Some changes may seem more dramatic short-term than in the longer term. Yet, they are relative and depend on the time scale used: operational (1 year), strategic (1–10 years) or visionary (20–50 years). Due to path dependence, major strategic decisions may even have an impact lasting over a century – to the futures and to the pasts.

The development paths have hardly ever been linear; on the contrary, the paths have usually divided into new development paths. In some cases, like when selecting a new raw water source, older paths may have been rediscovered. The driving forces seem to be linked to legislation and especially to water pollution control. Instead of dramatic ad-hoc reforms, overall water services evolution in Finland has mainly been based on the principle of continuous development.

In the future, we need to pay worldwide more attention to institutions as well as to management, institutional, policy, and governance issues, including the challenges of pricing and asset management of water services infrastructures.

Keywords: sustainability, institutions, path dependence, pasts, futures

1. Introduction

Water and wastewater systems are of fundamental importance to the development of communities and the welfare of people and nature. Water services – here mainly community water supply and wastewater services – will face huge challenges in the coming decades in Finland, Europe, and the rest of the world. If the current trend continues without major improvements, up to two thirds of mankind will suffer from chronic water scarcity and/or polluted water in 2050. In spite of its problems and challenges, Finland has been among the top countries in many international comparisons of water and environment management. The rapid structural change of society has also been reflected on our water services. A key challenge is to increase the weight of the invisible water services and systems in societal decision-making.

While there is a huge demand for further investments in water and sanitation systems worldwide, it is an even bigger challenge to improve the efficiency and functioning of the current systems. In both cases proper institutions, or rules of the game, are required.

Water services are managed and governed at lower levels and scale than water resources. As concerns the wider role of water in development, the International Law Association (2004) pointed out that water and wastewater services are *vital human needs* of communities. In other words, they are the most important purpose of water use (Katko and Rajala 2005). At least in the western world, water services, a fundamental, yet mostly invisible part of the community infrastructure, are taken for granted, assuming that they are available 24/7. As Golder et al. (2013) pointed out, water is one of the most taken-for-granted aspects of daily life. Yet, in most cases in developing economies, intermittent water services pose severe challenges for citizens, especially the poor.

Unfortunately, many developing and transition economies still lack water service systems, or they are inoperational, or provide service only for a few hours a day and cannot therefore be taken for granted. The World Water Development Report 2003 highlighted this major problem as follows: "Sadly, the tragedy of the water crisis is not simply a result of lack of water but, essentially, one of poor water governance" (UNESCO 2003). Accordingly, OECD (2015) reminds that "managing and securing access to water for all is not only a question of money, but equally a matter of good governance". Thus, there is an urgent need to assess recent experiences, identify good practices, and develop practical tools for assisting different levels of governments and other stakeholders for more effective, fair, and sustainable water policies.

2. Methods and approaches

This paper is based on cumulative experiences of a variety of studies by the Capacity Development in Water and Environmental Services research team at Tampere University of Technology (TUT) since 2000. The paper builds on material and research conducted by the author and the research team in some 80 research projects, 10 doctoral dissertations, and 25 MSc theses. The paper aims to explore the role and significance of institutions and their development within the overall development of water services. The paper is largely based on a project analysing the major findings on water services development within its wider institutional context after WWII and especially during the last decades, including implications for the futures. This study (Katko 2016) has been supported by several foundations and the Academy of Finland (no. 288153) which is highly acknowledged.

In this context of water services organisations, the definition of *institutions* by D.C. North, a Nobel Laureate in Economics, is here applied. He used the football (soccer) analogy and defined institutions as the "rules of the game" while organisations are the "players" (North 1990). The rules differ in size and shape. This New Institutional Economies (NIE) calls into question many ideas of the more classical schools of thought.

Andrews (2013) uses the iceberg metaphor for reminding that "a large part of institutional logic is unseen or below the water line because it is informal". He further reminds that institutional reforms can only work if they are tailored to the local context and therefore the so-called best-practice reforms tend to fail. Whereas, for instance, the World Bank links "institutional context" typically to laws and other regulations, Scott (cited by Andrews, 2013, 43) points out that institutions include regulative, normative, and cultural-cognitive elements.

Based on a sustained institutional framework, a distinction between service *provision* and *production* should be also made, as articulated by Ostrom (1990, 31) and Oakerson (1999). This distinction is important since in most countries such as Finland legislation puts municipalities in charge of providing or arranging the services, whereas services are produced or implemented by utilities or cooperatives. Yet, professional literature seldom recognises this fundamental difference (Katko and Hukka 2015).

Another key definition refers to the concept of *technology*. Here, technology is considered in a wider context which covers (i) technological artefacts, (ii) procedures, and (iii) knowledge required how to apply both (i) and (ii) (Leppälä 1998). A somewhat similar definition was presented by Jacob Bigelow (cited by Hughes 2004, 2–3) already in 1831 when he stated that "technology involved not only artefacts but also the processes that bring them into being".

Hughes (2004) further pointed out that technology is not limited to technological practices – often considered engineering – but ought to include also the processes that bring technology into being, namely invention and human ingenuity. Regarding engineering sciences, Naukkarinen (2015) identified five categories of doctoral dissertations at TUT: experimental design science, mathematical design science, naturalistic design science, explanatory inquiry, and interpretive inquiry. The categories may also overlap and they do not necessarily follow any faculty borders, showing the diversity of engineering sciences and technology development. Hukka et al. (2007) addressed the need for methodological and even philosophical diversity in water management since a single approach cannot answer to all of the research needs, and the fact that a bias in favor of a single research approach may prevent finding adequate answers to wider governance issues. Indeed, it is possible to create most valuable findings in areas that are between various disciplines.

In the late 1970s, Pacey (1977) discussed the dimensions of *appropriate technology*, and concluded that technology alone is not enough, but in addition we need a variety of criteria for technical, social, and economic appropriateness. In order to discuss technologies Pacey (1983) also introduced two major spheres: *user sphere* and *experts sphere* and argued that "good technology" should take advantage of both of these major spheres. Futures researchers have pointed out the *evolutionary nature of development.* This means that development and technology are not deterministic, but at certain points we will face bifurcation or turning points (Mannermaa 1991).

The relationships between the empirical data collected from the real world and the various theories used in this research programme and by the wider CADWES team are shown in Figure 1. Empirical data from the real world are to be tested by various methods, often according to the so-called PESTEL framework which categorizes environmental influences into six main types: political, economic, societal, technological, environmental, and legislative. The PESTEL framework has proved useful since it forces one to assess development in a wider institutional and socio-economic framework.

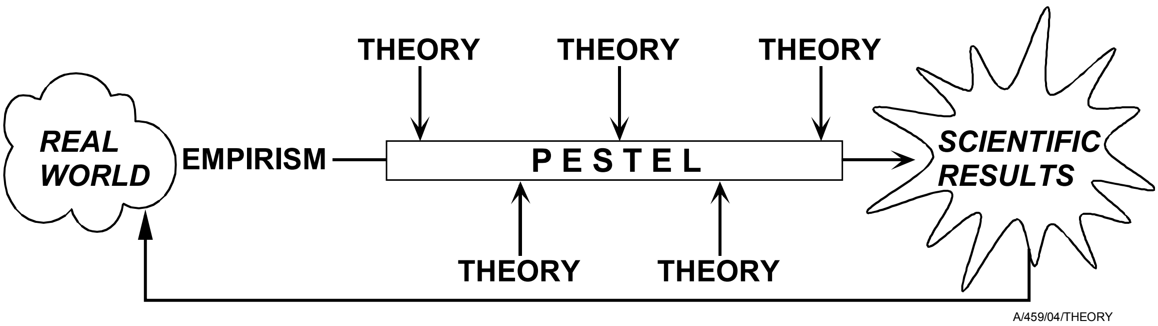

Figure 1: The major approach of the programme: relations between real word, empirism, research theories, and scientific results (Eskola 2001, 138; modified by the author)

3. Major Frameworks for Institutional Development

Water services in Finland are provided and produced at least at four different levels through various modes: from on-site to cooperatives, municipal utilities, and various types of inter- and supramunicipal arrangements (Table 1). These four levels are often connected to each other by various means. Municipal utilities are under public law whereas cooperatives are private. This diversity and multi-level governance describes both organisations and institutions. For some it may seem fragmented but in the Finnish conditions this "insdiversity" – different ways of providing services – gives flexibility to operate case by case based on local conditions. This is not to understate the challenges that they also have. In any case, the overall development is to take into account the connections between the various levels, bearing in mind the poem by Limerick (2012): "Rural and urban places, Are tangled together like laces. They´re like sister and brother, They have never been opposite cases".

As articulated by Ostrom (1990, 31) and Oakerson (1999), a distinction between service provision and production should be, however, made. This distinction is a major concern in most countries where legislation often puts municipalities in charge of providing or arranging the services which are produced and implemented by utilities. This distinction goes undetected by almost all parties involved and literature generally uses only the term "provision" without explaining its more accurate meaning.

Table 1. Four key levels of water services in Finland with their key characters (Katko 2016 forthcoming)

Level	*Features*	*No. of systems*	*Population served (%)*
On-site systems	*Dispersed rural areas*	*many*	*10*
Water Users Associations	*Villages and towns*	*1400*	*5**
Urban water and wastewater undertakings	*Water and wastewater often merged*	*300*	*50*
Inter- and supra-municipal systems	*Inter-municipal agreements* *Wholesale water* *Wholesale wastewater* *Regional water and wastewater companies****	*many*** *24* *12* *3*	*n.a.* *n.a.* *n.a.* *28*

** some 20 in large villages and towns* *** some continuous, some as reserve*
**** 2 stakehold companies owned by municipalities, 1 federation* *n.a. not available*

Through mere legislation and requirements, water services have many stakeholders and interest groups (Figure 2). Water entities at various levels produce services that in Finland are arranged by municipalities except for small and on-site systems. In fact, globally municipalities or other public authorities are owners of some 90 percent of water utilities, 95 percent of wastewater systems, and likely close to 100 percent of stormwater systems. Water utility board members are elected officials. Likely the core resource of any utility is competent personnel. Activities require economic resources obtained, ideally, by charges from customers – such as the case is in Finland – rather than through taxation. Local administration supervises the actions through regulations. The State and the European Union are in charge of legislation, policy, and regulation that are controlled by regional authorities.

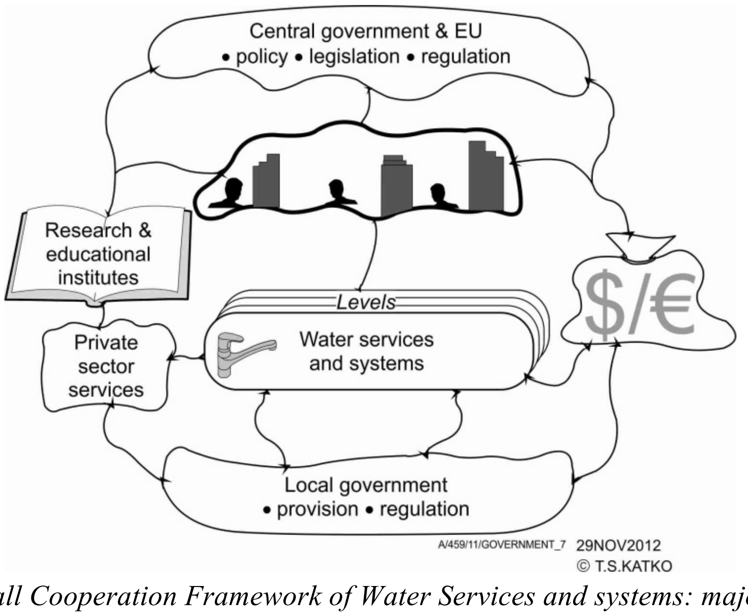

Figure 2: Overall Cooperation Framework of Water Services and systems: major stakeholders and their relationships (Katko, forthcoming 2016)

Water utilities buy services from the private sector as they have done since the beginning of the water systems (Juuti and Katko 2005). For the purposes of this study, we call this *public-private cooperation* instead of *partnership* that has been misleadingly used for the promotion of multinational companies and their long-term contracts, thus in practice reducing competition (Hukka and Katko 2003). Educational and research institutes create the basis for competences and human resources. As for lobbying for water services, the Finnish Water Utilities Association and the Association of Finnish Water Cooperatives are major actors. In addition, we have other direct or indirect stakeholders, which have their own specific roles. These include, e.g., health authorities, water protection associations, and regional councils. In any case, it is essential for each of the stakeholders to have a role that fits to the totality in the most appropriate way.

Another major feature of water services management is related to time. Nowadays futures and strategic thinking is used in many sectors for identifying and having influence on the development of services. The former "prediction" by futurologists has been replaced by futures research and forecasting that rather tend to have active influence on preferable futures and development paths. (Bell 1997) Yet, it is good to remember the argument by George Santayana (1863–1952) " those who cannot remember the past are condemned to repeat it".

Water services' futures can be explored through three different timeframes (Figure 3): operative daily actions (one year), strategic thinking (5–10 years), and visionary leadership (10–50 years). The thinner the rectangle, the less time is generally spent on it. The core of visionary thinking is that a sector or organisation tries to identify a state of futures which seems most preferable. Thereafter, from this visionary state, alternative development paths and strategies will be explored for reaching the identified state. Due to path dependence, major strategic decisions may even have an impact lasting over a century – to the futures and to the pasts (Kaivo-oja et al. 2004). Sometimes the argument "we are not interested in history, we are interested in the futures" is actually presented seriously. However, history and futures do not exclude each other. This misconception is mainly due to the path dependence of water services infrastructure development (Melosi 2000); certain strategic decisions have unavoidable long-term impacts.

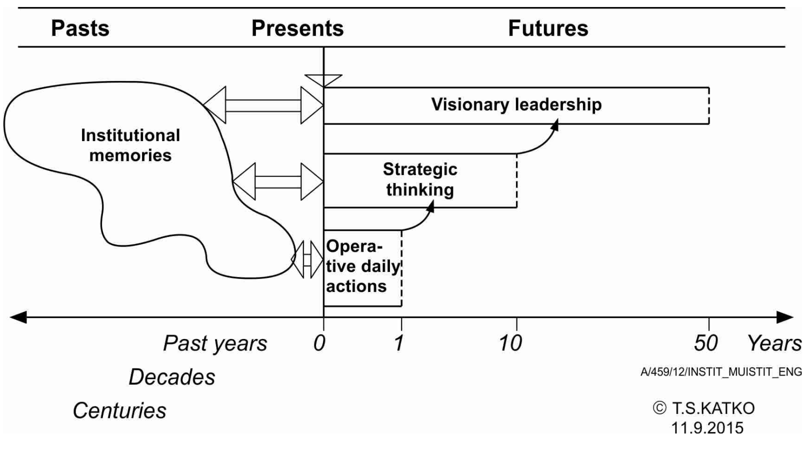

Figure 3: Timeframe for futures thinking and leadership: from operational to strategic and visionary thinking (Katko, forthcoming 2016)

At least in Finland, the selected major paths have hardly ever been linear; on the contrary, the paths have usually divided into new development paths. In some cases, such as selecting a new raw water source, older paths may have been rediscovered. The driving forces seem to be linked to legislation – especially to the requirements of water pollution control (Katko et al. 2006).

Water services are under continuous need of reassessment. In the short-term some of the changes may seem dramatic, but they are not necessarily so in the longer term. Such changes are anyhow relative and depend on the viewpoint and timeframe (Figure 4). In fact, the timeframe of water services development is exceptionally long, up to 125 years to the pasts and 125 years to the futures. Therefore, instead of one year "the quarter of water services" needs to be counted from a millennium, a fundamentally different timeframe. By no means is this to deny that daily operations are to be managed as well as possible; they should not be ignored.

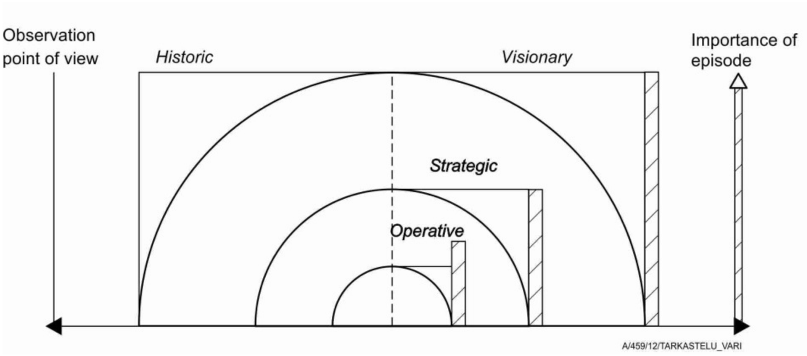

Figure 4: Suggested timeframe for water services of a quarter of a millennium: 125 years to the pasts and another 125 to the futures. The relative importance of change depends on the viewpoint and timeframe used. (Katko, forthcoming 2016)

4. Core and non-core activities of water utilities

In water services production public-private cooperation (PPC) has been practised in Finland since the early days. From strategic point of view one of the key questions is the division of core and non-core activities of utilities (Figure 5) and to what extent it is possibly feasible in various conditions to outsource the latter. Core activities may include main responsibility for required investments, strategic asset management, financial management, ownership, strategic thinking and management, bidding, business development, reputation and stakeholder management, as well as customer relations. Non-core activities, on the other hand, may include design, construction, equipment, spare and chemical supplies, vehicles and machinery, repairs, inspections, laboratory services, accounting, training, billing, meter reading, operation and maintenance, water and wastewater treatment activities, and research & development.

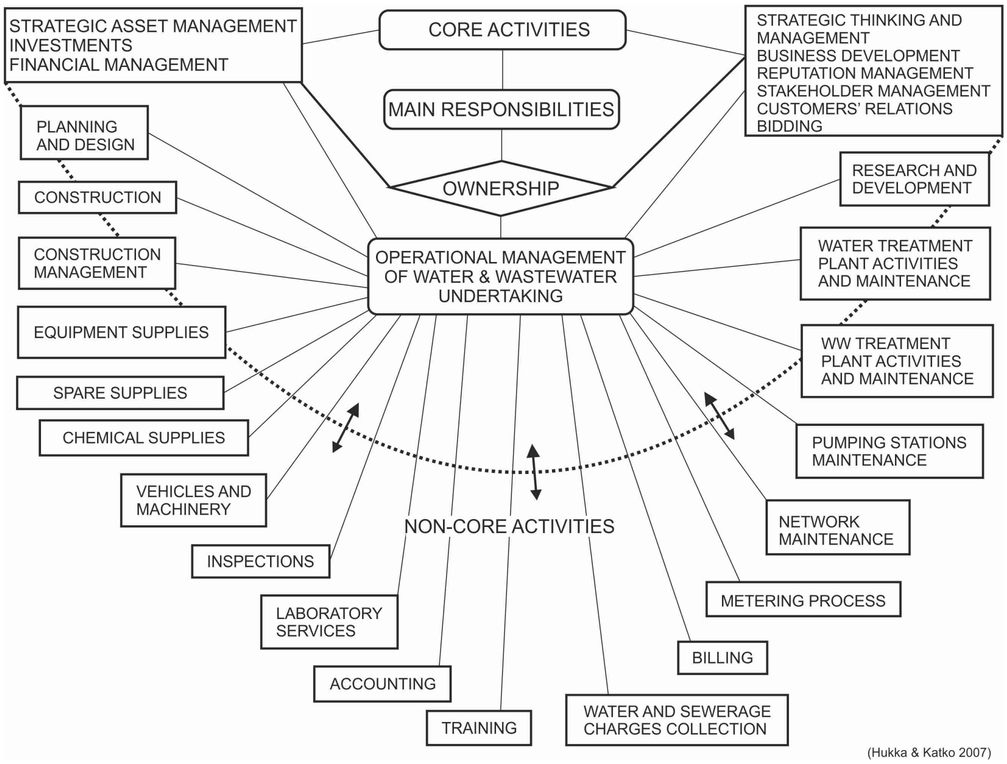

Figure 5: Core and non-core activities of water and wastewater utility (Kraemer 1998, 324; modified by Hukka and Katko 2003, modified by the authors)

Bearing in mind the difference between provision and production described earlier, the above-mentioned core and non-core activities are likely different for municipalities and, on the other hand, for water utilities. These may also be assessed through three different strategic functions: the first category being those obliged to municipalities by legislation, the second those being of major strategic importance to utilities, and the third other strategic functions.

The first mentioned core activities in Figure 5 are those closer to municipalities as utility owners. Utilities have their own strategic and operational functions. Under the latter, core activities and non-core activities can be identified. Thus, in reality the core activities and non-core activities in Figure 5 become even more complicated. In any case, it is of high importance that activities seen of strategic importance should not be outsourced.

From the point of view of education and research, it seems surprising how the current education and curriculum seem hardly to cover such strategic issues and the role of core activities. It is very obvious that these fundamental core issues cannot be left merely to continuing education and on-the-job training only. In spite of some trials on MSc Programmes or MBA programmes on Water Utilities Management, they seem not to get much ground. This is likely due to the prevailing focus on natural sciences and treatment technologies which are of course important as such. However, they are not able to give any answers to wider management, institutional, policy and governance (MIPOG) issues, such as the challenges of appropriate pricing and feasible asset management. Indeed, worldwide we have a huge challenge of proper asset management and need for rehabilitation to rates that are likely two- or even threefold compared to the present reinvestment rates. (Hukka and Katko 2015)

5. Discussion

Instead of dramatic ad-hoc (one-time) reforms that are not uncommon in developing economies, overall evolution in Finland has mainly been based on the principle of continuous development and determined policies. This has been very evident especially in water pollution control since the 1960s. On the other hand, it may be that flexibility could have been practised more. Perhaps an example of this overall finding is the Decree on Water Pollution Control in Dispersed Rural Areas passed first in 2003. In 2011 it was revised (196/201) and in 2015 it is on the Parliament table again. Changing rules of the game for several times does not sound feasible, although there might have been some obstacles in drafting the first version.

Most likely the biggest challenge of water services in the coming 20 to 30 years in Finland and also elsewhere will be aging infrastructure, especially deteriorating networks (Heino et al. 2011; Hukka and Katko 2015). The current state of the networks in Finland is satisfactory and it will get worse unless clearly more resources are directed to rehabilitation. Compared to the experiences gained from water pollution control it seems evident that we need better “rules of the game” and institutional arrangements if we want to avoid the collapse of the current water infrastructure systems. In the case of water pollution control clear requirements and enforcement were needed. In the case of aging water infrastructure more clear requirements on long-term investments will be needed, respectively. Sector professionals and utility managers also have to take this more seriously than so far in order to convince decision-makers on the matter.

As a whole, the ways of implementing water services are in any case highly dependent on *local conditions*. Available options should be always seriously considered and accumulated knowledge be used. In water services, private, non-profit systems are justified whereas international instances on profit-maximization have produced warning examples. However, the successes of any water services can finally be assessed only from the point of view of the results: how well they have fulfilled their societal objectives.

The challenge is proper asset management and need for rehabilitation to rates that are commonly two- or even threefold compared to the present reinvestment rates. In order to improve this situation it is necessary to pay more attention to institutions, the rules of the game.

6. Conclusions

The following major conclusions can be drawn on this paper:

(i) The timeframe of viable water services development is exceptionally long, up to 125 years to the pasts and 125 years to the futures, thus a quarter of a millennium.

(ii) In education and research on water services undertakings clearly more attention should be paid to strategic functions of municipalities as owners and on the other hand those of utilities.

On the whole, it is evident that to reach more sustainable futures and water services we need to pay more attention to institutions, "rules of the game", and even wider to management, institutional, policy and governance (MIPOG) issues including the acute challenges of appropriate pricing and feasible asset management.

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Need of Services and Understanding of Service Providers in Water and Sanitation: A Case of Ethiopia

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Abstract

Water and sanitation services are basic requirements for the development of a nation. The provision of these services should necessarily be arranged by the national government through policies, and long-term and short-term plans. Moreover, follow-up of the implementation of principle in policies and plans will determine the service level on the ground. This paper is intended to explore gaps in the policy-making and implementation in the areas of water supply in Ethiopia. Review of Ethiopian water sector policy, universal access plans, growth and transformation plans and other literature are employed to achieve the objective of this paper. Moreover, the experiences of the first author that he acquired during data collection for his doctoral study are taken into account to draw conclusions. Hence, the study shows that standards set at the federal level fail to consider the actual situation on the ground and the experts at implementation level are to interpret some aspects of the policy ambiguously. Therefore, this paper recommends the policy-makers and higher officials to consult the people in charge of putting policies in effect to have contextualized and work for uniform desired-output. Service providers need to understand the notion of the receiving community in order to provide the services that satisfy the users.

Keywords: Services, policy, service provider and service producer, water supply, sanitation

1. Introduction

Well-articulated and in-depth organized policies alone cannot guarantee the achievement of the intended goals of a country. Rather, they need to be followed by systematic regulations and directives to put them into practice (Matland, 1995). Moreover, it is not only the policy-makers who require an understanding of the real problem to be solved and the mechanisms of alleviation but also every concerned member at various levels of the government, partner organisations and the receiving communities need to know to have a successful implementation. This aspect determines the thought of policy-making if it is top-down or bottom-up as explained by Matland (1995). It should also have a favourable platform to accommodate both internal and external actors.

Platforms that are provided by national policies and strategies could guide the way of actions of governmental and non-governmental organisations, and donors in a particular country. Either from the legal or logical point of view, external imposition cannot achieve a substantiated impact in terms of contributing to the developmental strategies of countries. Support in this context means helping countries to achieve their own goals, policies and strategies (MoWR, 2001b); otherwise, the effect will be retardation.

On the other hand, the detail of a national policy on a specific agenda is very critical to accommodate both local and external partners who work in a certain sector. If it lacks clarity and depth, the implementation will still be ambiguously challenging. Moreover, in the presence of excellent policies and directives, achievements might be trivial due to the way they are understood by the members of the implementing bodies both in the governmental and non-governmental organizations. Therefore, before going into a deep analysis of the situation in the country, let us see the points boldly mentioned in the Ethiopian water sector policy.

This paper is not to make a thorough critique of the entire water policies of Ethiopia, but to make a review where improvements are suggested on how to fill the gaps observed in the area of water supply and sanitation. The main question here is how accurately the policy flows down to the community though the intermediary government levels – in other words how the policy-makers control the effectiveness of the policies? Moreover, we will try to discuss the process of policy-making based on the facts in the national programmes and make conclusions accordingly.

The rationale for selecting this subject is the remarkable national effort to the development of water supply and the visible gaps in the sector. Moreover, the merit of the expertise of the authors in the field has agitated this paper. The first author has done his research on the rural water supply of Ethiopia since 2012 and the second author was involved in a project which works for the rural water supply of Ethiopia with the collaboration of the Finnish government.

The focus of this paper is to create awareness among the Ethiopian policy-makers in the way they can think of the future and how to monitor the effective policy-making and implementation. Moreover, the study is on Water, Sanitation and Hygiene (WASH) services in general with more focus to rural water supply.

2. Ethiopian water sector policy and development programmes

Based on the history of water resources development in Ethiopia, clear changes in the area of water supply and sanitation have been observed very recently (Behailu, et al., 2015). Moreover, the department, which was responsible for the water supply and sanitation, was not clearly placed appropriately until the active policy came into force in 2001. Earlier, the department was placed in different sectors where it had less attention, especially at the district level. During the years 2003-2004, when the administration of the country was decentralized, for the first time, a water desk under the natural resources department of the Agricultural development office was established at the district level (Calow, et al., 2012). In fact, currently, it is being transformed into an autonomous water office.

In institutionalizing the water supply and sanitation sector, the new millennium has a historical record. After the current active policy of the water sector enacted in 2001, several programmes and plans have been launched and are in operation to improve the life of citizens. These plans and programmes are water resources development strategy (MoWR, 2001b), Universal Access Plans (UAP, 2008; UAP-II, 2011 & UAP-III, 2011), WASH Implementation Framework (WIF, 2013), One WASH National Programme (OWNP, 2014) and Growth and Transformation Plans (I & II) (GTP, 2010 & 2015). These plans and frameworks have water supply and sanitation as a key component. Therefore, this paper will review them from the angle of water supply.

2.1 Ethiopian water sector policy and strategy

The Ethiopian water sector policy and strategy have comprehensively addressed irrigation, hydropower, drainage, water supply and sanitation. Water resources protection, management and optimization are well articulated in the policy, and in the case of limitation, water supply has been given priority (MoWR, 2001 a&b). The documents intensively describe the importance of clean water and sanitation as they are directly linked to the health problems of the country and base for the economic and social development (70% of the diseases in the country are waterborne (MoWR, 2001b).

As the focus of this paper is on water services, this section will review the policy and strategy from the angle of explaining water supply and sanitation. Moreover, water supply for urban and rural areas will be viewed differently since they have a different perspective in the documents. The role of administrating the urban water supply in Ethiopia is vested in the autonomous body consists of users or board. The board of the user council is responsible for rising investment capital and money for operations and, with a limited assistance from regional and federal governments, to seek loans in the case of large projects. In the case of urban water supply, the users are expected to cover the full cost – the initial cost and cost of Operation and Maintenance (O&M) (MOWR, 2001a).

In the case of rural[1] water supply, the source of initial investment is the government or external agents whereas O&M is the responsibility of the communities (Calow, et al., 2012; MOWR, 2001a&b). As a result, the policy stressed the need for user consultation to the development of such systems in order to create ownership feeling for active O&M. Thus, the success of rural water supply mainly depends on the availability of the government's capital budget and funds from donors and the O&M on the approach followed during implementations. This, in turn, significantly affects how the implementers understand the policy in the context of consultation and participation of the user community.

According to the Universal Access Plan, UAP (2008), the user community contribution should cover at least 10% of the capital cost of the projects, in order to motivate and create adequate ownership feeling. Moreover, users are deemed to cover the cost of operation and maintenance of their water system – cost recovery in the rural context is partial (MoWR, 2001a), only for operation and maintenance unlike to the urban water supply. The policy document has clearly pointed out water is not for sale since it is a public good. Therefore, service charges are to cover operations and maintenance costs, not for using the water resources. The cost recovery context here has been considered in different ways. Therefore, the tariff setting is left for the community and the rate is observed to be very small compared to the requirement for operation and maintenance (Behailu, et al., under review). According to national directives on policy and strategy, the role of tariff setting is left to the user community. Yet, the amount they agree to pay is not sufficient to cover increasing prices of spare parts.

To smooth the implementation of the policy, detail procedures and directions are provided in the water sector strategy. The strategy contains the ways the policy of water supply and sanitation from technical, financial, institutional, capacity building, social and environmental aspects. In general, it is more concerned to provide sustainable, effective, efficient, reliable and affordable services. Maybe due to the high proportion of the rural population, it recommends hand pumps as the best means to expand sustainable service. In practice, however, hand pumps are limited to the areas where there is shallow groundwater table and not universal in terms of availability. Moreover, it is susceptible to climate change as shallow groundwater is easily affected by the amount of direct recharge. Therefore, the strategy did not provide alternative solutions for the areas, which do not have plenty of surface and groundwater resources. Hand pump water systems that are installed in shallow wells will not guarantee sustainable services in communities with rapid population growth, areas that are affected by climate variability now and then, and water resources are in a declining trend.

In terms of finance, the implementation of water supply in rural areas is advised and supported by the local financial institutions like micro-financial institutions, local saving institutions and banks to access loans to implementation, operation and maintenance of water supply and sanitation systems. This is, actually, to supplement the external supports and government

[1] Rural in Ethiopia accounts for 84% of the approximately 100 million populations.

subsidies for water supply development. The strategy emphasises to maintain social equity by providing a subsidy for those who are not able to cover the cost of their services (MoWR, 2001b). However, the majority of rural communities are not able to finance water supply projects. Thus, this situation is making the work in water supply difficult to finance and address all in a short period.

Ensuring transparency, fairness, responsibility, and accountability in utilizing and managing of the WASH funds are the priorities of the strategy of the water sector. According to Calow, et al. (2012), the country has managed to maintain corruption on a low to medium level in rural water supply. However, the efficiency of systems requires improvement to operate at their full capacity.

In terms of training in the capacity building, the national water resources development strategy has attractive capacity building scheme (MoWR, 2001b), but it lacks the proper way to handle the existing trained staff not to migrate out. The shift of personnel from one organisation to the other does not matter to the overall performance of the sector, but there are areas that suffer heavily – rural areas where technical staffs do not like to work due to the lack of facilities and incentives.

2.2 Water supply in the Universal Access Plan I & II

The first Universal Access Plan (UAP) was for the period 2006-2012 and its target was to achieve the water supply coverage of 98% as a country including both urban and rural areas. The core of the first UAP was community mobilisation. Creating awareness among the community is crutial to handle the system sustainably. However, the plan was revised in 2011, to harmonize with the GTP.

In the revised version of the UAP, the rural and urban water supply were separated and designed to achieve 100% of coverage by 2015. However, the levels of services remained the same as in the previous plans such as 15 litres for rural and 20 litres for urban per capita per day in the radiuses of 1.5 km and 0.5 km, respectively.

In terms of the technical details, UAP-II has comprehensive plans that hold technical, financial, institutional and social aspects. Moreover, it has plans for operation and maintenance, rehabilitation and expansion. Otherwise, all documents of UAP have detailed the explanations of implementations of water supply systems both in rural and urban areas.

At the end of 2015, the objectives of any of the three plans have not been achieved. On top of that, the second Growth and Transformation Plan has already started with new standards, 25 litres for rural and 40 – 100 litres for urban water supplies. This implies that the new UAP will be expected very soon.

2.3 WASH Implementation Framework (WIF)

WASH Implementation Framework (WIF) is a framework formulated by four Ministries in Ethiopia, all directly involved in water supply and sanitation implementation. The goal of the framework is to bring fragmented efforts together to improve their impact. The Ministries involved in the framework are Health; Water, Irrigation and Energy; Education and Finance. In one way or the other, these Ministries have been taking part in the development of water supply and sanitation, thus, they sat down together to harmonize their efforts for greater impact.

The key elements in WIF are integration, harmonization, alignment and partnership (WIF, 2013). These elements are also the starting point in implementing One WASH National Program (OWNP, 2014). It means that WIF has paved a way for OWNP by creating a common understanding of the four ministries, which are involved in water supply and sanitation implementation.

The point that needs to be encouraged is the action taken to harmonize the activities of WASH in the country that was fragmented. The effort of integration in the country will, at least, reduce the cost of information, and duplication efforts in the same areas. On the contrary, actors in the sector did not give attention to local situations. It seams that they are still think that one principle will work uniformly everywhere in the country. For instance, a uniform system intended for all areas will not funcion ideally in both agrarian and pastoralist areas. In the national policy, "water supply" includes the domestic consumption and water for cattle. Therefore, water supply services in the context of pastoralist have a wider perspective than water supply for the area where their livelihood is typically agriculture. However, the framework is sticking to 15 litres per head per day as a target to achieve.

However, the commitment of the ministries to lay the foundation of harmonization and paving the way to One WASH National Program is appreciable. This is due to the fact that the experiences of many other countries still lack the concept of resource harmonization and avoiding working independently without coordination.

2.4 One WASH National Programme

The principle of one budget, one program, and one report is the motto of One WASH National Programme (OWNP). Its objective is to harmonize actors in the sector. This actosrs are including donors, partner organisation (NGOs), and governmental organisation and the private sector. In the conventional way of implementation, these actors operate separately based on their preference and hence their outputs achieved can not be measured. Moreover, different actors would have worked in the same area and caused duplication of efforts. Following the WIF, the coordination of the four ministries mentioned above created a fertile ground to establish one WASH. The national government together with regional counterparts and partner organisations should lead the development direction as outlined in the OWNP.

OWNP is launched in 2013 and is now in the implementation phase. The programme is expected to bring harmonized campaigns in the sector to address the marginalized rural, especially who are situated in the most remote areas without accessible roads.

2.5 Water in the Growth and Transformation Plan I&II

An amazing plan that has created big questions among the citizens of Ethiopians is known as Growth and Transformation Plan (GTP). It was launched in 2010 with ambitious goals that seem unachievable throughout the development sectors in the country. The plan was designed for five years and the second GPT has already started as of July 2015. Grand Renaissance Dam, Addis Ababa light train, Djibuti – Addis Ababa and Awash – Waldia – Mekkel express train projects are a few that are observed changing the image of the country. Water supply, as one of the development sectors in the country, has similar attention in the growth and transformation plan. Although the initiation of the government on the development is very appreciable, there are doubts among the citizen on the effectiveness of the plans in the short periods of the plan horizons. As indicated in Figure 1, the horizontal axis shows water supply coverage under different service levels. According to the national government, each service level has denoted by each GTP and each GTP is assumed to promote the country from one economic level to the other. In 2010, the country has designed a plan to grow from the least developed status of the lower middle income and then to the upper middle income level, before promoting to the status of the developed economy in three consecutive five-year-plans. However, it is hard to judge how many GTPs can transform a country from one economic level to the other.

Urban and rural water supply targets of the previous GTP were 20 litres per capita per day for urban and 15 litres for rural areas. Having these figures in mind the country could not achieve full coverage with this level. Nonetheless, the country again displayed a new standard of quantity supplied – 25 l/c/day for rural and 40-100 litres for urban – based on GTP 2. In fact, the service level increases through change of GTP and economic.

The point that we want to discuss at this juncture is that how the water supply systems, which were constructed for the previous standards could better fit in the new standards. Moreover, natures of the water supply schemes in the country are not in a capacity to render the GTPs proposed service level.

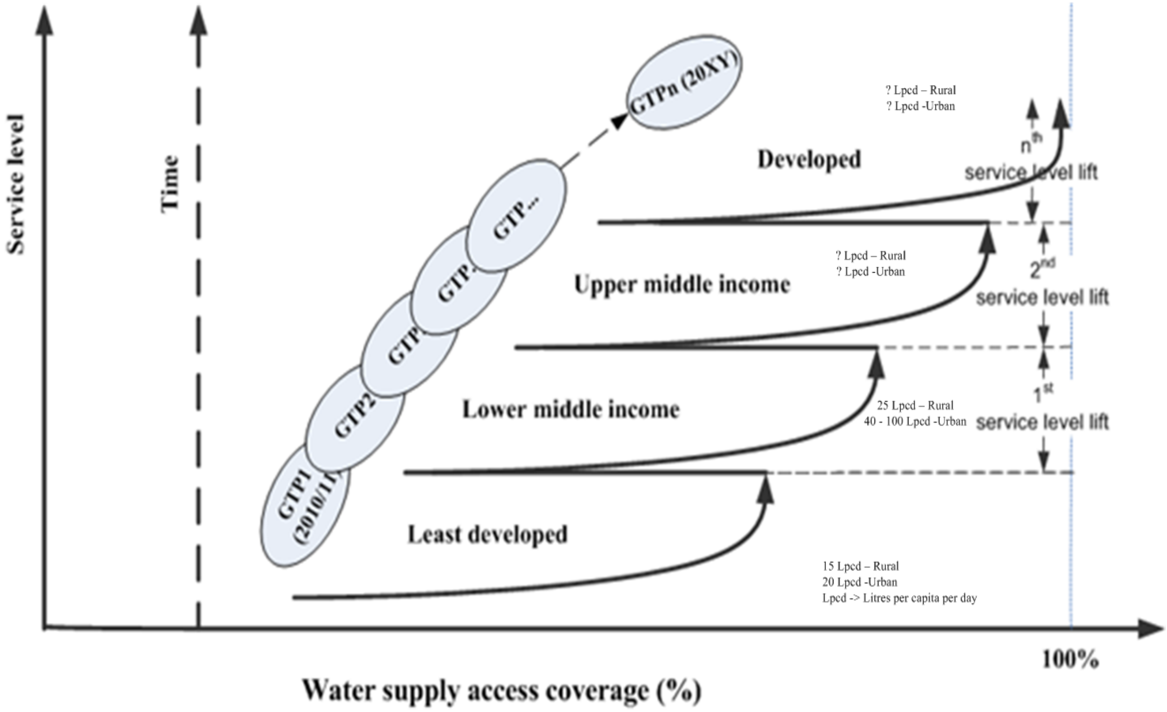

Figure 1: Tracking the Spiral Uphill Journey Path to Water Supply Universal Access to the Highest Service Level (modified from Mekonen, 2015)

3. The existing situation of services

Matland (1995) explained the top-down approach of policy-making manifested by three important drawbacks, such as lack of addressing the public objectives, excluding users and lack of a boundary between administration and policy. From these aspects, the Ethiopian water sector policy could fall under the top-down approach due to the following reasons: (1) the implementations at grassroots level are lacking pure knowledge about the policies, (2) interests of the community are not well addressed – they are driven by the consent of implementors and (3) the administration of the country is led by the political environment.

Ethiopia was celebrated for the achievement of Millennium Development Goal target 7 C in March 2015. The water supply coverage was improved by 57 % for the last couple of decades. The achievement was evaluated based on the national standard for rural and urban. The rural people are assumed to get 15 liters per capita per day and the urban 20 liters per capita per day and within the distances of 1.5 and 0.5 km, respectively (UAP, 2011). However, the study conducted in two regions of the country showed that the water supply coverage is highly subjected to insufficient service, particularly from quantity point of view. At least 40% of the populations are still without any water service. Therefore, the central point of this paper is to answer a question “How much service providers are concerned about sustainable services of the system they are in charge of?”

The served populations of the country are still uncomfortable about the service they are getting. In rural area at least 75% of the served population gets water less than 15 litres per day, which is below the national standard. Furthermore, almost all cities in the country have frequently experienced service breakdowns and a shortage of supply. For instance, Addis Ababa (the capital city); Adama, Dire Dewa, Bahirdar, Harar, Hawassa and Mekele (Regional Capitals) and other small cities usually report for residents' complaints about water scarcity. The causes of the problems might be various, but the dominant ones are poor standards of provision and production, the instability of technical personnel, and lack of commitment to feel the pain of the end user.

Ethiopia is a country that has various climatic conditions and standards of living. Some cities have a temperature low enough to freeze water in the pipelines and some have an average temperature of over 40 degree Celsius. However, the national standards do not consider these disparities. This can be good evidence of the gaps that exist between service providers and producers. The technical personnel are more concerned in discharging their responsibility than the provision of adequate services.

According to the Ethiopian governmental structure, the district level is the most important governmental entity in facilitating services to the rural communities. However, the facilities and salaries at that level cannot attract skilled manpower. Regional, federal or non-governmental organizations attract skilled manpower. As a result, staff turnover is a common and known practice in the country. One of the threats in the growth and transformation plan (GTP) is also marked as staff turnover – 60% of skilled manpower from the total required expected to be available during the plan period. The implication of this is that the service providers are not ready to understand the rural community and not significantly concerned about the sustainable services.

4. Conclusions

The last two decades have been extraordinary for the water supply and sanitation in Ethiopia. In terms of providing policy, regulations, strategies and plans many have been done since 2001. Moreover, physical implementations of services are not insignificant, although diversified plans have been introduced to improve the coverage of the services. However, from the criteria of top-down and bottom-up approaches, the policy dominantly looks fitting the top-down approach. For example, 15 litres per capita per head is a national standard of the rural community in the country with diverse climatological regions. If the policy was bottom-up, the policy-maker would understand that this amount is not enough.

From the view of creating ownership feeling, the national government has a regulation to keep the public participation to make at least 10% contribution. The basic objective of contribution is not primarily to seek money, but to retain the involvement of the users to feel ownership and make them able to manage the systems after the implementation. However, in practice, the people at the implementation level can feel it as a burden that they must provide participation level to the government to prove the involvement of the communities. In this regard, the way of participating is not achieving its target in many cases.

Therefore, the national policy needs to be extended to every stakeholder and confirmed if policies are implemented in the sense of its original objective. Moreover, service providers or producers must shoulder the responsibility of providing intended services. To materialize these, actually, there must be a forum to create understanding among users about the future of the systems.

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Life Cycle assessment of Anti- and De-icing Operations in Norway

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Abstract

During winter maintenance in Norway 2014-2015, 225 445 tonnes of chemicals were used and 1 610 000 km driven while removing snow and ice on national and state roads. Despite this significant amount of chemicals and distance, winter maintenance is often omitted from current environmental studies of roads and transportation. Current studies focus primarily on vehicles, fuel technology and construction activities. This focus has been based on the fact that these are the largest source of emissions from road transportation. However, as vehicle and fuel technology advances and have less impact per unit, other aspects of transportation, such as maintenance and operation of infrastructure become increasingly important and should be included in LCA studies of roads in cold climates. In this study, life cycle analysis (LCA) is used to estimate the environmental impacts of the production, transport and distribution of chemicals during winter maintenance in Norway. The study is based on reported quantities for winter maintenance during an average winter between 2010-2015. The functional unit is set as anti- and de-icing operations on national and state roads per km during winter an average winter from 2010 through 2014. The results show that environmental impacts from winter maintenance are significant, and thus we argue that winter maintenance should be included in LCA of roads in cold climates. Further investigations on current winter maintenance methods and future options are to be conducted in order to avoid solving one problem while creating another one (problem shifting) during policy development.

Keywords: Winter maintenance, highway, life cycle analysis, environmental impact, anti- and de-icing

1. Introduction

The transportation sector is estimated to be responsible for over a quarter of greenhouse gas (GHG) emissions in the world (Chapman 2007, European Commission 2015). Direct emissions from road transport are the single largest source of GHG emissions within the transportation sector, and therefore emphasis on vehicle technology and emission reduction in the use phase has been dominant (European Commission 2015). However, GHG emissions and the resulting global warming potential (GWP) is not the only impact transportation has. Other impact categories include ozone layer depletion (ODP), acid deposition and reduced air quality in urban areas, which affect human health (Colvile, Hutchinson et al. 2001).

As transport and transportation infrastructure are essential to our society, the construction of new and the handling of existing infrastructure has become a cornerstone of sustainable development (Reza, Sadiq et al. 2014, Santos, Ferreira et al. 2015). Sustainability in transport is only achieved if all aspects are optimized. Therefore, planning and designing new infrastructure as well as maintenance of existing ones are essential as roads are rarely dismantled but rather reconstructed (Stripple 2001). To be able to take into account all aspects of infrastructure life cycle analysis (LCA) is a tool often used. LCA accounts for emissions throughout the whole life cycle of a product or a service from production to the end-of-life. Additionally, LCA is useful to avoid problem shifting.

Several LCA studies have been directed at road infrastructure. These studies focus on various aspects of the transportation sector including fuel use, road construction materials, pavement options, lighting and vehicles (eg. Birgisdóttir, Pihl et al. 2006, Zhang, Keoleian et al. 2010, Huang and Parry 2014, Huang, Bohne et al. 2015). In addition, several reports have also been published especially the report by Stripple (2001) is of importance as a practical guide to LCA inventory analysis of road construction processes. Many of the processes mentioned in the report have been studied while other processes, like winter maintenance operations, have not been sufficiently explored. It is becoming increasingly important to include these operations in LCA studies on road and transport in colder climates as vehicle and fuel technology advances have led to less impact per unit.

The aim of this study is to estimate the environmental impact of anti- and de-icing operations in Norway. The results are presented in a way that allows for further use in other studies so that anti- and de-icing impact can be included in future LCA studies of roads in cold climates.

2. Winter Maintenance Operations

The general goal of maintenance operations is to ensure mobility and traffic safety, limit environmental effects, provide good service and take care of the road infrastructure capital that exists (Statens Vegvesen 2014). One of the most important method for achieving this is friction control. Friction between the tire and the pavement is essential for control of the vehicle and effects acceleration, breaking distance and directional control. Friction control is achieved by either salting or sanding, where salting is used on roads with heavy traffic while sanding is more common on road with lower traffic (Norem 2009).

In the report *National Plan of Action for Road and Traffic Safety 2014-2017* (Statens Vegvesen 2015), where the goal of zero casualties is presented, it is shown that fatalities and severe injuries are most likely on national and state roads with total share of 37% and 45% respectively. Fatalities directly linked to weather and driving conditions were on average 16% of the total fatalities in the years 2005-2012. The category where the speed is well over the speed limits, or higher than road conditions allow for, has a share of 45% of the fatalities (Statens Vegvesen 2015). This could be directly related to road conditions. It is, however, known that drivers do not adjust their speed in proportion with reduction in road friction (Norrman, Eriksson et al. 2000). The report lists several measures to reduce incidents that include:

- Increased user awareness
- Control measures
- Motor vehicle measures
- Measures on roads.

Winter maintenance falls under the category *Measures on roads:* clearing of snow, increasing friction as well as training winter maintenance operators. Winter maintenance operations are often complicated and unpredictable and require vigilance. Of the more important tools that winter maintenance operators use are weather forecasts. However, the forecasts' quality and reliability varies, as does local situation and sudden changes in both temperature and precipitation. In a standard for operation and maintenance for roads, there are guidelines for activities that winter maintenance operators are to follow. These activities are, for example, to monitor the situation visually and through the weather forecast, use anti-icing when needed as well as de-icing and mechanical snow- and ice-removal (Statens Vegvesen 2014).

The term anti-icing is used for the action of applying chemicals to prevent wet pavements from freezing by lowering the freezing point of the water. De-icing is the act of using chemicals to remove snow and ice that have already bonded with the pavement. Additionally, chemicals are used for anti-compaction purpose where the chemicals weaken the bond between the snow crystals and prevent the snow from forming a hard crust and bonding to the pavement surface making snow removal easier (Wåhlin and Klein-Paste 2015).

In Norway, highway winter maintenance has evolved over the past decade from reactive operations towards more proactive actions. A study conducted in North America regarding operators experience shows that most winter maintenance operators felt that anti-icing and pre-wetting helped them to improve roadway safety as bare pavement was achieved more efficiently and made mechanical snow removal easier (Cui and Shi 2015). Even though salting is very helpful in winter maintenance, it is not always appropriate. In Figure 1 the temperatures and precipitation (in mm water equivalent per hour) where salting is advised, not advised or should be done with caution are presented.

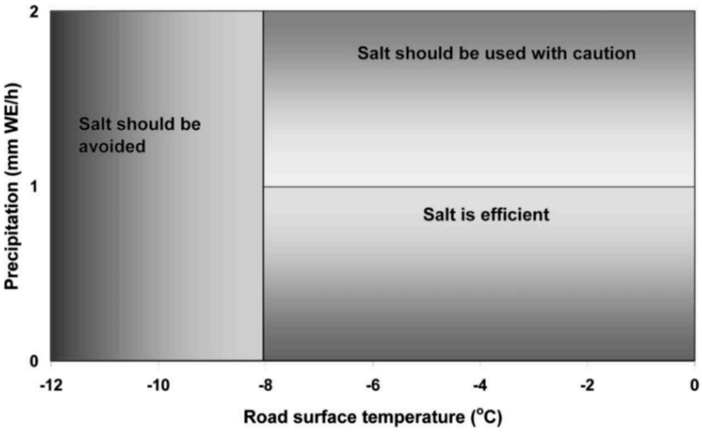

Figure 1: Weather situation and salting efficiency (Norem, 2009 p. 115)

The lower the temperature, the higher the concentration of salt must be in order to efficiently prevent ice formation and to reduce the risk of bonding between both snow crystals and snow crystals and the pavement surface. Therefore, the salt quantity is highly dependent on these weather situations shown in Figure 1 where the highest consumption is then when the weather is cold and with precipitation while salting is most efficient for temperature -8 to 0 degrees Celsius with fairly low or no precipitation (Norem 2009).

Other factors affect the amount of salt on the road are dependent on three physical processes: the initial loss, the dissolution of salt and the loss of salt (Lysbakken and Norem 2011). The initial loss of salt occurs when it is spread to the roads by wind or turbulence from the winter service vehicle (WSV) itself or because of the speed of the vehicle and spreader. The initial loss can be reduced by pre-wetting or by spreading brine. Other factors such as road surface conditions and texture as well as wind also affect the initial loss of salt. Dissolution of salt in water or brine on the road surface is mainly affected by the solubility of the chemical used and the dissolution rate. The process of salt loss includes several process where the salt leaves the road surface. These processes include salt lost by traffic as either blow-off (dry) or spray off (brine) and finally the runoff (Klein-Paste 2008). It is important that winter maintenance operators are aware of these physical processes.

3. Method

LCA is often used in assessing environmental effects from products and services in order to avoid problem shifting. LCA is therefore a very suitable tool in assessing environmental impacts of winter maintenance operations. An LCA study is conducted in four phases. First, goal and scope are defined; this includes defining the functional unit and system boundaries. Then inventory analysis is conducted where all physical products that go in and out of the system are accounted for. Environmental load of these flows are then calculated to form an impact assessment and finally the results are interpreted (International Standards Organization 2006). During each of these phases, the previous and next phase should be reconsidered in order to make any necessary changes that are revealed during the investigation. The LCA software SimaPro was used for this study, with the ecoinvent database (Weidema, Bauer et al. 2013) and calculations made with CML baseline impact assessment method.

It is very important that the inventory is carefully executed and accurately reflects use of any equipment, materials and energy. Poor inventory will only lead to high inaccuracy and maybe even wrong environmental impact results at a later stage.

3.1 Goal and Scope

The goal of this study is to map and analyse the activity of anti- and de-icing operations in Norway. The system boundaries are limited to winter maintenance operations; specifically anti-icing, de-icing and anti-compaction for increased friction and making ploughing easier. Within the system boundaries are material production and transportation as well as storage but also equipment and energy use. However, the chemicals effect on the environment after distribution is left outside the system boundaries due to lack of data.

By mapping the activities, a detailed inventory can be made to realize resource intensity. The study covers average winter maintenance operations in Norway for winters 2009/2010 through 2014/2015, from now on referred to as winter 2010 through 2015, on national and state roads. Mechanical snow removal is however outside the scope of this study.

The results are intended to be available for use by other LCA practitioners as well as winter maintenance personnel. Therefore, the results will be set up systematically, making it possible to contribute to other LCA studies that have results per kilometre to give an indication of the environmental impacts of winter maintenance.

3.2 Functional Unit

The functional unit is the very corner stone of any LCA but finding a suitable functional unit within the transportation sector can be difficult. This difficulty stems from large variations in design, location, material use, geographical profile, transportation distances and traffic load. In this study, the functional unit is the *anti- and de-icing operations on national and state roads per km during winter an average winter from 2010 through 2014*.

4. Life Cycle Inventory

The inventory for winter maintenance is quite complex and different from a more common product based inventories. It is different in the way that there is no standard recipe for achieving safe roads during the winter season. Therefore, it is necessary to base the calculation on an average. Whether it is most suitable to have an average based on the previous winter or if the last five should be used, is debatable. In this study the average of the last 5 winters was chosen as they are believed to be well documented and give good representation of an average winter in Norway. These averages will then have to be presented per kilometre for all different types of equipment, materials and transportation distances. There are few things that are constant, or could be assumed constant, between seasons. Locations of the distribution storage for example, where the ships dock and the salt is unloaded and stored, can be assumed to be fairly constant as the biggest importers have the same or similar locations (Aslaksen 2015, Heggedal 2015). In the following section, necessary equipment and materials needed for winter maintenance are listed along with important background information.

4.1 Equipment

Equipment in winter maintenance mainly refers to the winter service vehicles (WSVs) such as trucks and their extra equipment. Extra equipment includes tanks, salt/sand spreaders and the different types of blades and ploughs. However, it also includes information about storage facilities for the salt and sand regarding type of storage, the location and possible energy use. In Norway, the most commonly used WSV is a truck or a tractor with mounted a spreader, plough, grader or loader. For highways, trucks with a mounted plough or a grader and salt spreader are the most common. These vehicles mentioned are used during and right after a weather event. Additionally, other WSV might be needed soon after a weather event to clear areas of snow for example to improve visibility or to remove compact snow and ice from the road. (Sivertsen 2015). The WSVs are owned and run by the contractors that are awarded contracts for approximately 5 years at a time. The quantity of vehicles in use during winter season is therefore difficult to determine.

Storage facilities are located at or near the shipping docks near the largest cities. These places are assumed to have storage facilities, which are warehouses with a roof and four walls. As they are assumed to have no heating and are used for a long time, they are insignificant in terms of emissions. The storage is therefore omitted from the inventory analysis.

4.2 Materials

Winter maintenance materials includes the chemicals used for anti- and de-icing. According to major importers of road salt and the largest contractors for winter maintenance operations on national and county roads, the largest share of salt is used in the south, west and mid-Norway to around the area of Trondheim. Information about the storage locations are obtained from Mesta (Heggedal 2015) and GC Rieber (Aslaksen 2015). Table 1 presents major storage facilities as well as quantity of salt in each location and percentage of the total imported salt.

Table 1: Location of salt storage facilities, quantities and share of total imported salt

Quantities / *Location*	*Salt [tonnes]*	*Percentage*
Oslo	*65 282*	*32%*
Arendal	*53 408*	*26%*
Stavanger	*52 511*	*26%*
Ålesund	*11 192*	*5.5%*
Trondheim	*11 192*	*5.5%*
Harstad	*4 602*	*2.3%*
Hammerfest	*4 602*	*2.3%*

The quantities of salt that are estimated to be at these locations are based on documentation from Norwegian Public Roads Administration (NPRA) and supported by information from importers and contractors. Reported quantities of salt used in Norway seem to be stable the last years and variations can be explained by changes in weather. However, when looking farther at years prior to the years included in the study, we can see that the use of salt has increased drastically. This increase is due to salt now being used on a larger portion of the road network (Sivertsen, Lysbakken et al. 2011). As mentioned previously, anti- and de-icing operations are beneficial within a range of approximately 0 to -10 degrees Celsius. This reflects well in the information from both importers, contractors and NPRA where salt quantities are lower per kilometre in the northern and in inland regions.

Note, that the impact assessment method used does not account for the salt itself during production. Which means that the production phase accounts for materials and energy used during production as well as equipment but not any effects of salt on the local environment at the excavation site. Additionally, there are no available LCA information about the effects salt has on the environment after distribution. Therefore, effects of salt after distribution are not included in the results. However, there are few things that should be mentioned.

The focus of available environmental impact studies are on the effect of salting on the ground, surface water, soil contamination and stress on vegetation (Fitch, Smith et al. 2013). Environmental impacts of salt are localized and are dependent on various aspects such as road location and weather where precipitation, temperature and wind are of importance. The salt mainly goes directly into roadside lakes, with run-off water to nearby lakes and streams or to roadside vegetation and soil (Ramakrishna and Viraraghavan 2005). During winter, road salt is released into nature in pulses, which can lead to a rapid change of salt in the surface water. This rapid change can have deteriorating effects on the water quality. It has been shown that chloride levels in roadside stream increase dramatically and is carried downstream. With a continued build-up of chloride in lakes, it can have serious effect on the use of the water in the future. Additionally, a large proportion of the salt can leach into the groundwater where drinking water supplies can be effected by the chloride concentration. Salt contaminated run-off water may impact surface water in several ways. It can alter both physical and ecological characteristics of lakes with insufficient mixing of denser deeper layers and fresher upper layers. Seasonal mixing is essential for oxygen transfer in the lake that is necessary for continued animal and plant life in lakes. Toxic metals in sediments can also be release as a result of high salt concentration in water bodies. Release of toxic metals such as mercury can lead to lake stratification which again effects animal and plant life (Ramakrishna and Viraraghavan 2005)

The effects of salt on soil are not as serious as the effects on water. However, it has the potential to increase overland flow, surface runoff and erosion while decreasing soil permeability and aeration. The impact of salt can therefore be assumed to potentially increase emissions that contribute to categories like fresh and marine water aquatic ecotoxicity and terrestrial ecotoxicity.

4.3 Transportation

Transportation of salt is an important factor as the distance are significant. Transportation starts at salt excavation point where it is transported to the harbour. From the harbour, the salt is transported on freight ships to Norway, specifically to the locations introduced in Table 1. To estimate the freight transportation distance an online tool was used (McGraw Hill Financial 2015) and the results can be viewed in Table 2.

Table 2: Shipping distances to the different storage facilities

Origin / Destination	*Spain*	*Tunisia*	*Germany*
Oslo	*4812*	*5274*	*963*
Arendal	*4513*	*5076*	*680*
Stavanger	*4410*	*5052*	*789*
Ålesund	*4621*	*5441*	*1248*
Trondheim	*5252*	*5712*	*1698*
Harstad	*5941*	*6276*	*2385*
Hammerfest	*6536*	*6628*	*2982*

It can be assumed that around 35% of the salt comes from Germany in the form of salt stone, while the remaining 65% come from Spain (25%) and Tunisia (40%) and are from salt lakes. To be able to calculate the environmental impact of the transport, it is important to find the average distance a kilogram of salt travels. Here the distance travelled with a freighter is 3620 km on average for each ton of salt.

The large centralized storage facilities are natural pick-up points for operators. The operators often collect salt on 30-tonne trailers (with a hanger) and either take the salt straight to distribution or drive to de-centralized storage for later use. Additionally, some of the salt is transported on smaller boats to local operators' storage facilities. The transportation distance from the central storage to a de-centralized storage is not taken into account, since commonly distributed directly.

4.4 Distribution

To be able to estimate the distribution distance, the salt quantity, which lies between 15-40 gr/m^2 (Statens Vegvesen 2015), was assumed 20 gr/m^2. The distribution distance can then be roughly calculated from the reported salt quantities used in each region. The result from these calculations are shown in Table 3. The table shows the distribution distance in kilometres for each region for year 2010-2015.

Table 3: Calculated kilometres driven during distribution of salt in each region

Year / Region	2010	2011	2012	2013	2014	2015	Average
East	*426 668*	*501 768*	*433 676*	*477 357*	*470 163*	*488 178*	*466 302*
South	*391 471*	*335 939*	*320 923*	*380 691*	*434 672*	*425 230*	*381 488*
Vest	*340 356*	*501 045*	*394 496*	*387 557*	*205 079*	*421 931*	*375 077*
Mid	*150 203*	*207 287*	*165 165*	*140 706*	*116 555*	*179 360*	*159 879*
North	*56 125*	*54 197*	*59 319*	*70 142*	*59 091*	*95 620*	*65 749*
Total	***1 364 823***	***1 600 236***	***1 373 578***	***1 456 463***	***1 285 560***	***1 610 318***	***1 448 495***

The average distribution distance is then used to calculate the emissions per kilometre. When mechanical snow removal is conducted, which is not included in this paper, salt is most often also distributed at the same time. However, the distance calculated here is assumed to be attributed only to salting. This is done instead of reducing the distance by attributing some of it to mechanical snow removal and then adding extra distance to account for distance driven during observation.

5. Results

The results are presented for 11 impact categories. The impact categories and the origin of the emissions are shown in Table 4, where it is clear that distribution of salt in Norway is the major contributor to all impact categories, with more than 99% share of total emissions.

Table 4: Impact results per kilometre road in Norway during one average winter

Life cycle stage / Impact category	Production	Freight transport	Distribution	Total emissions
Abiotic depletion [kg Sb eq.]	*0%*	*0%*	*100%*	*2.42*
Abiotic depletion [MJ]	*0%*	*0.02%*	*99.98 %*	*1.4×10^{7}*
Global warming [kg CO2 eq.]	*0%*	*0.02%*	*99.98 %*	*8.8×10^{5}*
Ozone layer depletion (ODP) [kg CFC-11 eq.	*0%*	*0.01%*	*99.99 %*	*0.16*
Human toxicity [kg 1,4-DB eq]	*0%*	*0.01%*	*99.99 %*	*4.0×10^{5}*
Fresh water aquatic ecotox. [kg 1,4-DB eq]	*0%*	*0.01%*	*99.99 %*	*1.1×10^{5}*
Marine aquatic ecotoxicity [kg 1,4-DB eq]	*0%*	*0.02%*	*99.98 %*	*2.7×10^{8}*
Terrestrial ecotoxicity [kg 1,4-DB eq]	*0%*	*0.01%*	*99.98 %*	*1.4×10^{3}*
Photochemical oxidation [kg C2H4 eq.]	*0%*	*0.07%*	*99.93 %*	*1.5×10^{2}*
Acidification [kg SO2 eq.]	*0%*	*0.11%*	*99.89 %*	*3.0×10^{3}*
Eutrophication [kg PO4--- eq.]	*0%*	*0.05%*	*99.95 %*	*7.1×10^{2}*

The only impact category that is slightly different from the others is acidification where freight transport contributes more than to the other impact categories. However, the main source of emissions is, like in distribution, the direct emissions of burning fuel during transport.

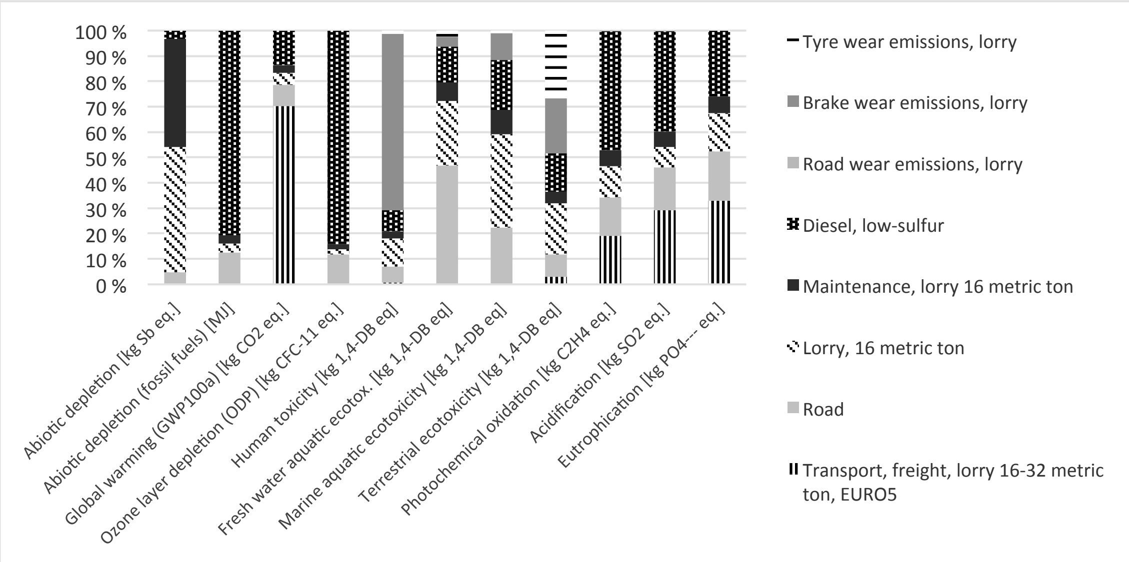

Figure 2: Emission source for the different impact categories.

Looking more closely at salt distribution shown in Figure 2, they are divided into 8 activities that contribute to the different impact categories. Towards global warming, the main contributor is the direct emission of burning fuel under transport while the production and maintenance of the truck are almost exclusively the source of abiotic depletion. The production of diesel is responsible for over 84% of the impact towards ozone layer depletion but also the largest contributor towards photochemical oxidation. Surprisingly, break wear emissions from the truck is responsible for approximately 70% of the emissions towards human toxicity.

For comparison, a Euro 5 personal vehicle would have to be driven over 2.7 million kilometres to reach the same emissions levels for global warming as is estimated emitted by salting operations in Norway.

6. Discussion

As expected, the results show that the highest impact from salting operations is from distribution in Norway. Because environmental effects of winter maintenance are highly linked to driving distances of the WSVs and material use it is important to reduce loss of salt as much as possible by optimizing speed of the vehicle and the spreader. Training and awareness of the winter maintenance staff can also contribute to less loss of salt and better winter road service. The quantities and the driving distance are however also very dependent on temperature and precipitation during the specific winter.

Furthermore, other efforts to reduce impact from winter maintenance are to focus on vehicle and fuel technology. Fuel efficiency combined with optimization of anti- and de-icing methods could potentially reduce emissions substantially. However, it should also be kept in mind that winter maintenance operators report that especially using anti-icing is beneficial as it makes mechanical snow removal easier and results sooner in clear and safe roads. Making mechanical snow removal easier can in itself be a method of reducing emissions during winter maintenance.

7. Conclusions

Life cycle analysis (LCA) was used to estimate the environmental impacts of the chemicals used during winter maintenance and their distribution. Results on the functional unit of *anti- and de-icing operations on national and state roads per km during winter an average winter from 2010 through 2014* show that environmental impacts from winter maintenances are significant. Therefore, we argue that winter maintenance should be included in LCA of roads in colder climates. The results are presented per kilometre so it can be used in other studies to roughly include the impact of anti- and de-icing.

Further investigations should be conducted on fate of salt after salting. In addition, mechanical snow removal and future options in winter maintenance will be investigated further within the current project. By doing so, enough information should be available for decision makers to avoid problem shifting.

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Between Domestic and Public: Women's use of space in low–income urban settlements, Surabaya, Indonesia

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Abstract

Urban development has brought many changes to our built environment. Despite the changes, various values remain attached to certain places, especially in the *kampung*, an indigenous urban settlement in Indonesia. The *kampung* is a self-help settlement, where houses are built incrementally by people and the community, predominantly of low and middle income groups. It has distinct features such as heterogeneity and preservation of traditional culture. Kinship is highly valued and maintained in these settlements, which is promoted by community gatherings. The limited space in each house does not necessarily limit the interaction between residents, as they use the immediate front, side or rear part of the house as a gathering space. Women in the *kampung* play a significant role in the use of these spaces, as they connect private and public space by inhabiting these areas for their activities. This paper will elaborate on the settings and features of spaces in and around the houses that support women's relationships in the community by applying observation and interview methods. These features have proved to be successful in creating a harmonious society in the low-income urban settlement.

Keywords: domesticity, public space, women, kinship, low-income urban settlement

1. Women in Human Settlements

Women are one of the leading actors in development. Their contributions through everyday life activities are extensively recognised by scholars, principally in the context of developing countries. Moreover, the empowerment of women and their full and equal participation in political, social, ecological and economic life are essential in relation to achieving a sustainable human settlement.

1.1 Global and National Perspectives

It is now almost forty years since the initial international commitment for housing development was completed in 1976 via the UN-Habitat conference. As a commitment, it is continued to be shared in relation to different focus; one of them being the needs and contributions of women. The commitment to sustainable development as stated in Agenda 21 (1992) recognised the requirement to strengthen the role of specific groups, such as women, children and youth, so as to generate sustainable and equitable development. The beginning of the 21st century also reaffirmed the goals of gender equity and the empowerment of women through Millennium Development Goals (MDGs). From the United Nation's report (2015), the endeavour of MDG have been able to increase the number of girls enrolling in primary to tertiary education by 30%, whilst also enhancing the number of women in parliament. However, gender inequality still persists, principally in connection with access to economic assets and participation in private and public decision making. Furthermore, women remain the greatest number of urban poor compared to their male counterparts.

In the recent years, with regards to Indonesia, MDG have accomplished their particular aims in relation to the education sector. Consequently, there has been equal participation of boys and girls in primary education (BAPPENAS, 2015). The number of women members in the House of Representatives and moreover women's contribution in the non-agricultural sector are gradually increasing. However, the development is not equally distributed, especially in the eastern part of Indonesia. More importantly, there needs to be an improvement related to the quality of women's lives apart from education, labour force and political participation. Thus, to achieve sustainable and equitable developments, housing and human settlements could be part of the way forward.

1.2 Kampung in Surabaya

It is worthwhile indicating that a kampung is not a slum (Funo, 2002), nor a marginal settlement (Silas, 1989). To a certain extent it is an urban village developed incrementally by the inhabitants and which has certain characteristics. These features are defined by Funo (2002) as variety, heterogeneity and autonomy, consisting of a highly serviced society, preservation of traditional culture and complexity of ownership relations and mutual aid system. By variety, it means that there are various characteristics of a kampung related to its establishment, such as the migratory background of the inhabitants, economic activities, spatial layout, and so on. For example, based on the geographical situation (distance from the city centre) a kampung can be divided into three types: urban, fringe and rural kampung.

Kampung have been an important part of the development of Indonesian cities, especially in Surabaya, the capital of East Java province and second largest city of Indonesia. Approximately 70% of the settlements in Surabaya are self-built by the community. There is a practice called '*gotong royong'* (working together), which is deeply ingrained in the lives of the kampung's inhabitants. This might be one of the reasons that community based programmes, such as the Kampung Improvement Programme (KIP) undertaken from the 1970s to the 1990s were well received and organized by themselves.

1.3 The Research

This study is part of a PhD research about women and housing in a low-income urban settlement. It was conducted in two kampung communities in Surabaya; Jambangan and Rungkut Lor. With regards to the geographical situation, Jambangan is a fringe kampung, while Rungkut Lor represents an urban kampung. The different location (urban or fringe) means that there are differences (to a certain extent) in terms of density and infrastructure. Based on economic activities, most of the inhabitants in Jambangan are traders and public or private employees, whereas in Rungkut Lor, residents are mostly industrial workers from Surabaya's neighbouring city. The different conditions of these two kampung might provide different backgrounds for women in using space especially at the neighbourhood and urban level.

This paper examines how women use the space in and around the house to perform their activities which relates to social relationships through gender perspectives. Observations and interviews are applied in conjunction with photographs and drawings. In dealing with the private and personal data, it is compulsory to obtain consent prior to the interview, so that every participant gave their permissions to publish the data. This includes using their real name in the document. The participant list in Table 1 describes only the women that are part of the discussions in this paper, but not all of the participants in the study. It is worth noting that there are two main activities which connect these women together as participants; environmental activity (recycling) in Jambangan and economic activity (making snacks) in Rungkut Lor.

Table 1. List of Participants

No.	Name	Age	Kampung	Notes
1.	Bu Mustaqim	44	Jambangan	a mother of two, sister of bu Bayu, active in recycling centre
2.	Bu Bayu	49	Jambangan	a mother of two, sister of bu Mustaqim, sells traditional drinks for additional income
3.	Bu Nur	47	Jambangan	a mother of two, neighbour of mbak Fitri, active in recycling centre
4.	Mbak Fitri	39	Jambangan	a mother of three, neighbour of mbak Fitri and cousin (by marriage) to bu Riana, active in recycling centre
5.	Bu Riana	49	Jambangan	a mother of three, cousin (by marriage) to mbak Fitri, runs a juice stall in the food court nearby
6.	Bu Pri	50	Rungkut Lor	a mother of three, a grandmother, neighbour of bu Latifah

7.	Bu Latifah	43	Rungkut Lor	a mother of two, neighbour of bu Pri, earning income from sewing clothes
8.	Mbak Titin	30	Rungkut Lor	a mother of one, selling traditional snacks.

2. Space and Social Relationships

We use space in many ways, as it serves many purposes. Lawson (2001) suggests that through space we can express individuality or support solidarity, gather people together or set them apart, while also conveying sets of rules within society. One of the many relationships that space can accommodate is the kinship network; while at the same time the kinship relation may shape how space is used. Space as it was traditionally defined by architecture is the space determined by architect or designers, whilst in gendered discourse, space is rather as it is found, used, occupied and transformed through everyday activities (Rendell et al., 1999:101). Public and private realms, kinship networks and social relations of exchange have been particularly important in examining the differing spaces men and women are allocated culturally, and the particular role space has in symbolising, maintaining and reinforcing gender relations (Ardener in Rendell, 2002:9).

2.1 Domesticity: Public and Private Realms

> *…women's experience in the city is not one of creating boundaries, drawing limits, or establishing categories; it is one movement in the margins, between and through categories, connecting rather than distinguishing and relishing contradictions rather than rejecting them (Andrew, 2000:158).*

Public and private are only one of the dichotomies related to the use of space, among others such as outside/inside, economy/family, work/home, duty/love (Jarvis et al., 2009:10). These separate spheres are usually associated with male and female respectively. However, as Andrew (2000) mentioned above, the use of space by women is not neatly patterned; instead it is more likely intersections between multiple identities. Women have different roles as wives, mothers, sisters, neighbours, and income earners. These roles are juxtaposed in the efforts of creating home comfort. Therefore, the role of women in defining home comfort is predominant. Rybczynsky (1987) suggests that privacy is one of the principal attributes in relation to home comfort in 17th century Europe. In this context, the idea of privacy is closely related to domesticity, as they both deal with the intimate part of a house. Subsequently, the notion of comfort then developed historically, and now has multiple layers of meaning, which include leisure, pleasure, efficiency and convenience. Modern discussions on domestic architecture are more broadly related to house and dwelling, the architecture of the everyday, as it challenges the notion of domesticity, which refers to the idea of the division between work and home, between male and female spheres, public and private space, regarding the difference between genders (Heynen and Baydar, 2005).

As domesticity changes meaning through time, it also varies culturally. In the case of traditional Madurese settlements in East Java, Indonesia, domestic activities such as cooking and bathing may take place outside the house, in a compound setting (Faqih, 2005). Although more often than not in modern settlements the kitchen and bathroom are located inside the house, the traditional custom of cooking outside the house is still conducted in the urban settlement, especially in the kampung, where women use the alley or front terrace to cook. In this sense, domesticity is not connected to privacy, but more in relation to the role of gender, where domestic spaces relate to women's use of space.

Bu Nur's house is one example of this. When the family renovated the property in 2010, she decided to have the kitchen at the front instead of at the back. Consequently, it occupies the space of front yard of the old house. The kitchen is connected to the front terrace by a stable door (Figure 1), which makes it practical when she bakes biscuits every year during the Islamic festive months, assisted by her neighbour. The large oven for the biscuits will be placed on the front terrace and any activity requiring kitchen utensils can be easily accessed straight from the front terrace. More than a practical reason, this example also gives an idea of how domesticity is played out in the house. The activity of cooking as one of the 'private' activities of the household has shifted into a more public domain, driven by economic motives.

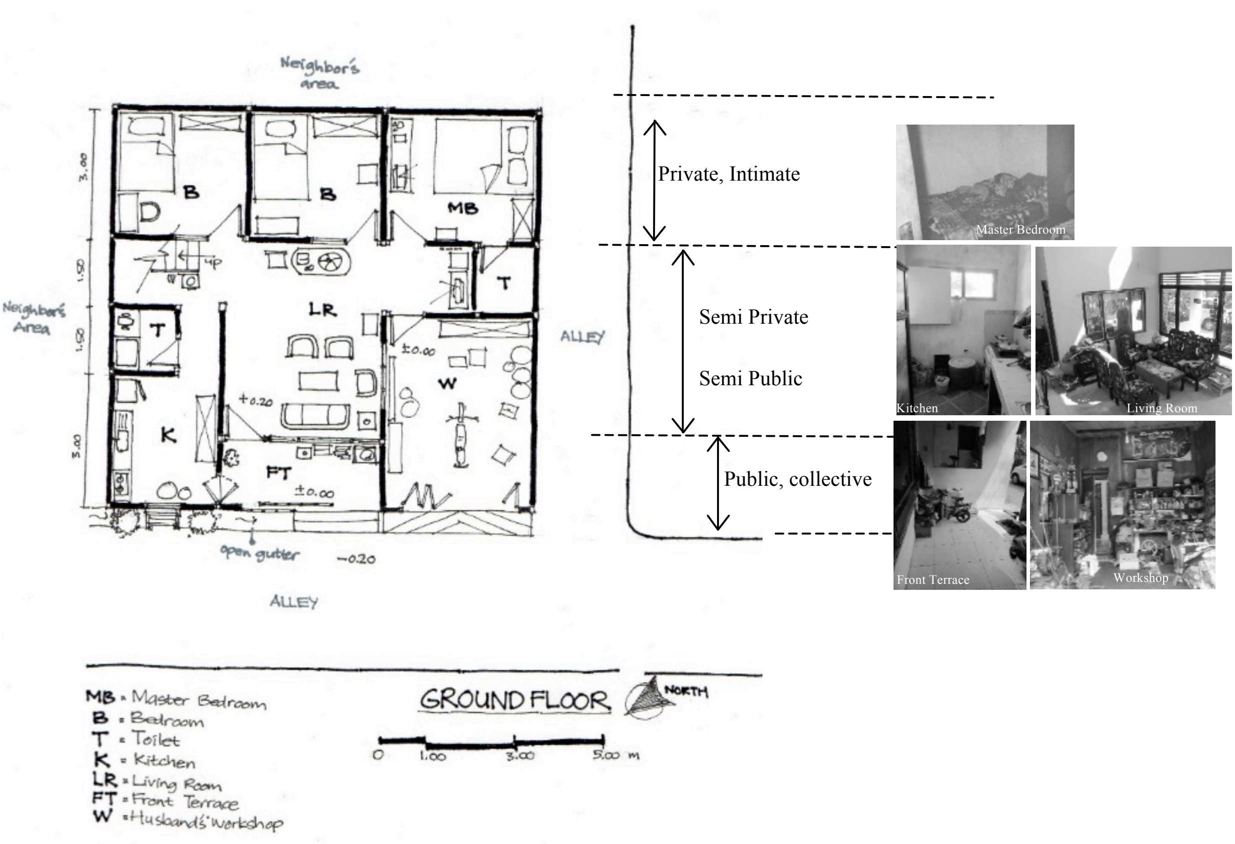

Figure 1. Bu Nur's house plan, the kitchen and terrace are connected by a stable door

2.2 Kinship: Biology and Culture

Discourse on kinship, principally from the anthropological point of view has tended to rest on the distinction between the biological and the social, the natural and the cultural (Carsten, 2004). Kinship as proposed by Sahlins (2013) is the **mutuality of being,** in which people are intrinsic to one another's existence. It is socially constructed, aside from consanguinity or affinity relationship. This is evident in many cultures, especially in Southeast Asia via a study by Rosaldo in 1980, where the Ilongot society in the Philippines share 'blood' through a history of migration and through research conducted by Carsten in Malaysia in 2004, which observed the sharing of food and co-residence in forming kinship (Sahlins, 2013: p.8).

In Javanese social structure, the nuclear family is the most important part of a kinship unit (Geertz, 1989:4). Therefore, we can observe the relationship between people through how they identify each other. Moreover, Geertz also suggests that social security within the family is significant for the functioning of Javanese society as a whole. By social security it means that in case something happens within the nuclear family (for example, parents become ill) a support system is provided by the surrounding community. This condition is still relevant today as almost all of the participants have family or relatives within the area.

A participant in Rungkut Lor, Mbak[1] Titin, lives in rented rooms near her parents, who also rent a house in the neighbourhood. She first moved to Rungkut Lor in 2005 due to the work she had at a factory in Rungkut Industrial park. Later on, her parents moved into the area to live closer to their children (their other daughter lives in Tenggilis, a neighbouring settlement located about two kilometres from Rungkut Lor). By having parents who live nearby, it is easy for Mbak Titin to go to training and other activities conducted away from home, since she can leave her 2 year old daughter under her parents' care. Bu[2] Pri, another participant in Rungkut Lor also has a son who is married and rents a room nearby. She will then gladly looks after her granddaughter during the day while her son and daughter in-law are working.

The research participants in Jambangan share different forms of kinship, from biological to cultural. For example, Bu Mustaqim and Bu Bayu are siblings. They live nearby on the same plot of land, although in different houses. Bu Riana and Mbak Fitri are related by marriage, as their husbands are cousins. In addition, more than being just a biological relationship, kinship is culture. Bu Nur and mbak Fitri's relationship evidently demonstrates the notion of kinship that is shaped by human engagement, rather than naturally given.

The different forms of social relatedness in some ways affect the way women use space (between participants). For example, in the first case, during one interview with bu Mustaqim, she told her first son to park the motorcycle in bu Bayu's place because the usual parking space

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[1] mbak is used as a form of politeness when calling an older – although there is not a huge age gap- woman, and literary means sister.
[2] 'bu' is the abbreviation of 'ibu', and literary means mother. It is often used before the forename in Indonesia to show respect to an older lady and is similar to the use of Mrs.

was being used for the interview. On another occasion, Bu Mustaqim kept some stuffs for bu Bayu in her house. Thus, this reveals that both of them use their separate house space in various ways as one unit, where they can interchangeably use each other's space without having to first ask for permission. This practice of shared space is not evident in the second case of bu Riana and mbak Fitri. The practice of sharing spaces is also evident in the third case of mbak Fitri and bu Nur, where they do not share a biological relationship, but share activities and experiences. The difference with the first case is that this shared space operates on a mutual basis, rather than equality, as can be noted in the first case. These three examples of relationships demonstrate the different practices incorporated in shared space, used by women.

Bu Nur and mbak Fitri have both lived in Jambangan since they married. As women who married a local man, they both have to live with the in-laws during the first years of their marriage[3]. This experience forms the basis of their relationship. Afterwards, both of them became involved in the same activities, such as the recycling centre, *posyandu* (children's healthcare) *arisan* (community gathering) and community savings. Simple everyday life activities, for instance baking biscuits and grocery shopping enabled their relationship to grow stronger and thus, they are like sisters. Furthermore, Mbak Fitri's son and daughter call bu Nur and pak[4] Slamet, *Budhe* and *Pakdhe*. This is how nieces and nephews call aunts and uncles in Javanese. Their close relationship can be perceived, as they mention it in the interview:

> *"…when we renovated the house, we did not move, we only used the existing two rooms, and when the new rooms were done, we used them while the builder worked on the other rooms. It lasted for two months, so we used the bathroom of bu Slamet (bu Nur) during that time. We still have some stuff there (in bu Nur's house) because now our space is so limited. Bu Slamet is always suggesting that my son should use their upstairs bedroom later when they finish renovating the house. But I still feel reluctant..."*
>
> *[Fitri, 39 years old, 10 June 2015]*

In the interview with me, mbak Fitri referred to bu Nur as bu Slamet (her husband's name) to show her courtesy and respect; while in daily interactions, she will call her 'mbak' Nur. It shows her close relationship with bu Nur, while at the same time maintaining the highest respect for her in front of me, the researcher. This courteous manner is also shown in her reluctance to let her son sleep in bu Nur's house. This reluctance however is not evident as she allows her first daughter to live with her brother-in-law's family in another city. In fact, this confirms evidence of how in Javanese culture, the concept of family is still closely related to blood relations.

As for bu Nur, mbak Fitri is a source of support in many ways. She assists her not only in community activities such as the recycling centre and children's healthcare, but also in her

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[3] It is common practice in the Javanese patriarchal system that the oldest or only son of the family will stay in the parents' house after marriage to look after them.
[4] Pak is the abbreviation of 'bapak' and literary means father. It is often used prior to the forename in Indonesia to show respect to an older man and is similar to the use of Mr.

economic activity (baking biscuits to sell), in particular when she became more dependent on her after the motorcycle accident that affected her ability to travel as easily as before:

> *"…the accident was about two years ago, and happened right in front of the house. I wanted to go to buy porridge for my husband's sister, as she was sick, when all of a sudden I fell and could not get up. I then realised I couldn't see my knee, and I screamed. The neighbours started coming, and among the first to come is Mbak Fitri's husband […] since the accident, I go with mbak Fitri to the market…"*
>
> *[Nur Isaroh, 47 years old, 10 June 2015]*

Bu Nur lives in a two-storey house with 4 bedrooms (the second floor was under construction, one room is used to store mbak Fitri's belonging), while mbak Fitri occupied one room in the family-owned rented rooms (Figure 2). In addition, their houses are only about 20m apart**.** Mbak Fitri's son is voluntarily helping pak Slamet (bu Nur's husband) in the construction of the house, helping to carry the bricks, cement, and other materials. In this case, the use of space in another person's house is exchanged with other forms of activity, when house space is limited or not available to other party.

Figure 2. Bu Nur's house (left) and Mbak Fitri's house (right)

2.3 Settings and Features of Kampung that Supports Kinship Values

In general, two types of space are occupied by women in the *kampung* which supports their social relationship. First is the space that was built or occupied on purpose, whereas the second is the immediate space in or around the house. The first space is primarily used by the women at certain times and for specific activity, while the second differs through time and activities.

2.3.1 Time and Activity-based Settings

The first type of space is promoted by the same primary activity, such as recycling in Jambangan and making snacks in Rungkut Lor. To accommodate this activity, each woman's group makes the effort, in order to have a specific place. Beyond the main activity, the relationships between these women also involve the social, cultural and economic aspects of their everyday life. For example, while doing the recycling and making snacks, they share information on raising children, community savings, undertaking the daily shopping with the cart seller that passes by or just by sharing stories. In another way, this relationship develops kinship as they have become mutually related. Thus, kinship configures how the space is used.

In Jambangan, this type of spatial configuration was evident in the recycling centre. This particular activity was first initiated in 2012, when the kampung participated in an environmental programme; 'Green and Clean' initiated by the city council. It started as a simple greening activity, and then developed into a recycling centre. With the recycling activity, more space was needed to store the recycled objects before they were collected by partner recycling agents. This facility was established as the woman's group asked the district office to provide them with more space for their activity and is constructed from very simple materials. On one occasion during the election campaign, the woman's group secured a donation to upgrade the building, as is shown in Figure 3. In Rungkut Lor, this type of space was a rented room, paid for by the cooperation of women who conduct the business. Here in the rental space, they receive purchase orders, receives guests and buyers, bake some of the biscuits, and also hold meetings. Both the spaces are relatively small, approximately 30 m2; nevertheless they are adequate enough to accommodate the women's activities.

Figure 3. The recycling centre in Jambangan (left) and Kampung Kue Secretariat inRungkut Lor (right)

2.3.2 Immediate Space around the House (Time-based)

The second type of space appropriation is the immediate space in or around the house. It is the space that is available in the first place, although it can be used in different ways, based on certain times and activities. For example, the terrace of a public reading room in Rungkut Lor was utilised at dawn to sell snacks and cakes not only for the neighbourhood buyers but also by other traders within the surrounding traditional market, as revealed in Figure 4. Aside with public facility, a number of people used the immediate space adjacent to or in front of their own houses (Figure 5).

Figure 4. The use of public reading room in the kampung at dawn (left) and noon (right)

Figure 5. The use of immediate space in front of the house for economic activity at dawn (left)

Another feature in the kampung that also has a significant role in creating and maintaining the social relationship between women in this setting are the benches (Figure 6). These come in different shapes and materials - from simple wood planks to more permanent concrete blocks and are usually located in front of the house. In general, they tend to be used from the afternoon until dusk (between 4 to 6 pm). This is the time where most of the women in the kampung have spare time (they watch children play, water the plants, exchange tips on cooking or tell each other interesting stories). It is also the most convenient time in relation to tropical weather to be outdoors.

Bu Latifah who spends most of the time inside the house because she sews clothes to make ends meet, recalls the ritual afternoon meeting on the benches as one way for her to strengthen her relationship with her neighbour during the first months of her stay in 2010. Nowadays, it is also a way for her to release stress after spending hours inside the house.

Figure 6. Different types of bench in Jambangan and Rungkut Lor

2.3.3 Immediate Space of the House (Activity-based)

The most common space in the house used by women to perform community activities is the front terrace. The activities comprise: *arisan* (monthly gathering), *pengajian* (weekly Qur'an recital) and *posyandu* (fortnightly children's healthcare). These spaces were used by prior arrangement, depending on the activities schedule. One example is the children's healthcare activity (Figure 7). In Jambangan, it was organised on every first and third Wednesday of the month. At the time the activity took place, children aged less than 5 years old were weighed, their height measured and on occasions they were given vaccines by a health practitioner.

Figure 7. Children's healthcare activity occupying the front terrace of the house

3. Moving Beyond Binaries

The examples above reaffirmed that women's use of space, principally in kampung, is not that of using separate spheres, but instead moves beyond the binaries of public/private, work/home, outside/inside, and even duty/love. We can see from the aforementioned examples that domestic space in this context is gender related and is less associated with the private sphere; thus it can occupy a public sphere. This might informs a different notions of domesticity as in most European and North American literatures which mostly relate with home and privacy (Rybczynski,1987; Kent,1990; Lane, 2007).

A further interesting finding is how a certain space is used primarily by women, despite its location in public areas. It appears to indicate the strong agency of women in claiming their own space. Women use space not only depandant on activities, but also on social relationships. Therefore, kinship relations plays an essential role in how these spaces are used, while at the same time these spaces with their different activities can nourish and strengthen the social relationships between women. In the context of low-income urban household, where the limited space of the house may encourage more shared use of public space, this interrelationship is therefore determinants in creating a harmonious urban settlements.

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INTERNATIONAL COMPARISONS OF CONSTRUCTION LABOUR PRODUCTIVITY

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Abstract

Comparing productivity of industry between countries is a crucial information base for research in comparative analysis and policy making. This comparison enables identification of shortcomings in one place and then look for ways to deal with them. The construction industry is characterised by heterogeneity and uniqueness of its product, complexity of its delivery process and industry structure and the country specificity of construction products. Aggregate quantity measures of construction are normally done with monetary value of construction output. The monetary value of construction output are normally converted with the market exchange rates into the same currency for comparisons of construction production across countries. The comparison is always distorted by the volatility of market exchange rate. An alternative is using Purchasing Power Parity (PPP). PPP is a neutral way of stating the ability of one nation's currency to purchase goods in different nation costs recorded in various national currencies in a single currency. Newly published Purchasing Power Parity data from the World Bank's International Comparison Program 2011 and employment statistics maintained by the International Labour Organization (ILO) are used to generate comparable data of the construction labour productivity (CLP) of 93 economies and the Construction Labour Productivity Indexes (CLPIs). The CLPI is the standardised index of the construction labour productivity of an economy relative to the world average. CLP tends to be higher in the high economies than the low income economies. CLP measures of the two methods are tending towards convergence as the economies grow from developing to developed status. CLP shows a relatively stronger correlation with nation's economic growth based on exchange rates. Construction industry is changing from being a long-established non-international traded industry to a more complex international traded industry.

Keywords: Productivity, Construction industry, International comparisons, Purchasing power parity

1. Introduction

GDP per capita, a common measure to provide an assessment of the performance of the market economy and to monitor cyclical fluctuations, is simply labour productivity multiplied by the proportion of the population that works. In the absence or difficulty to construct a perfect alternative metric, GDP is still being commonly used to understand what makes countries rich and the underlying causes of productivity change. A country's productivity is the average of its industries productivity weighted by its size. Therefore to understand what makes countries rich is best achieved by evaluating the performance of individual industries. Such a micro approach reveals the importance of industrial productivity (Lewis, 2006).

Construction is an important industry because its output is large and it represents a significant part of the economy. It produces investment goods which are vital for the wellbeing of any economy. In most countries, construction provides about half their gross domestic fixed capital formation (Hillebrandt, 2000). The world construction industry stands at 5.5% of world Gross Domestic Product (GDP) in 2013 (United Nation Statistics Division, 2014).

On the other hand, low productivity in the construction industry has been a constant concern. To raise economic performance, it needs to focus on the causes of productivity differences among companies, industries, sectors, and countries. The international comparisons form a crucial information base for research in comparative analysis and policy making. It is difficult to compare construction products between economies because the construction industry of each economy is basically unique. The complexity and the country specificity of its products results with no two economies build exactly the same kind of house or power station (The World Bank, 2015). The most commonly used method for such international comparisons is to express the GDP of the countries concerned in the same currency unit so that the differences in the economies are readily identifiable. There are long recognized shortcomings in GDP as a measure of economic performance such as home production, technological obsolescence and environmental degradation or depletion of natural resources are excluded in the measurement of GDP (Stiglitz, et.al. 2009). This comparison is exaggerated when the economy's foreign-exchange rates is used to convert its national currency. An alternative approach to overcome volatility of market exchange rate in the comparison is to replace exchange rate with purchasing power parity (PPP) as conversion factor (Todaro & Smith, 2015). PPP is the ability of one nation's currency to purchase goods in a different nation. It compares how different currencies function in the same country, rather than trying to compare different currencies in different countries (Taillard, 2013).

The following section highlights in more detail the problems of making international comparisons, introducing the concept of PPP and International Comparison Programs by the World Bank and summarising the PPP approach to construction expenditure by the World Bank's International Program. It explains the different productivity measures and justifies the single factor gross output measure used. The next section provides details of the sources of data for the construction expenditure and construction employment statistics of the different economies. Sections 4 compares the results the construction labour productivity and

Construction Labour Productivity Indexes (CLPIs) of 93 economies computed in this study. Section 5 discusses the productivity differences between the economies based on PPPs and exchange rates. Section 6 concludes the findings of the study.

2. International Comparisons

International comparisons of levels and more importantly of rates of growth play a very important role in the policy design. It enables structural reforms to import the "best practice" of the country performing the best in terms of productivity, if the productivity of the two countries are computed in the similar way. Reported National Accounts are good sources of data to be drawn for international comparisons. Comparisons are indeed possible if the procedures and definitions used to compute the accounts are comparable, but there are still large differences in the ways National Accounts calculations are carried out (Stiglitz, et.al. 2009).

The main issue in the international comparison is the inconsistency of definitions used in national measures of construction activity. In addition, the output of construction is so heterogeneous, aggregate quantity measures of construction is not feasible, and using monetary values is the only option (Meikle & Gruneberg, 2015). Often costs are converted to USD (or any other currency) in order to compare costs between countries. The supply and demand for currencies are influenced primarily by factors such as currency speculation, interest rates, government intervention, and capital flows between economies. A high exchange rate will make local costs look high against the comparison country. A low exchange rate will do the opposite (Turner and Townsend, 2015). Comparing national economies via measures such as gross domestic product (GDP) using exchange rates can be very much distorted by price-level differences between countries (Best & Meikle, 2015). The differences between the levels of GDP in two or more economies reflect both differences in the volumes of goods and services produced by the economies and differences in the price levels of the economies. They do not reflect the relative purchasing power of currencies in their national markets (The World Bank, 2015).

Many goods and services such as buildings, government services, and most household market services are not traded internationally (The World Bank, 2015). The volatility of exchange rates can distort a country's construction costs compare with others in international comparisons of construction activity (Meikle & Gruneberg, 2015).

2.1 Purchasing Power Parity

PPP removes the impact of volatility of exchange rates (Turner and Townsend, 2015). The International Comparison Program (ICP) conducted under the charter of the United Nations Statistical Commission (UNSC) provides globally comparable economic aggregates in national accounts (The World Bank, 2015). It is the principal source of data on the PPPs of currencies, real domestic product and real per capita income. The latest round of the ICP 2011 participated by 199 economies provides the full set of results for 177 economies, accounts for about 97 percent of the world's population and 99 percent of the world nominal GDP (The World Bank, 2015). The participating economies report their expenditures that are valued at national price levels in national currencies i.e. nominal expenditures. These nominal expenditures are converted to real expenditures (i.e. expenditures that are valued at a common price level) by PPPs (The World Bank, 2015). Real expenditures reflect real or actual differences in the volumes purchased in economies and provide the measures required for international volume comparisons (The World Bank, 2015).

ICP comparisons are designed to compare the volumes of goods and services that enter GDP at specific points in time. They are not designed to measure the relative rates of growth in GDP between these points. Each ICP comparison produces indexes of real GDP that show the relative volume levels of GDP among participating economies for the reference year. When the indexes for consecutive reference years are placed side by side, they appear to provide points in a time series of relative GDP volume levels over the intervening years (The World Bank, 2015).

PPPs are calculated in stages: first for individual goods and services, then for groups of products, and finally for each of the various levels of aggregation up to GDP (The World Bank, 2015).

2.2 Purchasing Power Parity of Construction Expenditure

Construction expenditure is one of the 25 sub aggregates expenditure reported in ICP 2011. It includes capital expenditure on the construction of new structures and renovation of existing structures. Gross fixed capital formation in construction is broken down into three basic headings: residential buildings, non-residential buildings, and civil engineering works (The World Bank, 2015).

The economies of Eurostat-OECD used the bill of quantities approach in comparison. All the economies are required to price the Bill of Quantities of a common set of standard fictitious buildings and civil engineering projects on the basis of the actual structures and materials and methods commonly used in their construction. Each economy was expected to price 7 out of 11 standard construction projects specified using prices of successful tenders submitted during the reference year. The price includes the contractor's mark-ups for general site costs, head office overheads, profit and cost of employing professional architects and engineers. The PPPs for construction are calculated using the overall prices of the projects (The World Bank, 2015).

The Commonwealth of Independent States (CIS) economies used a modified version of the bill of quantities. These economies were required to provide unit prices for 66 inputs covering materials and labour for the regional coordinating agency in order to price simpler and less complete bills of quantities of an extensive range of model structures. The PPPs for construction were calculated using the overall prices for the model structures (The World Bank, 2015).

Other participating economies were required to collect unit prices for 38 kinds of basic building materials, the hourly cost of hiring five types of building equipment with and without an operator. The economies were also asked to include the hourly rate at which compensation was paid to construction workers across 7 occupations and for a common set of 55 inputs. They had to indicate the types of structures for which each of the inputs was commonly used and the average resource mix for each of the three basic heading. PPPs for the basic heading were obtained by aggregating the PPPs of its subheadings with subheading expenditure weights (The World Bank, 2015).

2.3 Labour Productivity

The productivity measures can be classified as single factor productivity or multifactor productivity. The single factor productivity relates a measure of output to a single measure of input, whereas the multifactor productivity relates a measure of output to a bundle of inputs (Organisation for Economic Co-operation and Development, 2001).

These measures capture the movements of output with gross output or value-added. When measured as gross output per unit of labour input, labour productivity rises as a consequence of outsourcing and falls when in-house production replaces purchases of intermediate inputs. This does not reflect a change in the individual characteristics of the workforce and a shift in technology or efficiency. The efficiency gain as a consequence of input substitution will not be captured (Organisation for Economic Co-operation and Development, 2001).

Value-added based labour productivity measures tend to be less sensitive to processes of substitution between materials plus services and labour than gross-output based measures. When outsourcing takes place, labour is replaced by intermediate inputs. This will reduce value added and hence lead to a fall in the labour productivity. At the same time, outsourcing means less labour input needed, this will lead to a rise in the labour productivity. Because labour productivity measures reflect the combined effects of changes in capital inputs, intermediate inputs and overall productivity, they do not leave out any direct effects of embodied or disembodied technical change. The embodied technical change enhances production possibilities for a given set of inputs, while the disembodied technical change operates via capital goods and intermediate inputs (Organisation for Economic Co-operation and Development, 2001).

The choice of productivity measures depends on the purpose of productivity measurement and the availability of data. Labour productivity relates to the single most important factor of production, is intuitively appealing and relatively easy to measure. It partially reflects the productivity of labour in terms of the personal capacities of workers or the intensity of their efforts and how efficiently labour is combined with other factors of production. It also reflects how many of these other inputs are available per worker and how rapidly embodied and disembodied technical change proceed (Organisation for Economic Co-operation and Development, 2001).

3. Research Methods

This paper used single factor productivity measure, based on gross output. It is simply the ratio of the quantity of gross construction output to quantity of labour input. The construction expenditure found in the ICP 2011 is used as the proxy for gross construction output. The expenditure includes capital expenditure on the construction of new and renovation of existing residential buildings, non-residential buildings, and civil engineering works. The quantities of labour input is obtained from the International Labour Organisation's central statistics database (ILOSTAT). ILOSTST provides recent labour data for over 100 indicators and 165 economies. Employment by construction that are used as proxies of quantity of labour input are extracted from the section of *Employment by Economic Activity and Occupation* of the databases (International Labour Organization, 2015).

There are 93 matching pairs of economies found in the employment statistics of ILOSTAT and construction expenditure in ICP 2011. They account to 82.5% of real construction expenditure and 89.9% of nominal construction expenditure. The computed construction labour productivities and Construction Labour Productivity Indexes (CLPIs) based on PPPs and exchange rates of these 93 economies are available in Appendix I. The construction labour productivity of different economies needs to be expressed in the same currency unit so that the differences in productive levels of different economies are readily identifiable.

The CLPIs are standardised indices expressed by the construction labour productivity of an economy relative to the world average productivity level, which is set at 100. Economies with CLPIs greater than 100 shows their construction labour productivity levels are higher than that of the world average. Economies with CLPIs less than 100 indicates their construction labour productivity levels are lower than that of the world average.

For analytical purposes the World Bank classification of economies is used in the discussion. The World Bank classifies economies as low income, middle income, or high income. As of 1 July 2011, low-income economies are those that had average 2010 incomes of nor more than \$1005; lower-middle-income economies had average incomes of \$1006 to \$3975; upper-middle-income economies had average incomes of \$3976 to \$12 275; and high-income had average incomes of \$12 276 or more. Low- and middle-income economies are commonly referred to as developing economies (World Bank, 2011). There are 49 high economies, 26 upper middle income economies, 16 lower income economies and two low income economies.

4. Results

It is apparent from Table 1 that CLPs of 80 economies are higher based on PPPs measurement method, leaving CLPs of 13 economies are higher when based on exchange rates. The former are low, lower middle, upper middle and partially high income economies and the latter are all high income economies. It suggests that developing economies tend to understate the construction labour productivity if based on the exchange rates measurement.

Table 2 shows the top 10 construction productivity and CLPIs of high income economies. CLPs of all the selected economies are higher based on PPPs with exceptions to Finland, France and Sweden. CLPI of Belgium is slightly below world average based on exchange rates, but appears as two times of world average when measured by PPP.

***Table 1**: Comparison of number of economies with higher CLP based on different measurement methods*

World Bank classification	*Number of economies*	*Number of economies with higher CLP based on PPPs*	*Number of economies with higher CLP based on exchange rates*
High income	*49*	*36*	*13*
Upper middle income	*26*	*26*	*0*
Lower middle income	*16*	*12*	*0*
Low income	*2*	*2*	*0*
Total	*93*	*80*	*13*

***Table 2**: Top 10 CLPIs of high income economies*

Economies	*Nominal consumption (based on exchange rates)*		*Real consumption (based on PPPs)*	
	Construction expenditure/ construction employment	*CLPI (world = 100)*	*Construction expenditure/ construction employment*	*CLPI (world = 100)*
Norway	*164 883*	*140.20*	*239 836*	*335.36*
Australia	*127 261*	*108.21*	*227 640*	*318.30*
Switzerland	*152 675*	*129.82*	*224 479*	*313.88*
Canada	*192 678*	*163.83*	*213 732*	*298.86*
Finland	*199 997*	*170.05*	*194 469*	*271.92*
Netherlands	*169 527*	*144.15*	*191 795*	*268.18*
Denmark	*179 506*	*152.63*	*184 002*	*257.29*
France	*206 154*	*175.29*	*183 479*	*256.56*
Belgium	*110 622*	*94.06*	*168 909*	*236.18*
Sweden	*183 807*	*156.29*	*157 615*	*220.39*

Table 3 shows the top 10 construction productivity and CLPIs of upper middle income economies. CLPs all the selected economies are higher based on PPPs. CLPIs of Romania and Albania achieved approximately two-third of world average when measured by exchange rates. But they performed marginal higher than world average when based on PPPs. Kazakhstan's CLPI is lower when based on PPP.

Table 4 shows the top 10 construction productivity and CLPIs of lower middle income economies. CLPs all the selected economies are higher based on PPPs. CLPIs of Indonesia is about half of world average when measured by exchange rates, it appears 35% higher than world average if it is based on PPPs. The CLPIs of Armenia, Georgia, Moldova and Ukraine are lower when based on PPP. Bhutan's CLP appears to be the highest among the 93 economies but it has a relatively smaller size of construction industry. Its construction expenditure in 2011 was USD 720 million and employed 4500 construction workers.

***Table 3**: Top 10 CLPIs of upper middle income economies*

Economies	*Nominal consumption (based on exchange rates)*		*Real consumption (based on PPPs)*	
	Construction expenditure/ construction employment	*CLPI (world = 100)*	*Construction expenditure/ Construction employment*	*CLPI (world = 100)*
China	*122 119*	*170.76*	*361 219*	*307.14*
Seychelles	*93 528*	*130.78*	*213 840*	*181.83*
Romania	*47 420*	*66.31*	*134 817*	*114.63*
Montenegro	*47 336*	*66.19*	*103 673*	*88.15*
Mexico	*46 035*	*64.37*	*88 701*	*75.42*
Albania	*44 298*	*61.94*	*128 236*	*109.04*
Colombia	*42 678*	*59.68*	*89 253*	*75.89*
Turkey	*41 891*	*58.58*	*102 283*	*86.97*
Kazakhstan	*41 736*	*58.36*	*56 466*	*48.01*
Costa Rica	*35 380*	*49.47*	*76 702*	*65.22*

***Table 4**: Top 10 CLPIs of lower middle income economies*

Economies	*Nominal consumption (based on exchange rates)*		*Real consumption (based on PPPs)*	
	Construction expenditure/ construction employment	*CLPI (world = 100)*	*Construction expenditure/ Construction employment*	*CLPI (world = 100)*
Bhutan	*159 595*	*223.16*	*680 664*	*578.77*
Indonesia	*34 681*	*48.49*	*158 391*	*134.68*
Mongolia	*33 156*	*46.36*	*112 181*	*95.39*
Armenia	*31 598*	*44.18*	*37 377*	*31.78*
Georgia	*24 015*	*33.58*	*29 674*	*25.23*
Sri Lanka	*19 897*	*27.82*	*83 397*	*70.91*
Senegal	*15 806*	*22.10*	*45 437*	*38.64*

Morocco	*14 853*	*20.77*	*75 983*	*64.61*
Moldova	*14 770*	*20.65*	*18 098*	*15.39*
Ukraine	*13 742*	*19.21*	*20 002*	*17.01*

Table 5 shows the construction productivity and CLPIs of the two low income economies, Ethiopia and Zimbabwe. Both CLP and CLPI of the two economies are higher when based on PPPs.

***Table 5**: CLPIs of low income economies*

Economies	*Nominal consumption (based on exchange rates)*		*Real consumption (based on PPPs)*	
	Construction expenditure/ construction employment	*CLPI (world = 100)*	*Construction expenditure/ Construction employment*	*CLPI (world = 100)*
Ethiopia	*9,225*	*12.90*	*55 759*	*47.41*
Zimbabwe	*6,398*	*8.95*	*17 111*	*14.55*

Table 6 shows in low income economies, CLP is 4.7 times of exchange rate when based on PPP. Ratios of CLP based on PPPs to CLP based on exchange rates are gradually narrowed to 3.5, 2.6 and 1.3 times in lower middle income, upper middle income and high income economies respectively.

***Table 6**: Average expenditure per capita and construction labour productivity based on PPP and exchange rates group according to economic development status*

World Bank classification	*Average expenditure per capita based on*			*Construction labour productivity based on*		
	PPPs	*Exchange rates*	*PPPs/ exchange rates*	*PPPs*	*Exchange rates*	*PPPs/ exchange rates*
High income economies	*39 692*	*38 750*	*1.02*	*140 865*	*107 176*	*1.31*
Upper middle income	*14 367*	*7 497*	*1.92*	*97 196*	*37 471*	*2.59*
Lower middle income	*6 727*	*2 809*	*2.39*	*89 689*	*25 597*	*3.50*
Low income	*1 296*	*524*	*2.47*	*36 435*	*7 811*	*4.66*

It is apparent from Figures 1 and 2 that, there is a strong correlation between construction labour productivity and expenditure per capita when they are based on exchange rates. Figure 1 shows that the coefficient of determination (R^2) of construction labour productivity and the expenditure per capita is 0.10 when they are based on PPP. However, the coefficient of determination (R^2) increased to 0.60 when based on exchange rate (Figure 2). This is equivalent to correlation coefficient (R) of 0.77.

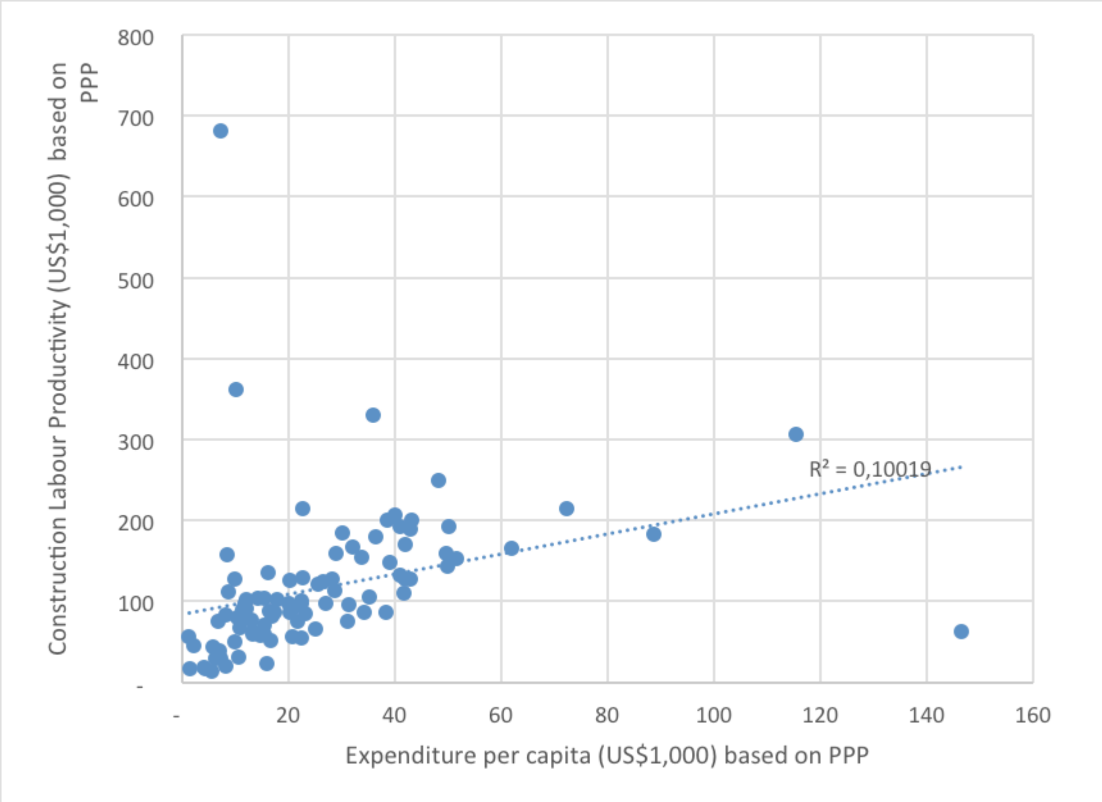

***Figure 1**: Construction labour productivity and expenditure per capita based on PPP*

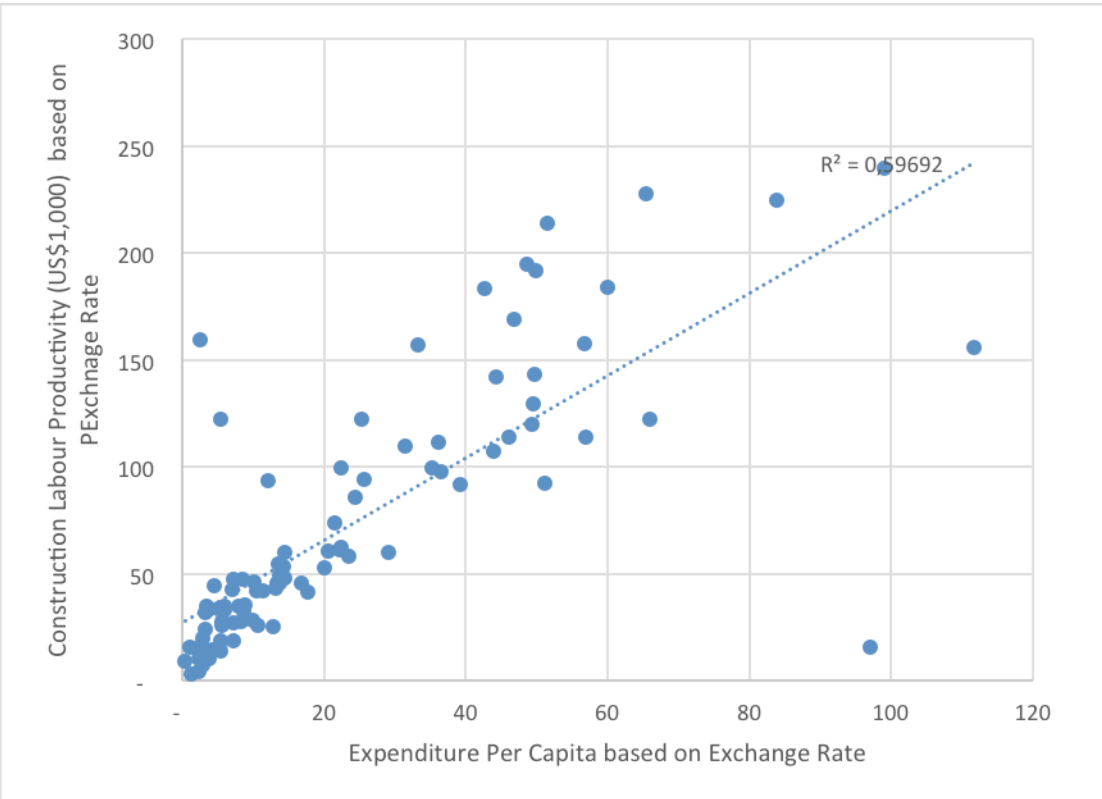

***Figure 2**: Construction labour productivity and expenditure per capita based on exchange rate*

5. Discussion

The above analysis shows exchange rates measurement of construction productivity tends to understate the CLPs. It is mainly because construction is an industry relying mostly on the local supplying of resources, such as materials and labour and it also depends on local demand for its output.

CLP tends to be higher in the high income economies than the low income economies. One possible reason for this is that construction industry in the higher income economies have a better opportunities for capital investment and replacing on-site manual works with mechanisation and off-site production.

In higher-income economies, the differences between CLP measures in PPPs and exchange rates are less compared to the low-income economies. The two methods of measurement are tending towards convergence as the economies grows from developing to developed status (Table 6). CLPs and economic development shows stronger correlation when based on exchange rates (Figure 2). This suggests that CLP will eventually be strongly influenced by the exchange rates. Construction industry is changing from being a long-established non-international traded industry to a more complex international traded industry. With the globalization of the world economy, today's construction business is fast becoming an internationally interdependent marketplace. According to the ENR (2014), the Top 250 International Contractors had USD 543.97 billion in contracting revenue in 2013 from projects outside their home countries, up 6.4% from USD 511.05 billion in 2012. Data published by ENR shows that ENR's top 225 international contractors in 2011 earned USD 453 billion in revenue from construction projects outside their home countries, which represents more than a two-fold increase over the USD 189.4 billion recorded in the last ICP 2005. In addition, with the rise of modern industrialized countries, increasingly complex civil engineering projects are being procured, and the increased scale of these projects has provided a launching pad for international construction. Advanced technology, fast transportation, convenient communications, effective knowledge transfer, integrated markets and trade liberalization have all helped to lower traditional barriers and transform construction into a fiercely competitive international marketplace where construction companies ebb and flow (Lu, et al., 2015).

6. Conclusions

Statistical analysis is subjected to alternative interpretations because they serve a multiplicity objectives. Policies and best practices may be drawn from inferences of statistical analysis. This paper attempt to compare the productivity of the construction industries of different economies in order to identify the high and low performance economies to uncover their underlying determinants of productivity performance in the further studies. Further researches need to be aimed at taking stock of what already been done, and assessing the strengths and weaknesses of these practices in order to shape the industry's future policy.

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Appendix 1 – Construction labour productivity on PPP and exchange rates in 2011

	World bank classification	Expenditure in construction		Construction employment (Thousands person)	Construction productivity (PPP)		Construction productivity (Exchange rate)	
		PPP (U.S. dollars, billions)	Exchange rates (U.S. dollars, billions)		USD / employment	Index (world = 100)	USD / employment	Index (world = 100)
Norway	H	61,879	99,035	189.9	164,883	140.20	239,836	335.36
Australia	H	42,000	65,464	1013.9	127,261	108.21	227,640	318.30
Switzerland	H	51,582	83,854	274.0	152,675	129.82	224,479	313.88
Canada	H	41,069	51,572	1294.6	192,678	163.83	213,732	298.86
Finland	H	38,611	48,686	176.2	199,983	170.05	194,469	271.92
Netherlands	H	43,150	49,888	438.1	199,997	170.06	191,795	268.18
Denmark	H	41,843	60,030	159.5	169,527	144.15	184,002	257.29
France	H	36,391	42,728	1885.4	179,506	152.63	183,479	256.56
Belgium	H	40,093	46,759	337.5	206,154	175.29	168,909	236.18
Bhutan	LM	7,199	2,600	4.5	680,664	578.77	159,595	223.16
Sweden	H	41,761	56,704	309.5	110,622	94.06	157,615	220.39
Israel	H	30,168	33,259	162.5	183,807	156.29	157,050	219.60
Luxembourg	H	88,670	111,689	39.2	182,156	154.89	155,719	217.74
United States	H	49,782	49,782	9039.0	143,268	121.82	143,268	200.33
Germany	H	40,990	44,365	2576.8	132,940	113.04	142,067	198.65
Austria	H	42,978	49,590	354.2	127,117	108.09	129,373	180.90
Macao SAR	H	115,441	66,063	28.3	305,957	260.15	122,469	171.25
Aruba	H	36,017	25,355	4.2	329,689	280.33	122,314	171.03
China	UM	10,057	5,456	17248.0	361,219	307.14	122,119	170.76
Ireland	H	42,942	49,383	107.8	189,143	160.83	119,622	167.26
Japan	H	34,262	46,131	5020.0	86,161	73.26	113,936	159.31
Cayman Islands	H	49,686	56,883	3.2	159,829	135.90	113,749	159.05
Italy	H	33,870	36,180	1791.2	154,327	131.22	111,454	155.84
Spain	H	32,156	31,534	1403.9	167,482	142.41	109,929	153.71
Iceland	H	38,226	43,969	10.0	86,830	73.83	107,394	150.17
Korea, Rep.	H	29,035	22,388	1750.7	158,699	134.94	99,343	138.91
Hong Kong SAR	H	50,129	35,173	277.0	192,501	163.68	99,243	138.77
New Zealand	H	31,172	36,591	172.0	74,616	63.45	97,956	136.97
Greece	H	26,622	25,654	245.8	123,895	105.35	94,053	131.51

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	World bank classification	Expenditure in construction		Construction employment (Thousands person)	Construction productivity (PPP)		Construction productivity (Exchange rate)	
		PPP (U.S. dollars, billions)	Exchange rates (U.S. dollars, billions)		USD / employment	Index (world = 100)	USD / employment	Index (world = 100)
Seychelles	UM	22,569	12,196	2.1	213,840	181.83	93,528	130.78
Singapore	H	72,296	51,242	402.7	214,864	182.70	92,255	129.00
United Kingdom	H	35,091	39,241	2202.1	105,104	89.37	91,871	128.46
Slovenia	H	28,156	24,480	54.2	127,832	108.69	85,667	119.79
Bahamas	H	22,639	21,490	14.3	129,530	110.14	73,778	103.16
Portugal	H	25,672	22,396	423.1	121,938	103.68	62,106	86.84
Malta	H	28,608	22,201	11.6	113,118	96.18	60,882	85.13
Czech Republic	H	27,045	20,592	431.0	96,723	82.24	60,597	84.73
Croatia	H	20,308	14,429	117.9	126,460	107.53	60,071	84.00
Cyprus	H	31,229	29,208	45.9	95,358	81.08	59,846	83.68
Saudi Arabia	H	48,163	23,594	1293.7	248,933	211.67	58,159	81.32
Latvia	H	19,994	13,658	60.9	97,609	83.00	54,657	76.43
Lithuania	H	22,521	14,212	85.1	100,747	85.67	53,577	74.92
Taiwan	H	39,059	20,030	830.6	147,983	125.83	53,002	74.11
Hungary	H	22,413	13,790	260.1	96,892	82.39	49,355	69.01
Chile	H	20,216	14,546	620.3	87,150	74.10	48,239	67.45
Romania	UM	16,146	8,549	631.3	134,817	114.63	47,420	66.31
Montenegro	UM	14,128	7,244	11.7	103,673	88.15	47,336	66.19
Mexico	UM	16,377	10,115	3716.8	88,701	75.42	46,035	64.37
Poland	H	21,753	13,382	1278.9	75,223	63.96	45,771	64.00
Estonia	H	23,088	16,821	58.9	85,278	72.51	45,591	63.75
Uruguay	H	17,343	13,722	120.3	87,055	74.02	45,405	63.49
Albania	UM	9,963	4,467	72.4	128,236	109.04	44,298	61.94
Russian Federation	H	22,502	13,298	5106.4	55,387	47.10	43,294	60.54
Colombia	UM	11,360	7,142	1144.7	89,253	75.89	42,678	59.68
Turkey	UM	17,781	10,435	1674.5	102,283	86.97	41,891	58.58
Kazakhstan	UM	20,772	11,358	614.0	56,466	48.01	41,736	58.36
Slovakia	H	25,130	17,762	241.0	66,477	56.53	41,546	58.09

Appendix 1 – Construction labour productivity on PPP and exchange rates in 2011

	World bank classification	Expenditure in construction		Construction employment (Thousands person)	Construction productivity (PPP)		Construction productivity (Exchange rate)	
		PPP (U.S. dollars, billions)	Exchange rates (U.S. dollars, billions)		USD / employment	Index (world = 100)	USD / employment	Index (world = 100)
Costa Rica	UM	13,030	8,935	123.8	76,702	65.22	35,380	49.47
Serbia	UM	11,854	6,027	118.7	97,928	83.27	34,941	48.86
Indonesia	LM	8,539	3,511	6324.5	158,391	134.68	34,681	48.49
South Africa	UM	12,111	7,963	1054.5	90,342	76.82	34,611	48.40
Macedonia, FYR	UM	11,957	5,050	40.0	101,554	86.35	33,361	46.65
Mongolia	LM	8,719	3,701	52.0	112,181	95.39	33,156	46.36
Peru	UM	10,981	6,066	866.2	80,006	68.03	32,980	46.12
Mauritius	UM	15,506	8,611	54.1	103,792	88.25	32,666	45.68
Armenia	LM	6,696	3,363	67.4	37,377	31.78	31,598	44.18
Malaysia	UM	20,926	9,979	1133.6	93,417	79.43	28,351	39.64
Belarus	UM	16,603	5,596	400.8	51,831	44.07	27,774	38.84
Panama	UM	15,369	8,411	162.0	60,070	51.08	27,578	38.56
Bulgaria	UM	15,522	7,284	228.7	70,051	59.56	26,798	37.47
Dominican Republic	UM	10,858	5,541	244.2	66,760	56.77	25,997	36.35
Venezuela, RB	UM	16,965	10,731	1117.7	81,385	69.20	25,636	35.85
Brazil	H	14,639	12,874	7814.4	58,637	49.86	25,305	35.38
Georgia	LM	6,343	3,231	65.2	29,674	25.23	24,015	33.58
Sri Lanka	LM	8,111	2,836	508.5	83,397	70.91	19,897	27.82
Azerbaijan	UM	15,963	7,285	308.9	23,059	19.61	18,869	26.38
Algeria	UM	13,195	5,518	1791.0	58,700	49.91	18,399	25.73
Senegal	LM	2,243	1,123	131.6	45,437	38.64	15,806	22.10
Qatar	H	146,521	97,091	497.5	62,358	53.02	15,754	22.03
Ecuador	UM	9,932	5,226	382.4	49,904	42.43	15,420	21.56
Morocco	LM	6,764	3,074	1059.0	75,983	64.61	14,853	20.77
Moldova	LM	4,179	1,971	66.8	18,098	15.39	14,770	20.65
Tunisia	UM	10,319	4,340	441.7	79,765	67.82	14,320	20.02
Thailand	UM	13,299	5,395	2173.4	63,334	53.85	14,110	19.73
Ukraine	LM	8,295	3,575	1311.9	20,002	17.01	13,742	19.21

Appendix 1 – Construction labour productivity on PPP and exchange rates in 2011

	World bank classification	Expenditure in construction		Construction employment (Thousands person)	Construction productivity (PPP)		Construction productivity (Exchange rate)	
		PPP (U.S. dollars, billions)	Exchange rates (U.S. dollars, billions)		USD / employment	Index (world = 100)	USD / employment	Index (world = 100)
Guatemala	LM	6,971	3,247	265.4	39,195	33.33	12,554	17.55
Paraguay	LM	7,193	3,836	199.0	30,065	25.56	10,264	14.35
Philippines	LM	5,772	2,379	2091.0	43,435	36.93	9,987	13.96
Ethiopia	L	1,214	353	380.6	55,759	47.41	9,225	12.90
Egypt, Arab Rep.	LM	10,599	2,888	2716.0	30,802	26.19	7,186	10.05
Zimbabwe	L	1,378	695	101.8	17,111	14.55	6,398	8.95
Bolivia	LM	5,557	2,360	393.5	13,667	11.62	4,340	6.07
Pakistan	LM	4,450	1,255	4414.5	16,650	14.16	3,113	4.35

H = High income, UM = Upper middle income, LM = Lower middle income, L = Low income

Source: Computed from ICP 2011 and employment database maintained by ILOSTAT

Influence of construction time on the productivity of construction works

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Abstract

Construction time has a major influence on the economically viable execution of construction works. Any short (or very short) construction period will severely affect the effective utilisation of production factors, which influences not only elementary (labour, materials, equipment and machinery) but also discretionary (project managers, site managers, technicians etc.) production factors. Clients often do not recognise this effect, or even deny it. Productivity is adversely affected not only by too short but also by exceedingly long construction times.

This paper demonstrates the basic correlation between construction time and productivity. Own approaches and methods known from pertinent literature are presented and critically reviewed to be able to quantitatively assess losses of productivity. This paper illustrates the influence of construction time on costing and, consequently, the actual construction process. Construction managers will be made aware of the necessity to closely monitor those construction-related factors that have an influence on construction time.

Another factor that deserves increasing attention is the gradual ("notional") shortening of construction time. Very often, more work needs to be performed than originally agreed upon whereas the construction period remains the same, and the contractor has to cope with a deterioration of the conditions under which work is to be executed. In most of these cases, contractors are forced to accelerate processes "incrementally" to adhere to the agreed-upon construction period, which partly incurs significant additional costs to be covered by the contractor if the client is not notified of the related disruptions based on the merit of the individual case.

Overall, this paper should create a better understanding of factors that promote or inhibit productivity whilst raising awareness of disruptions to the construction process, with the aim to further improve the effective utilisation of production factors but also to identify, and subsequently evaluate, thresholds of productivity losses more easily.

Construction time influences both the quality of individual processes and work steps and the overall quality of the project, as well as the number of construction process disruptions and thus the amount of additional costs claimed.

Keywords: construction time, productivity, production factors, costs, construction process disruptions

1. Introduction

Construction management is characterised by a combination of production factors. Pricing is essentially determined by defining which production factors to combine in which way and at what points in time. As part of the zero-base costing exercise (i.e. calculating cost-covering prices of construction works to be performed at a later point in time, excluding speculative elements), the expected costs of construction works must be determined. The costing exercise uses various construction work scenarios that are "played back" as a mental "construction film". The type and combination of production factors required for the construction work scenario that is considered most likely at the time of bid costing are applied.

Costs result from the consumption of production factors that is measured in monetary amounts. The intensity of this consumption is essentially driven by the time available for construction. The final bid pricing should always be determined on the basis of a zero-base costing exercise. At the very least, this approach makes bidders aware of the risk/opportunity range in which their quoted final prices lie. If the client specifies a construction period that is shorter than normal, and if the bidder then decides to quote a price that is, say, 20% lower than the zero-base level, the bidder should at least be fully aware of the fact that it runs a very high project risk. In such a case, it is often no longer possible, even if production factors are combined in an optimal fashion, to make up for this deficit that exists already at the beginning of the construction phase.

2. Production system

In construction management, production factors include elementary (labour, equipment and machinery, materials) and discretionary factors (project managers, site managers, technicians etc.). Production factors are particularly influenced by environmental and ambient conditions. Any effective or efficient construction process is characterised by combining these production factors in an optimal fashion. This optimal combination is reached if and when production factors can be employed at a "normal productivity" level (cf. Hofstadler (2014); Produktivität im Baubetrieb; pp. 13).

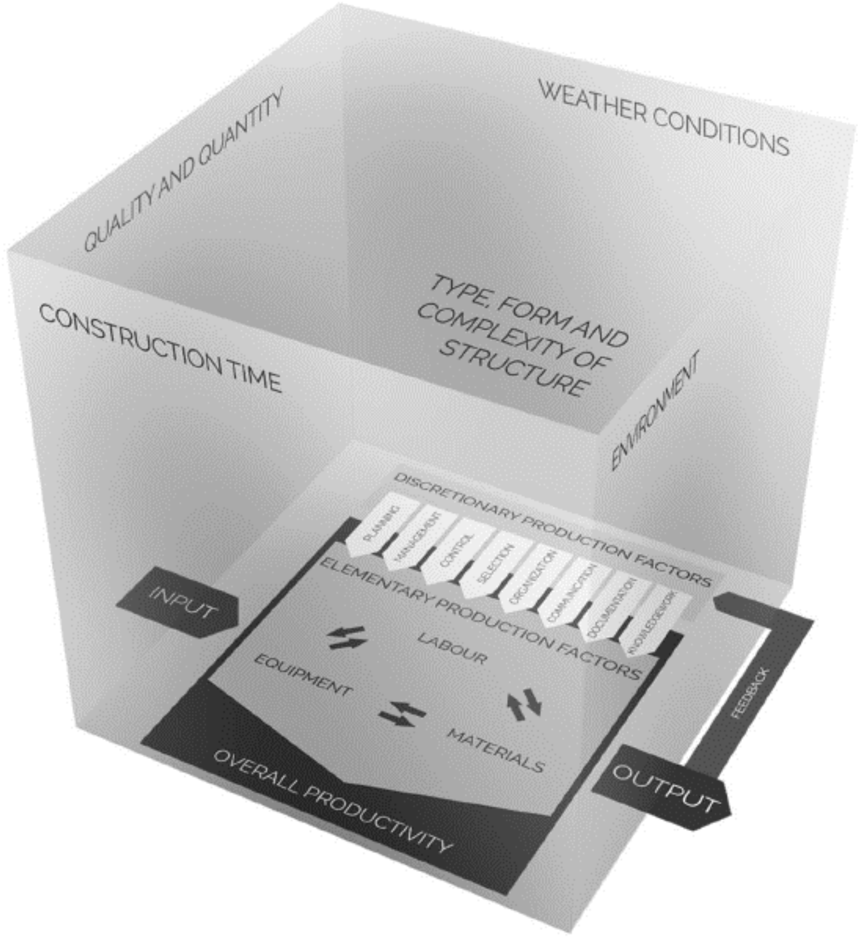

Figure 1: Influence on total productivity

The way in which production factors can be combined in a cost-effective fashion essentially depends on the type, shape and complexity of the structure as well as on the conditions governing work performance (see Fig. 1). Furthermore, achievable total productivity is determined by the required quality features and quantities, construction time, the site environment, and – last but not least – by prevailing weather conditions.

Any new construction project will always be subject to different boundary conditions; production factors must be adjusted to the specific circumstances of the project.

3. Importance of construction time

Construction time influences the project in many different ways. This parameter is relevant not only in terms of construction management and economics but also from a legal point of view. Construction time influences individual quality features as well as total quality and the number of disruptions to the construction process, and thus additional cost claims.

Generally speaking, sufficiently long periods must be scheduled for preparing quotations and construction activities and for actual work performance on the job site. Additional factors to be considered when determining normal construction time include seasonal effects and specific site conditions as well as other influential factors and difficulties.

Whenever short construction times coincide with a specified high quality standard of the building or structure and adverse weather conditions, this setting leads to a particularly unfavourable situation.

4. Specification of construction time

Construction time is usually specified by the client or principal. Contractors use this information to derive the utilisation of production factors required to fulfil their contractual duties. Labour consumption rates serve as a baseline indicator for all labour-intensive activities; labour consumption rates are subsequently used as key input variables to calculate output values. Bidders use labour consumption rates as an important basis for their costing and final pricing exercise.

How do production factors and productivity develop over the period of construction? This question is crucial for both preparatory project measures to be implemented by the client and for the costing exercise carried out by bidders and contractors asl well as for work execution and the billing of construction works. Clients are well-advised to thoroughly deal with the question of which intensity of production factor utilisation is most appropriate and useful to prevent any risk to achieving their project targets (quality, completion date, costs etc.). As a matter of course, clients are free to neglect this issue and to rely on a comprehensively worded construction contract. However, this approach might be associated with major disadvantages in terms of the project outcome (including cost overruns, quality issues and construction delays) because, obviously, any building or structure will always be constructed not by virtue of a mere contract but by an appropriate combination of production factors. It is the purpose of the construction contract to provide a proper framework for performing and billing construction work as well as rules for conflict resolution. It would thus also be advisable for the client to deal with the change in productivity and production factors over time. Bidders and contractors are bound to do this anyway because they would otherwise not be in a position to prepare a source-based costing exercise and to write the “optimal screenplay” for executing construction works (including spatial, temporal and intensity-related progress of work steps). In this context, the following question needs to be answered: Which trend should be assumed with regard to productivity and production factors during the construction period?

There will always be fluctuations in productivity because it will not remain constant over the entire period to project completion. When evaluating productivity, the individual project phases must be considered in relation to work performance (see Fig. 2). The following basic distinction can be made:

- Productivity during the ramp-up phase (D_{RU} = duration of ramp-up phase)

- Productivity during the main construction phase (D_{MC} = duration of main construction phase)
- Productivity during the final phase (D_{FP} = duration of final phase)

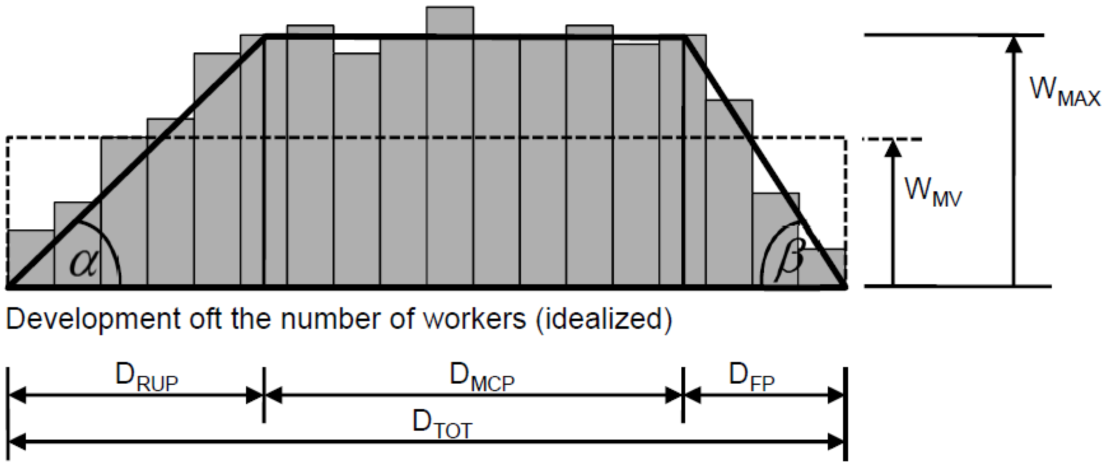

Figure 2: Number of workers on the construction site; see Hofstadler (2014), p. 14

Disruptions to the construction process are particularly disadvantageous in the ramp-up and final phases because optimally adjusted resources are not yet or no longer allocated to site operations.

4.1 Significance of construction time for the construction contract

By specifying construction time, the client exerts a direct influence on costs, and thus on construction prices. Construction times that are too short lead to losses of productivity and to higher costs. In the short term, higher costs are incurred, for instance, if the planning-ahead process does not work as intended or if other circumstances related to work performance (within the scope of the client) have changed. At a later stage, this situation will lead to issues caused by poorer structural quality as well as medium to long-term obstructions of use due to changed maintenance and repair scenarios. Limits for losses of productivity are still partially unknown or open to dispute.

Provided the client specifies normal construction times, contractors are in a position to optimally combine their production factors so as to perform their work owed under the contract at the lowest possible construction cost whilst adhering to the allocated budget (see Fig. 3). Thus, there is a lower risk of non-compliance with the specified construction time and cost as well as the agreed-upon quality standard.

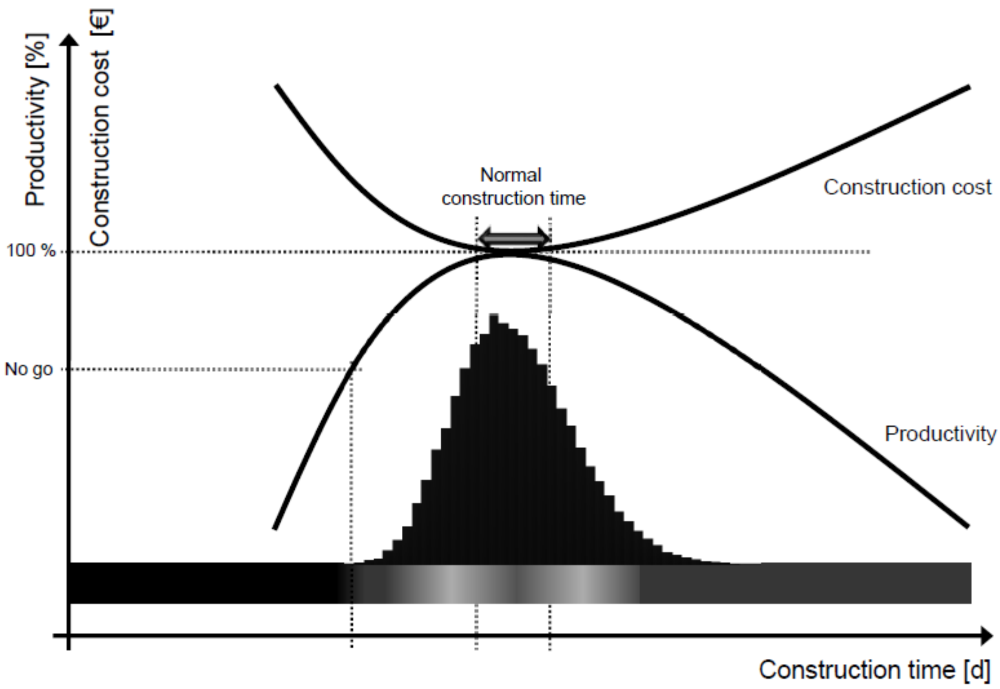

Figure 3: Relationship between construction time and costs; see Hofstadler (2014), p. 39

When determining construction time, the client usually considers limiting boundary conditions with an influence on site operations and management only to an insufficient extent, or not at all. These limiting factors result, for instance, from structural and operating conditions and have a major influence on the parameters that determine work output, such as the maximum number of usable workers or the maximum number of usable pieces of equipment.

A major issue in the context of calculating construction time is the linear nature of currently applied methods. In most cases, linear construction management-related correlations are used for the calculation process although these do not reflect reality. Any over- or underrun of thresholds or limits will lead to losses of productivity when capacities increase or decrease; these losses have a significant influence on calculation results. To accurately determine construction time, the various influences of productivity, such as limited available space for construction equipment, on production factors must always be considered.

Hruschka stresses that any calculation or optimisation of construction time must consider the mutual obstruction of the existing potential to prevent unrealistically short construction times. The construction time of a project cannot be shorter than permitted by the working capacity of the maximum installable transport equipment (Hruschka, 1969, p. 165).

Blecken states that the assumption of a deterministic production process leads to an oversimplification of the production model. Linear methods are chosen although most correlations of the combination of construction factors do not follow a linear pattern. He considers the additional application of stochastic methods to be a key tool to achieve significantly improved outcomes.

4.2 Definitions of construction time

The concept of construction time designates the calculated construction time prior to considering any buffer (assumed by the contractor). After determining construction time and considering the boundary conditions related to construction management and economics, the client should additionally account for a buffer to be able to compensate for any delays within its scope of responsibility.

Construction times are generally categorised as follows according to Hofstadler, 2014 (p. 57):

- Extremely short construction time
  Construction time is determined in such a way that the number of workers and pieces of equipment to be utilised productively exceed the corresponding maximum values (= thresholds to losses of productivity) by 20%.

- Very short construction time
  Construction time is determined in such a way that the number of workers and pieces of equipment to be utilised productively exceed the corresponding maximum values by 10%.

- Short construction time
  Construction time is determined in such a way that the number of workers and pieces of equipment to be utilised productively represent the corresponding maximum values. Any disruption to the construction process may immediately lead to losses of productivity when adhering to the construction time target.

- Normal construction time
  Construction time is determined in such a way that the number of workers and pieces of equipment to be utilised productively are 10% lower than the corresponding maximum values.

- Long construction time
  Construction time is determined in such a way that the number of workers and pieces of equipment to be utilised productively are 25% lower than the corresponding maximum values.

5. Influence of construction time on productivity

The qualitative correlation between construction time and productivity has been outlined above and is also reflected in the current literature pertaining to construction management. The missing piece, however, is the quantitative correlation between productivity and construction time. It is important for all parties involved in the project to find out how productivity changes in the event of deviations from “normal construction time”.

5.1 Construction time and losses of productivity

How can reliable data be derived that quantitatively describe the correlation between construction time and productivity in a generic rather than project-specific manner? Any *ex post* analysis will be difficult because massive changes in the type and circumstances of work performance will have occurred at least to a certain extent, and additional works or services will have been commissioned, compared to the situation when the construction contract had originally been entered into. The originally agreed-upon construction project does no longer correspond to the actually completed building or structure. It is virtually impossible to arrive at a source-based differentiation to determine whether losses of productivity were caused by changes in construction time and/or changes in the type of work, the circumstances of work performance, or contracted additional works or services.

For this reason, subsequent studies were based on *ex ante* considerations as a practicable alternative.

To generate valid data, an expert survey was conducted at Graz University of Technology to determine the quantitative correlation between construction time and labour consumption rates, and thus productivity. A total of 35 experts working for construction contractors were interviewed (both from construction trades and industry; survey period from August 2012 to April 2013). Respondents had an average work experience of 17 years (minimum experience: five years; maximum experience: 43 years).

Experts were asked to estimate increases in labour consumption rates or losses of productivity to be expected if deviations from the optimal construction time occur from a construction management and economics perspective (first stage: questionnaire completion; second stage: discussion of the questionnaire with the expert). "Normal" construction time serves as a reference where production factors can still be utilised without losses of productivity.

Prior to analysing data from the expert survey more thoroughly, an exploratory analysis was carried out to get an overview of collected data. This step was necessary to check plausibility and distributions as well as to identify any outliers. Box plots of the variables were prepared as part of the analyses to graphically represent distributions. A box plot describes the location and spread of a distribution and indicates any existing outliers. Outliers and extremes may significantly distort arithmetic means depending on the distance from the box plot whisker. This phenomenon was prevented by applying the M-estimator method, which made it possible to move existing outliers/extremes closer to the "main mass" of data by assigning a lower weighting to them. Arithmetic means and M-estimators were used as a basis for preparing diagrams and trend curves for increases in labour consumption rates and losses of productivity.

The differences in the increases in labour consumption rates for shorter or longer construction times are reflected in the diagram shown in Fig. 4 to consider the influence of construction time at the costing stage or in the process planning phase. The x-axis represents the extension/shortening of construction time relative to normal construction time as a percentage whereas the y-axis shows the percentage increase in the labour consumption rate for reinforced concrete works.

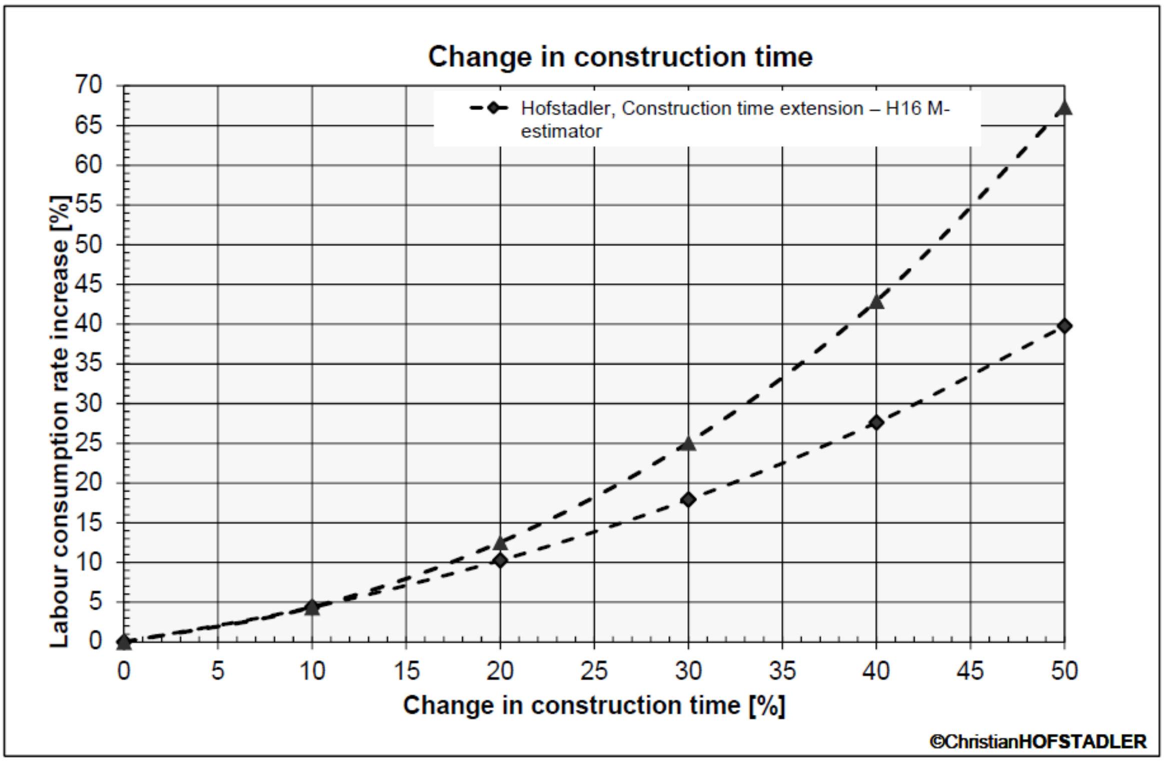

Figure 4: Trend curve for labour consumption rate increases – comparison between extension and shortening of construction time for reinforced concrete works (Hofstadler, 2014, p. 445)

The two curves are almost identical up to a 10% change in construction time. Only from the 15% threshold do the two curves deviate from each other. For instance, a 50% reduction/increase corresponds to a difference of about 27.6 percentage points. At a 50% shortening of construction time, the labour consumption rate increase amounts to about 67.4% and is thus 69.4% greater than in the case of construction time extension [= 67.4% * 100% / 39.8% -100%].

This comparison clearly demonstrates that a shortening in construction time is associated with greater labour consumption rate increases compared to an extended construction period. It is commonly known that shortened construction times lead to superimposed disruptions to productivity, particularly in the event of underruns of minimum available workspace and crane capacity.

There is a trend towards several different losses of productivity occurring simultaneously in the case of shorter construction times compared to construction time extensions.

5.2 Comparison with pertinent literature

The diagram shown in Fig. 5 compares the values cited in the pertinent literature to the results of the expert survey. This diagram represents the effects of shortened and extended construction times and the resulting losses of productivity. Oberndorfer, Petzschmann and Reister subsequently introduced generic limits and ranges for plausible productivity losses. Prior to using these limit values, care must be taken to ensure that the concept of productivity losses as interpreted by these authors is fully understood, as well as the calculation methods applied by them.

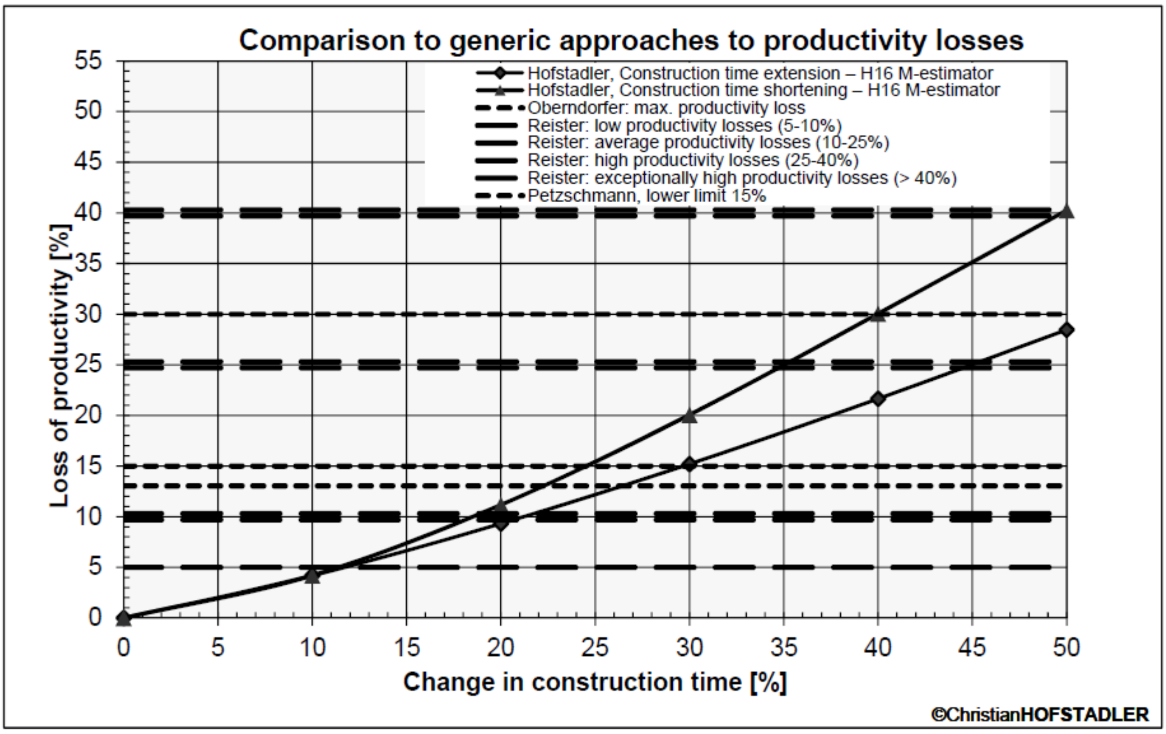

Figure 5: Trend curve of labour consumption rate increases – comparison between extension and shortening of construction time for reinforced concrete works (Hofstadler, 2014, p. 479)

The comparison with the limit defined by Oberndorfer shows that this limit is equivalent to the losses of productivity that would occur at a construction time shortening by about 22% and a construction time extension by about 27% as determined in the study conducted by Hofstadler.

In the event of simultaneous disruptions to the construction process, Petzschmann indicates a potential loss of productivity that ranges from 15% to 30%. The 50% productivity reduction according to Petzschmann is roughly equivalent to a 24% construction time shortening or a 30% construction time extension.

When considering the upper limit of 30%, the construction time shortening amounts to 40% whereas the construction time extension exceeds 50% (there is no point of intersection of the two curves in this case).

Reister considers ranges that cover the entire area of losses of productivity due to construction time extension or shortening. When considering a 45% construction time extension, it becomes apparent that the associated 25% productivity loss precisely coincides with the terminal average and initial high losses of productivity according to the categorisation applied by Reister.

For the 50% construction time shortening, the associated 40% loss of productivity precisely coincides with the terminal high and initial exceptionally high losses of productivity according to Reister.

The comparison of current results of the expert survey with the limit defined by Oberndorfer shows that this limit need not necessarily be applied, and that higher losses of productivity might occur. The limits stated by Petzschmann appear to lie within a plausible range. The ranges defined by Reister appear to be fairly plausible from a construction management perspective, depending on the extent of changes in construction time.

6. Conclusions

The correlation between construction time and productivity was shown both qualitatively and quantitatively on the basis of the new study published by Hofstadler. The effects on productivity and labour consumption rates to be expected if construction time is shortened or extended compared to the “normal” period were demonstrated. Related input data were collected directly in the expert survey. Arithmetic means were complemented by robust mean values calculated using the M-estimator method, which made it possible to systematically underweight any existing outliers and extremes in the calculation. The curves shown in the diagrams are thus very robust and reliable.

Any construction time that leaves sufficient room for considering all relevant construction management aspects will be beneficial for both parties to the contract. On the one hand, if the client specifies a normal construction time, this creates the preconditions for a construction process with very few disruptions. On the other hand, bidders can be highly confident in being able to utilise their production factors at their planned “normal productivity” level if a normal construction time is specified. Any disruptions can be overcome more easily compared to a construction process that had been disrupted already when work commenced due to an exceedingly short construction time.

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Productivity and performance measurement in the construction sector

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Abstract

Performance measurement has been applied systematically in many different sectors to drive improvements in productivity. Attempts have been made to establish measurements and benchmarking in the construction sector, but we still have not reached a situation where performance is measured systematically and consistently along the construction process. This paper reviews performance measurement theory pertaining to the construction sector to understand how performance is currently measured. Using participative workshops and interviews, we have mapped requirements of different stakeholders toward a performance measurement system. Based on literature and collected data, we outline issues to consider when attempting to develop further mechanisms for measurement. We also report briefly from a study to analyze different measurement and benchmarking systems to understand strengths and weaknesses of these initiatives. Based on this analysis, we have in Norway established a project to systematically test the CII 10-10 system to see whether it can meet measurement requirements at several levels in the construction sector.

Keywords: Performance measurement, benchmarking, productivity, construction sector

1. Introduction

The word of mouth says that the construction industry around the world has great potential for improvement in productivity and performance, and this impression is supported by current research (Abdel-Wahab and Vogl, 2011, Ingvaldsen et.al., 2004). Multiple efforts have been launched to address this issue in recent years, but the main challenges for the industry are to document the real performance of the industry, understand where improvements are needed, and document whether improvement efforts have had the effect they were supposed to have. The fact is that the construction industry does not have a common measure, nor a common tool to measure, how productivity and performance improves or falls over time. This paper will argue that the construction industry should drop *productivity* as a measure and instead adopt *performance* measurement in order to support performance improvement efforts. The paper will also illustrate how a comprehensive performance measurement system should be constructed to address five different performance levels, and it will outline an ongoing effort to test the suitability of one performance measurement tool on the project level.

Today, productivity is the dominating indicator for performance in the construction industry. Productivity is the only measure available on an overall level in most countries, which is also the case in Norway, the country we have studies the most closely. The Norwegian Central Bureau of Statistics, SSB, provides annual productivity statistics. These statistics are based on the annual economic reports provided by all organizations registered doing business in Norway.

Figure 1 illustrates how productivity for the construction industry has declined, using the productivity in 1995 as a benchmark. By comparison, the productivity for non-construction has nearly doubled in the same time span. The statistics are, however, flawed and certainly not 100% reliable. First of all, not all organizations in the construction industry are represented in these statistics. Some organizations are included in other industries, such as oil and gas, since they have projects within both industries. Second, these figures are very high-level and fail to capture activity-level improvements. It is also a major problem that improvements that entail moving toward industrial production, i.e., off-site prefabrication of building modules, often has a double negative effect on construction productivity; this production is often transferred from construction to manufacturing in industry statistics. This means that the most productive activities are removed from the construction statistics, leaving the industry worse off than before the improvements were implemented.

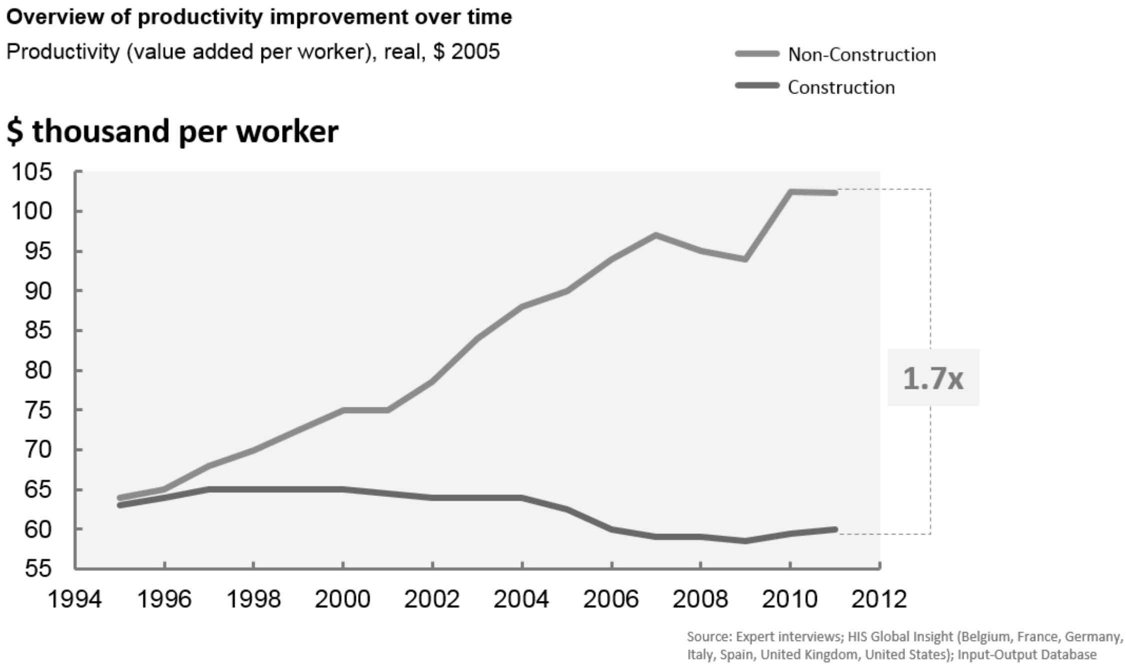

Figure 1 - Comparison of productivity improvement over time

Why, then, is it so hard to measure performance and get reliable measurements? Some of the answers are found in the characteristics of the industry itself. The construction industry comprises a large number of small construction firms, and a few larger contractors. A typical construction project consists of several small or medium-sized organizations temporarily working together, and they normally do not have any long-term relationship or partnership lasting longer than the duration of the project. They usually apply a contract model that does not give incentives for carrying out improvement efforts that will result in improved performance or increased value creation for other organizations. In other words, most improvement efforts are focused on increasing value for one single organization, and they do not necessarily find it interesting to help other organizations in the same project to increase their profits from that particular project. These characteristics results in sub-optimization and makes it harder to establish common measures and tools for performance measurement.

The long-term objective for the research project presented in this paper is to establish a set of tools that will support structured performance improvement efforts in the construction industry. The first step in this research effort is to select and test one tool for performance measurement in a range of Norwegian construction companies representing different actors in the project value chain. In addition, the first step will make sure that the experiences gained by each company is documented and shared between the companies.

2. State-of-the-art

According to Vogl and Abdel-Wahab (2015), in their review paper on the topic, there are not many papers that attempt to synthesize the existing literature in productivity research. Some attempts have been made (Yi and Chan, 2014; Dolage and Chan, 2014; Panas and Pantouvakis, 2010). Thus, it is difficult to find authoritative overviews of approaches and methods used to measure productivity/performance in construction. The fact that the approaches employed originate from quite different academic fields further complicates efforts to provide such an overview.

Notice that we deliberately wrote "productivity/performance", since these terms are often used either interchangeably or simultaneously (and then having somewhat different meaning) in publications. Many authors have discussed these terms, e.g., Page and Norman (2014), stating that "productivity measures how efficiently inputs are used to produce outputs" whereas "performance measures how well something achieves its intended purpose." Takim et al (2003) defined performance measurement as "the regular collecting and reporting of information about the inputs, efficiency and effectiveness of construction projects… used to judge project performances, both in terms of the financial and non-financial aspects and to compare and contrast the performance with others, in order to improve program efficiency and effectiveness in their organizations". These and many other definitions emphasize that performance is more detailed, with productivity often being seen as one aspect of performance.

Roughly, two main fields have contributed to the body of literature:

- Economics, discussing different ways to measure (and compare) productivity at a national and sector level.
- Operations management, looking at mechanisms to measure (and improve) performance at a business process and project level (both fields have also touched upon enterprise level measurements).

Under the economics approach, there are again two primary approaches; single-factor and multiple-factor models (Crawford and Vogl, 2006). The most widely applied single-factor model is the measurement of (average) labor productivity, which is typically applied by national statistics bodies in many countries. The calculation is done by dividing the aggregate output/value created by the labor input spent to produce the output. Multi-factor models attempt to explain productivity by considering factors beyond labor productivity, such as capital, technological progress, management, skills, etc. There are advantages and disadvantages of both approaches (ibid). Single-factor models require less data and allow cross-national benchmarking due to their widespread use, but at the expense of accuracy. Multi-factor models provide better insight through more fine-grained measurements, but require more data that can be difficult to collect. Extensive criticism has also been raised regarding the accuracy of high-level economics models, for example lack of suitable data (Allmon et al., 2000), that available statistics are unable to determine whether productivity in reality has decreased or improved (Rojas and Aramvareekul, 2003), and that a trend from on-site building to offsite manufacturing shifts this activity from the construction to the manufacturing sector (Haas et al, 2000). Irrespective of which economics model is applied, there is little relevance in terms of application at an operational level, in projects and companies and actors in the sector have therefore pursued alternatives (Harrison, 2007).

The operations management field offers bottom-up approaches, often termed "activity-level" measurement, based on measuring individual construction activities/processes. Equal to economics-derived approaches, also here different mechanisms have been developed. Back in 2000, Allmon et al described how economics-based measurements could be replaced by activity-level measurements, but still relying on publically available statistics (Means' Building construction cost data, published by the R.S. Means Co. Inc. from 1960-1997 in the US and deflating costs using the Consumer Price Index). A different approach to operational performance measurement builds on so-called performance measurement frameworks, defined by Brown et al (1997) as "a complete set of performance measures and indicators derived in a consistent manner according to a forward set of rules or guidelines." According to Yang et al (2010), the primary frameworks applied in the construction industry are excellence models (e.g., the European Foundation for Quality Management excellence model), the Balanced Scorecard framework (Kaplan and Norton, 1996), and key performance indicators models (e.g., the KPI framework developed through the Construction Best Practice Program in the late 1990s (Lin and Shen, 2007)). As we show later, systems based on key performance indicators seems to have become more prevalent lately, as seen in the operational performance measurement systems currently available.

Goodrum et al. (2002) outlined some advantages of activity-level measurement over traditional aggregate measurement; by measuring output in real quantities (e.g., square area of building spaces or volume of materials) the issue of price indexes is eliminated, by measuring labor effort in terms of labor hours there is no need for using cost-index-based deflators, and it is easier to compare input and output changes over time. More importantly, while high-level productivity measurements at best capture a very few factors that affect the performance of the sector and its projects, there are a number of issues that affect the long-term viability of the sector. One set of such factors was proposed by Page and Norman (2014), factors such as building to quality the market needs, maintaining health and safety standards, developing and maintaining skills, adopting technology, innovating, etc. According to Harrison (2007), the key disadvantage of more detailed activity-level measurement is that assembling a complete sector view would require summing up all tasks in some manner, while it would be easy to omit tasks. And for all tasks, large amounts of high-quality data are required.

A last topic of relevance when it comes to activity-level measurements is at which level such measurements can target. Yang et al (2010) reviewed performance measurement studies undertaken in the construction sector and found three levels being discussed; the project level, the organizational level, and the stakeholder level. Of these, project level measurements came first (Lin and Shen, 2007), and encompassed a large numbers of different dimensions of performance, e.g., environmental performance, human resource performance, procurement performance, safety performance, technology innovation, etc. (many of these coincide with Page and Norman's factors (2014)). For enterprises in the construction sector, project-level measurements are valuable but the need for more aggregate company-level assessments induced efforts to measure performance at the organizational level (as reported by for example Bassioni et al, 2005). Such measurements cover both financial, as would be expected, and non-financial aspects (Bassioni et al, 2004). The third level, stakeholder-focused measurements, is arguably also important, as project success is ultimately judged by different stakeholders. Wang and Huang (2006) found that the owner's, supervisor's, and contractor's performances were significantly related to the different criteria of overall project success. According to Yang et al (2010), there has been less work at this level of measurement.

We have so far briefly mentioned some more specific models/systems for performance measurement. To conclude this chapter, we outline in some more detail a selection of such models/systems, based partly on previous studies and partly on mapping undertaken ourselves. Going back to 2003, Takim et al reported from work to synthesize systems of measuring project performance in the United Kingdom, the USA, France, India, Hong Kong, Saudi Arabia and Malaysia. They found that these systems had different aims and focus of measurement; measuring both productivity and performance at a project level, assessing project viability, as well as targeting project quality. As far as we have been able to ascertain, few of these systems are still in use today, and we therefore conducted a renewed search for existing performance measurement systems. Table 1 lists the systems found that we judged to be most relevant for further investigation (we make no claim that our search was exhaustive).

Table 1: Overview of selected existing performance measurement systems

Performance measurement system	Country of origin	Measurement purpose	Data providers
Construction Industry Institute: 10-10 program	USA	Assess project performance at the end of each project phase through performance measurement and benchmarking	Project manager, project participants
Construction Industry Institute: General Program	USA	Detailed performance analysis after project completion using benchmarking	Project owner
Constructing Excellence: KPIzone	UK	Detailed performance analysis after project completion using benchmarking	Project owner
Benchmark Centre for the Danish Construction Sector: KPI System	Denmark	Evaluation of contractors in the form of a scorecard as a basis for more informed future choice of contractors and contractor improvement	Project owner
Performance Based Studies Research Group: Performance Information Procurement System	USA	Evaluation of contractors to allow selecting future contractors based on other criteria than price	Project owner
Project Norway: Health Check/Project Evaluation	Norway	Assessing performance throughout the life cycle of a project	Project participants
BRE: Key Performance Indicators for Construction Industry	UK	Performance measurement for a set of performance indicators that can be compared across projects or companies	Project participants
Customer satisfaction measurements	In use in different countries	Measurement of client/end-user satisfaction with the completed building	Client/end-user

We will refer to Table 1 and these systems in the discussion section of the paper.

3. Methods

The research presented in this paper has developed slowly, from an idea presented and discussed at a formal search conference in the Norwegian industry to identify ways to improve the performance of the sector. This turned into a research project, started in 2013, and currently has funding until 2017. The mentioned search conference prioritized performance measurement as one of six initiatives to be undertaken, as a means to truly knowing the current status, verifying whether improvement efforts have an impact, and undertaking industry analyses. The Norwegian Directorate for Building Quality (DiBK) funded an initial study to document the challenges facing the industry when trying to implement performance measurement and use the data to improve their performance. In turn, the first study laid the foundation for a secondary study, where the aim was to select and test one specific performance measurement tool in order to gain experience in both how that tool worked, what proper handling of the tool demanded of the organization using it, and how structured performance measurement should be carried out in practice. The main project started in august 2015, and will be carrying on until summer of 2017. The long-term objective for the whole portfolio of research effort is to develop a set of tools for performance measurement in the construction industry in order to support future efforts for continuous improvements in the industry.

A combination of different methods for data collection and data analysis formed the methodical framework for the research presented in this paper. Data collection was carried out using interviews, focus groups and expert panels. In addition, document studies were used as well as existing descriptions and documented experiences in using the different performance tools under evaluation. The representatives from the construction industry also participated in workshops where the findings were discussed and scrutinized. To a large extent, the same methods were used to analyze the data, especially focus groups, expert panels, and workshops. The integrity and validity of the data were ensured through triangulation, both researcher triangulation (using more than one researcher to analyze the same data) and the application of different types of data.

We have made some choices regarding methods, research approach and sample selection. First, we have not been able to identify and review a complete sample of tools available for performance measurement in the construction industry. Hopefully, our sample is satisfactory and encompasses the most frequently used systems that are publicly available. Second, the organizations involved come from the Norwegian construction industry. Still, our research has shown that there are many similarities internationally in the construction industry. Our findings could therefore be valid for other countries, even though this has not been the aim for this study, Finally, the research is still ongoing so our findings are not finalized yet, and the results should be reviewed in this perspective.

4. Results and Discussion

As chapter 2 showed, measurement of productivity and performance has been extensively discussed in relation to the construction sector. However, although many countries measure high-level productivity and several performance measurement framework and systems have been developed, we still have not reached a situation where performance is measured systematically and consistently along the construction process. As briefly discussed in chapter 3, as part of the research project aimed at investigating a possible new, operations-focused measurement system, we mapped the needs of different stakeholder groups in terms of measurement and measurement data. This led to the identification of five characteristics to consider when designing a performance measurement system (and based on these five characteristics, the subsequent development of a framework for evaluating a performance measurement system in terms of fulfillment of measurement requirements). The five characteristics are:

- *Level of measurement*; at which level of construction sector activity the measurements are undertaken, as discussed by Yang et al (2010) and treated in more detail below
- *Who undertakes the measurements*; who is responsible for collecting the measurement data, e.g., the project owner, engineering consultants, contractors, authorities, external actors, etc.
- *Dimension of performance measured;* the performance measurement literature suggests a wide range of aspects of performance that can be measured, spanning dimensions like time, cost, quality, flexibility, SHE, communication, innovation, learning, environmental impact, and ethics
- *Project phase targeted*; construction projects can be divided into a number of different phases and the measurement needs will typically vary across phases (this is for example evident in how CII has chosen to link the 10-10 performance measurement and benchmarking system to five project phases)
- *Type of project/building/infrastructure*; not surprisingly, we found that the usefulness of the selection of performance indicators applied vary from project type to project type, e.g., office building, laboratory facility, rail line, etc.

Regarding the first of these dimensions, the sector/activity level addressed by the measurements, for activity-level measurements, Yang et al (2010) identified three levels; the project level, the organizational level, and the stakeholder level. In our mapping of measurement stakeholder groups, we found five distinct groups that also logically correspond with measurement levels:

- *The country level;* by this, we think of the economics-type measurements undertaken at a high level of aggregation, typically for the whole construction sector of a country. This level of measurement has many stakeholders with highly differing needs for measurement, but some key measurement purposes can be to demonstrate the importance of the construction sector in society, promote the reputation of the sector, improve competitiveness, feed national and supranational statistics to allow tracking of trends and benchmarking.
- *The project/value chain level*; we have combined the terms *project* and *value chain* to clearly communicate that this level addresses whole projects and their (often multiple) value chains that contribute to delivering the project (this corresponds to the project level

identified by Yang et al (ibid). To measure and promote better performance of projects, this level of measurement must be able to assess the performance across individual actors to determine how well they collaborate to perform the project. Such measurements should provide detailed insight into the performance of the projects, especially which performance drivers affect overall performance, as well as stimulate behavior that create win-win situations.

- *The company/organizational level*; meaning the individual (private) company or (public or non-profit) organization participating in the construction project (corresponding to the organizational level discussed by Yang et al (ibid). Many measurements at this level are required by authorities or for accounting purposes, but other measurements that aggregate results from the organizations' projects are also important.
- *The construction process level*; academic sources and practitioners apply different terms to the lowest activity level of a construction project, e.g., construction processes, business processes, work processes, and we refer to these processes, for example land acquisition, production of drawings, electrical installation, etc. These measurements serve several different purposes; provide a platform for fact-based improvement efforts, promote an end-to-end view on processes to counter sub-optimization, assess effects of changes in processes, etc.
- *The user level*; this last one is not as clear a "level" as the other four and could even be argued is a phase of the project rather than a level of measurement. What we mean here is the users' perceived performance of the project and its deliverables, an important aspect of performance often overlooked in existing literature, and one that can only be measured after completion of the project, ideally even only after some period of use, this indicating that this is a matter of project phase. However, we could also argue that this is a singular instantiation of the stakeholder level outlined by Yang et al (ibid), and we have therefore chosen to include it as the fifth level. The purpose of these measurements are to assess whether the delivered building or infrastructure fulfills it purpose (usability), to understand the long-term life cycle performance of it, evaluate user satisfaction, etc.

Put together, the five characteristics of a performance measurement system can be construed as spanning a five-dimensional matrix. Every single cell in such a matrix would represent a unique measurement context be populated, and in an absolutely complete performance measurement system, each cell would be populated with at least one performance indicator serving a unique purpose. In reality, the different combinations carry highly differing relevance, and a "complete" measurement system would be extremely complicated and contain many measurements of little interest. To identify cells of the matrix that seem to have the highest potential for delivering relevant measurements, we defined a set of criteria to use when mapping measurement requirements among sector stakeholders:

- Is there a measurement need and purpose?
- Is there sufficient availability and quality of the data required?
- How much effort and cost will be involved in establishing the measurement?
- Do other established performance measurement systems undertake this measurement, thus allowing benchmarking?

Regarding the issue of data availability and quality, it is obvious that any performance measurement system and regardless of which exact performance indicators are defined, will require a fair amount of performance data. An effective construction sector system should strive to exploit lessons learned from other sectors when it comes to data collection, where we see that there a number of "archetypes" of measurement approaches that pose different opportunities:

- Manual or automatic harvesting of data from public records, e.g., industry statistics, accounting systems, license data, etc.
- Automatic data collection from different sensors or sources. This is an area with a large potential for effective data collection. Approaches can include collecting measurements from sources like moisture sensors, drone-mounted cameras, scanners, step counters on smart phones, etc. See Akinci (2015) for a presentation of some opportunities different technologies provide for data collection.
- Exploiting so-called crowdsourcing where large numbers of users cooperate to populate databases with relevant data. An example of this approach is the Danish construction scorecard system where public sector project owners score suppliers according to a number of performance dimensions, where this data is later made available to other project owners.
- Establishing a structured database for benchmarking, where users are encouraged to input performance data by allowing them to compare their own data against others'. Several of the performance measurement systems listed in Table 1 build on this principle.

Irrespective of the chosen performance measurements and which approach is used to collect the performance data required, the purpose of any measurement effort is obviously to give users of the system new insight. A fundamental analysis is to identify relationships between so-called *outcome measures/result indicators* and *performance drivers* (Kaplan and Norton, 1996). Result indicators say something about the end performance level of an activity or process, for example quality expressed by user satisfaction or warranty costs, productivity expressed as the portion of craft hours spent on value-added activities, or safety expressed as recordable incidents or time away due to injuries. These are the results of different performance drivers, characteristics about how the processes are designed or other contextual factors, for example the level of involvement of building contractors in the engineering phase, degree of prefabrication, distance between storage and work area on site, etc. Important insights can be gleaned from investigating whether changes in results indicators can be explained by differences in performance drivers, as this can help identify good practices that will improve performance.

The identified characteristics of performance measurement systems and assessment criteria presented here can be combined to either evaluate existing systems or as guidelines when designing a new system. In the end, the criteria we developed and that were used to evaluate the systems mentioned in Table 1 are those shown in Table 2 below. The table also shows our assessments of each system, and we underline that these were subjective assessments made considering our requirements for a measurement system to be pilot implemented in Norway.

The conclusion was that there is not one single system that meets all requirements. However, we found that the CII 10-10 system seems best suited for adaptation into a national construction industry system for Norway as it had the best score of all the systems presented in Table 2. This system will be tested in a number of companies and at the aggregate level during the next two years.

The 10-10 system provides benchmarking of project performance based on anonymously surveying project management team members and collected facts on project progression. 10-10 surveys by phase instead of at completion, and uses five distinct but overlapping phases (front-end planning/programming, engineering/design, procurement, construction, commissioning/start-up) using simple statement-based questions. In addition, the system uses ten leading indicators (input measures) and ten lagging indicators (outcome measures) to collect facts, hence the name 10-10. A project benchmarks its performance with other projects in the same phase, and it is possible to see how the performance of the project develops during the project life cycle. A more thorough description can be found on the CII web site[1].

5. Conclusions

This paper reports from a study undertaken on the use of performance measurement in the construction sector, a study that addressed several issues that need to be resolved for such measurements to be meaningful and have an effect. Previous studies have investigated different levels measurements can be undertaken at, typically distinguishing between country/industry and project/activity level measurements. We have found that in order to provide a comprehensive set of measurements that serve a number of different purposes, an extensive measurement system is needed that addresses five levels; the industry/sector level, the company level, the project level, the process level, and the user “level”. Furthermore, the range of issues targeted for measurement must also be expanded, from pure labor productivity assessments and a narrow set of project level factors to a wide set of performance indicators that can be used to facilitate understanding, improvement, and aggregation to higher levels.

Having looked into existing measurement systems and evaluated these against a set of requirements, it seems clear that there is no extant system that meets all requirements. It is probably not likely that one unified system ever will exist, but we see that it is crucial that if several systems must be used, these must be linked and allow aggregation of data across the different measurement levels.

In the Norwegian construction sector, we have found the CII 10-10 system to be the one existing system that promises to meet the most of our requirements. Together with about twenty organizations in the industry, we will initiate extensive testing of this system to see how well it manages to serve both process and project level improvement efforts, analyses into performance drivers and their effects, as well as industry-level statistical needs. We will report from this work in future papers, and in the mean time hope other countries experiment with other measurement models and systems so that we jointly can move the industry forward.

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[1] https://www.construction-institute.org/benchmarking/10-10.cfm?section=pa

Table 2: Evaluation of existing performance measurement systems (= criterion met, (-) = criterion partly met, _ = criterion not met, N/A = not relevant)*

Criteria	Systems							
	CII 10-10	CII General program	Constructing Excellence KPIzone	Benchmark Centre for the Danish Construction Sector KPI System	Performance Based Studies Research Group PIPS	Project Norway: Health Check/Project Evaluation	CCI KPI Engine	Customer satisfaction measurements
System availability, can be put to use without extensive adaptations	*	(-)	(-)	*	(-)	*	*	*
User-friendliness	*	_	_	*	(-)	*	_	*
Data presentation, how easy is it for users to comprehend presented data	*	(-)	(-)	*	*	*	(-)	*
Ease of extracting data and analyzing the data to create insight into project/company/industry	(-)	(-)	(-)	(-)	(-)	(-)	_	
Ability of the system to handle a large number of users	*	*	*	*	(-)	*	*	*
Potential to be used by most actors within the sector	*	*	(-)	(-)	(-)	*	*	_
Likelihood that the system will be available in the long run	*	(-)	_	(-)	(-)	*	(-)	*
Usage of existing data to minimize data collection needs	*	(-)	(-)	(-)	(-)	(-)	*	_
Quality check/verification of data before used in analyses	*	*	_	(-)	(-)	_	_	_
Ability to deliver new insight through data analysis	(-)	(-)	(-)	(-)	_	_	(-)	_
Usefulness at different levels of measurement	*	(-)	(-)	(-)	*	*	*	(-)
Possibility for aggregating data	(-)	(-)	(-)	_	_	_		(-)
Overall assessment of ability to satisfy requirements for a measurement system	*	(-)	(-)	(-)	(-)	_	(-)	_

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The interplay between formal and informal networks in construction projects

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Abstract

The primary aim of this research is to examine the interplay between formal and informal networks in construction project-based organisations (PBOs), with a view to understanding its impact on project performance. PBOs, as an organisation form, have been widely adopted to organise works in various industries, especially construction, information communication technology, automobiles, film-making and the media, and so on. Previous studies have recoginised the importance of formal institutions (e.g. hierarchies, contracts) while that of informal institutions (e.g. social network, culture) has yet to be well documented, or at most, merely treated as a supplement to the formal ones. This study goes beyond that by arguing that the interplay between the formal and informal institutions has a significant effect on project performance. It does so by conceptualising PBOs as social networks, including formal and informal networks, which are representations of the formal and informal institutions, respectively. Three PBO case studies in the construction industry are conducted. With the help of Social Network Analysis (SNA), the graphical and mathematical presentations of both formal and informal networks in three PBOs are explicated. It is found that the greater the extent of "fit" between the formal and informal networks/institutions of a PBO, the better the project performance will be. The research contributes to the knowledge body in two folds: (1) methodological innovation through integrating PBO, SNA and institutional analysis, and (2) examination of the impact of interplay of formal and informal networks on project performance.

Keywords: Project-Based Organization, Social Network Analysis, Fit, Construction

1. Introduction

PBOs as an organisation form have been widely adopted to organise works in various industries, especially construction, information communication technology, automobiles, film-making and the media, and consulting and professional services. According to Sydow et al. (2004), PBOs refer to a variety of organisational forms that involve the creation of temporary systems for the performance of project tasks. Here, a project can be defined as a temporary organisation to which resources are assigned to undertake a unique, novel and transient endeavour (Turner and Miller, 2003).Winch (1989) classed PBOs as 'intra-firm' and 'inter-firm' organisations. Intra-firm PBOs, e.g. in-house projects, are still under the ambit of a single economic unit or firm. The operations of intra-firm PBOs are normally governed by hierarchical relations. By contrast, inter-firm PBOs are a coalition of multiple firms with divergent economic and social interests (Winch, 1989). Project governance in inter-firm PBOs is mainly through contracts, and more recently has seen a shift of focus to informal institutions such as relations, trust, and culture.

The advantages of PBOs include less inertia associated with permanent organisations, better processes, higher output quality, increased ability to respond to customers' needs and innovation in collaboration with clients and suppliers. However, the downside is that PBOs bring new challenges to knowledge management, human resource management, and strategic management. Researchers have endeavoured to explore how to maximise the advantages while overcoming the downside of PBOs.

The construction industry has been consistently used as a typical institutional setting for inter-firm PBOs research and practice. It is an industry in which the forms of PBO have long been taken to be the norm across a significant swathe of activity (Morris et al., 2011; Bresnen et al., 2004; Gann and Salter, 2000; Winch, 1989). Without PBO, the industry may not have developed so many roads, bridges, offices, housing projects and the like, which are instrumental in influencing human health and social behaviour as well as cultural identity and civic pride (Pearce, 2003). The industry is said to be the largest industry employer globally (WTO, 1998), accounting for around 10% of the world's GDP, and yielding an output of approximately US$ 4.8 trillion per annum (Flanagan et al., 2007). Nevertheless, the industry has also received its fair share of criticism for its widespread problems such as late delivery, budget overruns, and lacklustre performance (Li et al., 2009). For example, in 2004, the Construction Industry Institute of the US estimated that 57% of money spent on construction in the USA is non-value-added and is therefore wasted (Eastman, 2008).

MacLeamy (2008) attributed the above problems to a fatally flawed system: design, bid, and build (DBB). Under the DBB system, professionals such as architects, engineers, surveyors, and contractors are separately contracted to do a parcel of the work. Although under the same umbrella as PBOs, they are not necessarily involved in the whole project lifecycle. As such, they do not always work together efficiently and, in fact, can have competing interests (MacLeamy, 2008). This is well known as the fragmentation and discontinuity that exists in construction PBOs. With such structural problems, it is not uncommon to see issues such as risk-aversion, short-termism, silo thinking, lost information, and ineffective communication. It is no exaggeration to say that the construction industry has witnessed almost every downside that a PBO could have. Responding strategies have been explored, e.g. encouraging communication (Dainty et al., 2006), promoting relational contracting, emphasising the importance of culture and trust (Rowlinson and McDermott, 1999), and advocating design and build integration (Walker, 2007) and public private partnership (Li and Akintoye, 2003).

There are many formal institutions of PBOs in the construction industry, such as ownership, financing modes, contractual relationship, outsourcing and sub-contracting, strategic alliancing, etc. These formal institutions have a great effect on the project performance. While recognising the importance of formal institutions associate with a PBO (e.g. organisation structure, hierarchies and authorities, and contractual arrangement), researchers increasingly start to examine the importance of informal institutions. For example, Pauget and Wald (2013) reported a vivid case of a French hospital construction project, in which relational competence in complex temporary organisations was investigated. While formal institutions define the "normative system designed by management" or the "blueprint for behaviour" (Scott, 1981), informal institutions define the actual behaviour of players. Informal institutions are largely shaped by soft factors such as players' mindset, trust, Guanxi, or project manager's charisma. They may or may not be in line with the formal institutions with the constraint of the specific PBO environment. Krackhardt and Hanson (1993) metaphorically describe the informal network is "the central nervous system driving the collective thought processes, actions, and reactions of its business units", and must be matched with the formal network, which is the skeleton of an organization, only by that the productive engine of the organizations can be fully steamed. However, as a whole, the importance of informational institutions in construction PBOs has not been well documented. Too often, they are treated as exogenous factors, which only passively responded to alternative formal institutions (Zenger et al., 2002). They go further and theoretically discussed the interplay of formal and informal institutions in organizations, and argued that it would have significant impact on the organizational performance (Zenger et al., 2002). Nevertheless, empirical studies on the interplay in construction PBOs are few and far between.

The aim of this research is to examine the interplay between formal and informal networks in construction PBOs, with a view to understanding its impact on project performance. The research question of this study is "how does the interplay of formal and informal networks associate a PBO affect project performance?", and the main research hypothesis is as H: *The greater the extent of "fit" between the formal and informal institutions associated with an innovative procurement system, the better the project performance will be*. The article is organized in the following way. Subsequent to this introduction section is the methodology, whereby construction PBOs are conceptualised as social networks, including formal and informal networks, which are representations of the formal and informal institutions, respectively. SNA is then employed as the main analytical tool, followed by the description of three case studies. Then, the results of data analyses are presented and discussed. Finally, conclusions, implications and limitations are provided.

2. Methodology

A mixed method comprising of case study, interview, survey/questionnaire, archival study, field study, and social network analysis are integrated to answer the research question. There are many possible ways to collect the data for mapping the SNs, such as the use of questionnaires, interviews, participant observations (Scott, 1991), and ethnographic methods (Hartmann and Fischer, 2009). However, these methods often rely heavily on personal judgment of the informants and are very time-consuming. This study collected relational data of informal institutions, which is often "off-the-record", thus requires considerable skills in interviewing, ethnographic studies that can interrogate real relations from those relations bearers. In this study, the information of informal networks occurred in workplace of a PBO was collected to characterize the informal institutions. Particularly, this study introduces a novel method, which is able to develop a set of SNs from timesheets. Case studies of three PBOs set the framework and boundary for this study. Interviews, survey, archival study and field study are the direct methods used in the data collection process, while SNA and related correlational analysis are employed in the data analysis.

2.1 Theoretical foundation

The relationships amongst the project team members in a PBO can be understood by treating them as a 'socio-technical system', which is a systems approach to complex organizational design that recognizes the interaction between people and technology in workplaces (Tavistock Institute, 1966). However, Winch (1989) argued that it has only limited analytical use in construction PBOs. Schweber and Harty (2010) thus proposed the "socio-technical networks" to examine the relationships. Notably, researchers have conceptualised PBOs as social networks (SNs), which consist of a finite set or sets of actors and the relation of relations defined on them (Wasserman and Faust, 1997). Loosemore (1998) investigated interpersonal relationships in PBOs under crisis conditions using SNA. Nohria and Eccles (1992) asserted that all organisations are SNs and therefore need to be analysed in terms of networks of relationships. Following this line of thought, Pryke (2005; 2012) suggested that a construction PBO can be represented as a multi-layer of interdependent networks. Chinowsky et al. (2008; 2010) also clearly stated that project organisations are SNs. Drawing upon these theories, it is appropriate for this proposed study, by emphasising the embeddedness of project management in a social context, to take the theoretical stance that PBOs are SNs.

If we accept that a PBO is an SN, then our understanding of the effects of formal and informal institutions interplay in a construction PBO can be related to the analysis of the network by using the established SNA approach. As an academic discipline introduced by Moreno (1960), SNA has matured over the past decades (Wellman et al., 1988). It is concerned with the structure and patterning of relationships over time and its purpose is to examine how the relationship structures impact behaviours, and to identify both their causes and effects (Wasserman and Faust, 1997; Scott, 1991). SNA is a new "language" to represent and understand PBOs (Pryke, 2012). Mead (2001) underscored the value of SNA in visualising project teams. The translation of PBOs into SNs also enables SNA to be applied, particularly its mathematical and sociological methods, to study project relationships in a manner that will inspire both academic and practical interest (Hughes, 2012).

2.2 Social network analysis

The collected data include data about formal networks and that about informal networks. The former mainly embrace contractual relationship and organizational structures, while the later contains self-reporting of the real-life communication and/or archival records of the work-related interactions. Data collected in all the three case studies are preliminarily edited, coded, and translated into SNA language. As shown in Figure 1, according to the information of the links, the collected data about formal networks are conversed into adjacent matrix, which is the SNA data input format used in *Ucinet* and *R*. Similar conversion method can be performed based on the collected data about the communication information. The validation of the networks is crossed checked and rectified through further enquiry by email, phone or face-to-face talk.

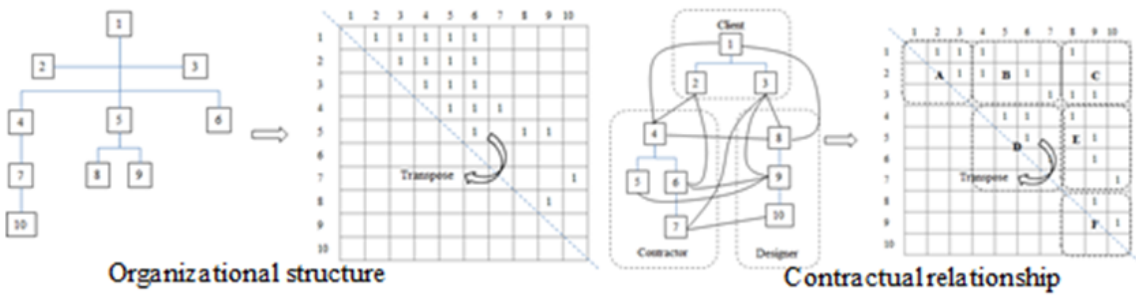

Figure 1 The illustration of the method to converse the collected data into adjacent matrixes

When the data are ready, it comes to the further data analysis, which constitutes of two phases. The first phase is the graphical and mathematical presentation of social networks to characterize the formal and informal institutions. SNA is carried out through the SNA software *Ucinet* and *R*. The visualization function in the software is able to convert the adjacent matrixes into various graphs of networks. The key actors, network density and clusters can be observed within the vivid images. It helps the researchers to get a big picture of the networks, and to gain the preliminary sense of the patterns of the data. The mathematical presentation of the social networks includes a set of metrics, e.g. network density, diameter, average path length, degree / closeness / betweenness centrality, clustering coefficient, etc. The metrics can be utilized to reveal the hidden patterns and trends in the data. Particularly, the physical meanings of the metrics, as explicated in Table 1, will be analysed and discussed in the rich context of the three case studies.

2.3 "Fit" between the formal and informal networks

To measure the fit of formal and informal institutions surrounding a PBO, a simple instrument was developed based on two main principles. First is the complementary/rival nature of a network metric. If a network metric is complementary, it means that an increase in the fit index leads to higher level of fit; if rival, an increase in the fit index leads to lower level of "fit" and it is expected to result in poorer project performance. Second is the benchmark, as set by the metrics of formal social networks. Here, the closer the fit index value is to 1.0, the more similar the formal and informal social networks are. In the context of PBOs, "fit" can be understood through the discrepancy between informal and formal institutions.

The fit index of a metric *X* at the individual level is assigned as the proportion of the average value of *X* in the informal network, denoted as $Average\ (X^I)$, and that in the formal network, denoted as $Average\ (X^F)$. The equation is shown as below:

$$Fit\ index = \frac{Average\ (X^I)}{Average\ (X^F)}$$

The fit indexes of the metrics at the network level are calculated according

$$Fit \quad index = \frac{Informal}{Formal}$$

Where, given a particular metric X, Informal stands for the value of X of the informal network and Formal stands for the value of X of the formal network. Two main principles behind when the author developed the concept of fit index are as follows:

1) The nature of complementary of a metric

The value of the fit index for a given SNA metric is expected to be closer to 1 in order to achieve a better project performance. By saying complementary, it means that the increase of the fit index leads to higher level of fit. Similarly, a fit index is rivalry means the increase of its value is expected to result in a poorer project performance.

2) Benchmark: the metrics of formal social networks are set as the benchmark.

As shown in the equations, the fit of formal and informal institutions are measured by the comparison of the formal and informal social networks. The closer the value of a fit index is to 1, more similar the formal and informal social networks are.

The level of fit between the formal and informal institutions is interpreted by Discrepancy of Fit (*DoF*) between the designed formal network and the actual informal network, which is equivalent with the extent of being close to 1.0. The discussion applies to both the SNA metrics at network level and individual level. Mathematically, *DoF* is measured in Equation 5.3, which is the same as Equation 4.2. Given a metric, the value of *DoF* is usually larger than 0, unless there is a perfect fit between the formal and informal networks in terms of the metric.

$$DoF = | Fit \quad index - 1 |$$

According to extensive literature review, the metrics selected for this study are grouped into *network level metrics*, including network density, diameter, average path length, global clustering coefficient, and *individual level metrics*, including degree / closeness / betweenness centrality, and local clustering coefficient. Totally, eighth metrics are employed to develop the main hypothesis (*H*) into eight respective sub-hypotheses, where the extent of "fit" in (*H*) is measured the metrics.

2.4 Case studies

The description of the three case studies is shown in the Table 2. Project Alpha is an infrastructure project in Hong Kong with four separated contracts. It is a complex construction project, with a huge amount of financial investment of about 36 billion HKD. Project Beta includes two public housing projects done by the same government department in Hong Kong. Project Gamma is a building project in Germany, with a relatively small financial investment of 180 million HKD. This project is the only one that is private funded. The network boundary of SNA is set to be active PBOs in the three case studies respectively (for the time being of data collection), with the actors the main project participants and the links the formal or informal "interactions" aforementioned above.

Table 2 Description of three case studies

Project Ref	*Alpha*	*Beta 1*	*Beta 2*	*Gamma*
Project type	*Infrastructure*	*Public Housing*	*Public Housing*	*Building*
Duration	*8 years*	*3 years*	*4 years*	*21 Months*
Financial size	*36,0000 Million HKD*	*470.0 Million HKD*	*610.4 Million HKD*	*180 Million HKD*
Financing method	*Government appropriation*	*Government appropriation*	*Government appropriation*	*Private fund*
Physical size	*4.5 km long trunk road, 3.7 km long tunnel and 3 km approach roads*	*11,950 m2*	*11,871 m2*	*14,800 m2*

3. Data analysis and results

There are totally 4 PBOs in the three case studies, 1 for Case Alpha, 2 for Case Beta, and 1 for Case Gamma. The main outcome of preliminary data processing mainly is the adjacent matrixes for both formal and informal networks. The two matrixes are imported into *Ucinet* to have the network visualization and into R to calculate the SNA metrics. Figure 2 is the graphical presentation of the formal and informal networks in Case Beta 1. The size of a node is proportional to the node's degree, and the displace rule of the two graphs in Figure 2 is trying to highlight the "important" actors in the middle. Hypothetically, the formal network shall set up the basic structure for the informal network, since the former shows the designed working relationships among actors within the PBO, while the later one is the actual interactions occurred during the project delivery process.

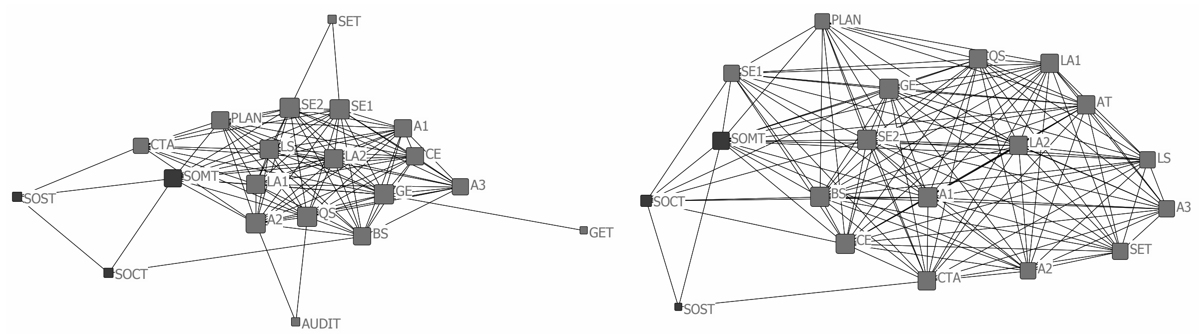

Figure 2 The graphical presentation of the formal and informal networks of Case Beta

The 'fit' of formal and informal networks will be examined at two levels, namely, individual level and network level. The former concerns the investigation of fit of formal and informal networks surrounding an individual, e.g. the degree centrality, and the clustering coefficient, while the latter concerns the overall fit between the formal and informal networks, e.g. density, average path length, and diameter. It is expected that to do so will allow a comprehensive understanding of the interplay from both a micro and macro perspective. The fit index of a metric X at the individual level is assigned as the proportion of the average value of X in the informal network, to that in the formal network. The fit indexes of the metrics at the network level are calculated as the proportion of the value of the metrics in the informal network to that in the formal network. The results of the SNA metrics of the four PBOs are presented in Fig. 3 and Table 2, respectively.

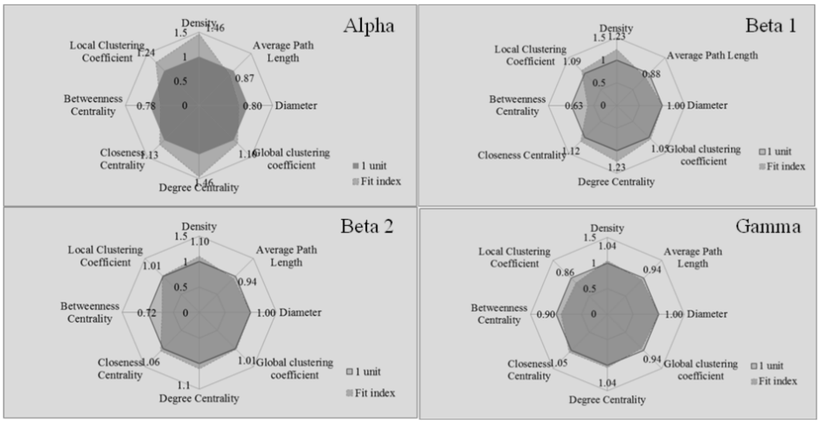

Figure 3 The spider diagrams of the fit indexes in the four PBOs

Table 2 A summary of DoF and project performance

			Alpha	*Beta 1*	*Beta 2*	*Gamma*
DoF	*Network level*	*Density*	*0.46*	*0.23*	*0.1*	*0.04*
		Average Path Length	*0.13*	*0.12*	*0.06*	*0.06*
		Diameter	*0.2*	*0*	*0*	*0*
		Global Clustering Coefficient	*0.1*	*0.05*	*0.01*	*0.06*
	Individual	*Degree Centrality*	*0.46*	*0.23*	*0.1*	*0.04*

	level	*Closeness Centrality*	*0.13*	*0.12*	*0.06*	*0.05*
		Betweenness Centrality	*0.22*	*0.37*	*0.28*	*0.1*
		Local Clustering Coefficient	*0.24*	*0.09*	*0.01*	*0.14*
Performance		*Time*	*4.00*	*4.25*	*4.50*	*4.10*
		Cost	*3.75*	*4.25*	*4.50*	*3.86*
		Quality	*4.13*	*4.25*	*4.50*	*4.44*
		Working Environment	*4.00*	*4.00*	*4.00*	*4.89*
		Health & Safety	*4.00*	*4.50*	*4.50*	*5.00*
		Total Performance	*3.96*	*4.25*	*4.43*	*4.36*

The data about the project performance of the four PBOs were collected through secondary empirical data and subjective assessment. The secondary empirical data from archival documentations and published materials are preferred to objectively measure the project performance and soliciting project staff and asking them to report their self-perception on project performance is also adopted as an alternative data collection method. After the collected data were edited, cross-checked, coded and standardized, a correlational analysis is carried out to discuss the interplay of the formal and informal networks and its impact on the project performance of the PBOs, followed by the qualitative discussions. The correlational result is shown in Table 3.

Table 3 Correlation between the fit indexes of the SNA metrics and project performance

DoF of SNA metrics	*Time*	*Cost*	*Quality*	*Work-En*	*H&S*	*TOTAL*
Density	*-0.27*	*-0.59*	*-0.40*	*-0.13*	*-0.32*	*-0.96*
Average Path Length	*-0.60*	*-0.35*	*-0.76*	*-0.23*	*-0.37*	*-0.87*
Diameter	*0.17*	*-0.84*	*-0.07*	*0.20*	*0.00*	*-0.93*
Global Clustering Coefficient	*0.11*	*-0.89*	*-0.41*	*0.54*	*0.38*	*-0.90*
Degree Centrality	*-0.27*	*-0.59*	*-0.40*	*-0.13*	*-0.32*	*-0.96*
Closeness Centrality	*-0.63*	*-0.30*	*-0.72*	*-0.32*	*-0.46*	*-0.84*
Betweenness Centrality	*-0.91*	*0.62*	*-0.50*	*-0.94*	*-0.94*	*-0.03*
Local Clustering Coefficient	*0.22*	*-0.94*	*-0.30*	*0.60*	*0.44*	*-0.88*

Note: the closer DoF to 0, the less discrepancy between the designated formal network and the actual informal network, i.e. the fitter.

The results in Table 3 show that the *DoF* of density has a negative relationship with the total project performance, with the correlational coefficient of -0.96. Furthermore, the negative relationship is confirmed in all five aspects of project performance. Therefore, H is accepted.

4. Discussions

This study explored the interplay of formally designed working network and the actual network of informal interactions. By using SNA, the graphical and mathematical presentations of formal and informal networks are compared to reveal the interplay of formal and informal networks. According to the result of correlational analysis and the implications of SNA metrics explicated, the impact of the interplay of formal and informal networks on the project performance could be probed.

The density of a network measures the extent to which actors are extensively interacting with each other. The smaller the network density in a PBO-based network, the better the project performance shall be. Smaller *DoF* of the network density in a PBO is equivalent to better fit of formal and informal networks in terms of density, which is confirmed to have a positive impact on project performance. This supports the hypothesis that higher density of formal or informal networks does not necessarily lead to better project performance; it also depends on the level of fit between the two.

Both average path length and diameter reflect the level of interaction convenience for actors within networks. They share a similar implication in organizational research in that a smaller value leads to more convenient interactions. The main difference is that average path length measures the average reachability, while the diameter describes the maximum distance of all node pairs. The smaller *DoF* of the average path length (or diameter) in a PBO is equivalent to the better fit of formal and informal networks in terms of path length (or diameter), which is confirmed to have a positive impact on project performance.

Degree centrality, closeness centrality, and betweenness centrality are the three measures of centrality at the individual level in SNA, which relates to individual members' influence and power within a PBO. These measures indicate that an individual with higher centrality has a more important role in the organization. Smaller *DoF* of either centrality measure in a PBO is equivalent to the better fit of formal and informal networks in terms of centrality, particularly in the consideration of average effects. However, the hypothesis for the Betweenness centrality is rejected with a non-significant correlation coefficient. Betweenness centrality is a reflection of the mediating effects in controlling and transmitting information flows within the network.

In the vocabulary of organizational studies, the four concepts are closely related to organizational cohesion (relevant SNA metrics including but not limited to density, average path length, degree centrality, and global clustering coefficient), organizational efficiency (relevant SNA metrics including average path length, diameter, and closeness centrality), and organizational effectiveness (relevant SNA metrics including degree centrality, betweenness centrality, and local clustering coefficient). By employing SNA, the formal and informal networks of PBOs were deciphered as a series of vivid graphs and quantitative numbers, and then their interplay is confirmed to perform an important role in the achievement of better project performance.

5. Conclusions, implications and limitations

The above discussions point to the conclusion that the higher extent of 'fit' between formal and informal network could be conductive to a better the project performance of PBOs, under the condition that the individuals of PBOs have relatively stable and normative working behaviours. The method used in this study provides a new perspective for the management board to probe into the informal working networks, to evaluate the original organizational design and collaboration mechanism, and then to more efficiently steer the operation of the PBOs. In reality, the working behaviours of individuals are also changeable under proper guidance. A good manager shall be able to make instrument for a more collaborative and trust organizational culture through the upper-down structural design of the PBO, and meanwhile be able to get a clear view of the informal networks, e.g. through the bottom-top feedback.

Within the boundaries of PBOs, formal networks set up the organizational skeleton for interaction and information exchange between project members, while the informal networks reflect the actual communication patterns and information flow. A denser informal network is perceived to be more cohesive, as long as the fit between formal and informal networks has reached a certain level. A project manager could diagnose organizational effectiveness by checking the fit of network density between the formal and informal networks. When a low level of fit is discovered, a project manager could take one of two intervention approaches. One is to investigate the formal institutions to see whether the work task-related communications among the corresponding professionals are sufficient, and if not, missing or long-distance information channels may be bridged at the organizational structure level, e.g. by using facilitating technologies. The other approach is to initiate informal institutions (e.g. project team camps).

This study is conducted in an innovative way to integrate SNA approaches, institutional thoughts and project management theories together, and the findings are limited to some factors, which shall be aware and improved in the future research activities. Firstly, the number of the case studies is relatively small, and the generalization of the findings in this study needs more evidence to decode the interplay of formal and informal networks and its impact on the PBO performance. Secondly, the significance level of the statistical analysis is marginal, and hence they are better treated as “indicative” instead of “decisive”. The quantitative analysis should be understood in conjunction with the qualitative analysis. Thirdly, SNA is a promising research method in providing a big toolkit for the organizational study scholars to explore, however, as to the authors’ knowledge, the exploration is just a corner of the iceberg. Particularly, the bridge between graphical / mathematical presentations of SNA and practical implications in organizational study is yet to be shortened.

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Direct Cost of Rework - A Subcontractor's Perspective

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Abstract

While it is widely recognized that additional costs due to poor quality have a significant impact on construction project success, limited research has been conducted to determine the direct cost of quality. When studies were conducted on the direct cost of quality (rework) they were usually from the perspective of the general contractor or owner and not from that of the subcontractor, where quality improvement would be most impactful. This study identifies the previously published work on the direct cost of rework; their data sources, perspectives, and calculations in an attempt to compare and contrast these investigations and add new data generated as a part of this research. An analysis of the inspection failure rates of subcontractors on California hospital projects was conducted and through a targeted survey the subcontractor's average cost of rework was identified in order to develop an additional cost analysis approach when calculating the true direct cost of rework. Previous research identified that the direct cost of rework typically ranged from 2.1% to 6.6% of the total project contract value with a mean of 4.2%. Utilizing a direct cost of rework calculation from a subcontractor's perspective, a cost percentage of 0.55% was calculated based on the total subcontractor contract value. These results delineated a clear and significant difference in the direct cost of poor quality depending on one's project perspective. This paper contributes to the study of quality by recognizing the true cost of rework from a subcontractor's perspective which assists industry in better understanding the motivations to improve quality. By recognizing the true cost of rework, steps can be taken to identify and reduce rework cost and ultimately further enhance construction project cost performance.

Keywords: Quality, Hospital Construction, Inspections, Direct Cost of Rework, Subcontractor

1. Introduction

The three criteria for assessing the success of a construction project are known as the 'iron triangle' of time, cost, and quality (Atkinson 1999). The first two objectives are relatively straightforward to define and measure: a subcontractor is either ahead or behind schedule, either over or under budget. Quality, the third objective, is much more difficult to assess and has received only limited attention in academic literature (Morris and Hough 1997). Quality control (QC) is the consensus term for a construction inspection process that verifies the quality of construction projects after work has been completed. This is in line with Crosby (1980) who defines quality succinctly as the conformance to established requirements.

This measureable description of quality is the foundation on which third-party quality control inspections are based for general contractors and more importantly for subcontractors whose perspective this study purports. Failed third-party inspections and the resulting direct cost of rework (also termed deviations), have been one cause of unnecessary construction costs attributed to lack of quality or cost of quality (COQ). If construction quality fails to meet the established criteria (applicable codes and contract document requirements) then additional resources must be spent (or wasted) on quality costs to make corrections. One goal of the construction process is to decrease the number of failed inspections (quality failures) and thus decrease the direct cost of rework or the direct cost of poor quality (DCOPQ). Being able to accurately and consistently calculate the DCOPQ across varying project types is an important factor in finding solutions.

While the cause of rework is an important topic and one which has garnered some attention, purporting and calculating the cost of rework has been widely inconsistent. A study was conducted on the quality inspection results from six California hospital construction projects. A survey was employed in an effort to uniquely calculate the Field Rework Cost (FRC) from the perspective of subcontractors. Based on this investigation a new calculation for the DCOPQ or direct cost of rework was developed and discussed to better understand and consider the entire concept of construction rework cost.

2. Background

2.1 Construction Rework Cost

For the purposes of this research, rework is seen as a negative term best defined by Rogge et al. (2001) as an activity in the field that has to be done more than once or activities that remove work previously installed as part of the project. A study conducted by Love and Edwards (2004) summarized most of the prior research conducted on the cost of construction rework. Their study emphasized the small amount of work done on the subject to date and the large disparity in the results. It was hypothesized that these variations were a result of researchers using different scope assessments, data collection methods, inconsistent calculations, and varying definitions of the term quality. A continuation of Love and Edward research can be found in Table 1 which is partially inclusive of their work and additional research found since their 2004 publication.

Table 1: Summary of reported total direct cost of construction rework studies.

Author	*Descriptor*	*Cost %*	*Formula*	*Data Source*	*Perspective*	*Country*	*Project Type*
Hwang (2009)	Field Rework Factor	2.12%	Total Direct Cost of Rework / Construction Cost	Project Reports	Owners and General Contractor	Various	Various Types
Love (1999)	Direct Rework Cost	2.40%	Rework Var. + Non-Var. + Defects / Contract Value	Single Case Study	Owner and General Contractor	Australia	Industrial
Burati (1992)	Deviation Cost	2.50%	Construction Deviation Cost / Total Project Cost	Nine Case Studies	CII Data Collection	USA	Industrial
Simpeh (2012)	Direct Rework Cost	2.93%	Direct Cost of Rework / Orignial Contract Sum	Survey	Construction Professionals	South Africa	Various Types
Ledbetter (1994)	Rework Cost	3.10%	Rework Cost Design + Construction / Project Cost	Single Case Study	General Contractor	USA	Heavy Industrial
Love (1999)	Direct Rework Cost	3.15%	Rework Var. + Non-Var. + Defects / Contract Value	Single Case Study	Owner and General Contractor	Australia	Residential
Wilis (1996)	Quality Deviations	3.30%	Deviation Correction Cost / Project Value	Single Case Study	General Contractor	USA	Chemical Plant
Barber (2000)	Quality Failure	3.60%	Quality Failure Cost / Contract Value	Single Case Study	General Contractor	UK	Highway Project
Mills (2009)	Defect Cost	4.10%	Defect Cost / Contract Value	Owners Claims	Ower - Housing Guarantee Fund	Australia	Residential
Josephson (2002)	Direct Rework Cost	4.40%	None Conformance Cost / Total Project Cost	Seven Case Studies	Owner and General Contractor	Sweden	Various Types
Josephson (1999)	Defects	4.85%	Defect Cost / Production Cost	Seven Case Studies	Owner and General Contractor	Sweden	Commercial
Love (2010)	Direct Rework Cost	5.07%	Direct Cost of Rework / Orignial Contract Value	Survey	Various Contractors and CM Co.	Australia	Heavy Civil
Hammarlund (1991)	Quality Failure	6.00%	Quality Failure Cost / Contract Value	Single Case Study	General Contractor	Sweden	Commercial
Love (2002)	Direct Rework Cost	6.40%	Direct Cost of Rework / Total Project Cost	Survey	Senior Construction Prof.	Australia	Various Types
Love & Edwards (2005)	Direct Rework Cost	6.40%	Mean Direct Cost of Rework %	Survey	Design, Contractors, & Consult	Australia	Various Types
Barber (2000)	Quality Failure	6.60%	Quality Failure Cost / Contract Value	Single Case Study	General Contractor	UK	Highway Project

This updated summary of reported rework cost studies reinforces the continued wide variation of descriptors, calculation formulas, data sources, and project types which researchers have utilized. These disparities and their lack of cohesion only adds to the confusion when rework cost comparisons are made between studies. As Love and Edwards (2004) reported and the results of Table 1 support, "while the calculation of rework can be an arduous and time-consuming task, there is an imperative need for rework definition and measurement before an accurate assessment of direct costs can be made" (p. 208).

Regardless of the descriptors used or how the calculation were formulated, all the research generated to this point analyze a version of the total direct cost of rework divided by the total project value or contract value. Undoubtedly construction research would benefit greatly from these values being calculated identically, so they can be directly compared industry-wide regardless of specific project circumstances. Unfortunately, the driving force when identifying the cost of rework and the formulas used have often been dictated by the data available. When this existing data is summarized a mean cost of 4.2% is calculated based on some determination of total cost of rework versus some total contract value.

2.2 Subcontractor Perspective

On commercial construction projects general contractors have typically subcontracted to specialty subcontractors as much as 75% to 100% of the work (Schaufelberger and Holm 2002). Despite the fact that subcontractors complete a large portion of most construction project, issues concerning subcontracts are seldom acknowledged or discussed. As Arditi and Chotibhongs (2005) confirmed, “little research has been conducted and little information is published on this topic” (p866). Efficient subcontracting (increased inspection success and reduced rework) would benefit all parties involved in the construction process including the general contractor, the owner, and the subcontractor.

Most research conducted in the areas of quality, quality control, and cost of quality has been from the perspective of the general contractor or the owner (Barlow 2015). A focused literature review on this topic as summarized in Table 1 confirms the lack of attention to subcontractor rework cost. Methods that improve the chances of subcontractor success by ensuring that all aspects vital to a subcontractor go well should be put in place (Boynton and Zmud 1984). This paper focused on the true cost of rework from a subcontractor’s perspective where the final quality of a construction project is truly determined. Unlike previous calculations of rework. the formula supported by this study is the direct cost of rework from a subcontractor’s perspective:

$$\frac{\text{Subcontractor's Total Direct Cost to Correct Inspection Failures}}{\text{Total Subcontract Contract Amount}} = \text{Field Rework Cost (FRC)}$$

In order to decrease quality inspection failures, which is the direct cause of rework, one must start with the subcontractor. The subcontractor carries the primary responsibility of obtaining quality success on a project, all others exist to support their efforts. Only by understanding and measuring subcontractor inspection success can we hope to decrease the amount of rework, decrease the DCOQ, and thus decrease the total cost of rework on any construction project.

2.3 California Hospital Construction

In California, healthcare construction projects are subject to a separate design review and construction inspection process due to their specialized nature and importance to the public. The California Office of State-wide Health Planning and Development (COSHPD) performs the regulatory oversight. In particular, the Facilities Development Division (FDD) of COSHPD reviews and inspects all healthcare construction projects in California. The FDD conducts plan reviews; issues building permits; confirms seismic compliance; performs construction observations and inspections; and interprets regulations, building codes, and policies.

In 2014, the FDD had over $20 billion worth of healthcare projects either under plan review or in construction (OSHPD 2015). In addition, the amount of anticipated healthcare construction to occur in California during the next ten years is predicted to be over $100 billion dollars. Alfeld (1988) advanced the view that construction, due to its magnitude alone, promises a greater payback for performance improvement than almost any other industry. Any small step in the direction of reducing the COQ due to inspection failures and rework in this field will likely save millions of dollars. The resources wasted on failed construction inspections could otherwise be spent on more desirable aspects of the healthcare cost ledger, such as lowering consumer costs for healthcare or saving lives.

3. Research Methodology

3.1 Mining Existing Data

This study first mined existing third-party construction quality inspection data generated by the FDD on six major California hospital projects. The data quantitatively revealed COSHPD inspection successes and failures at a subcontractor level over the entire project. The existing data were extracted and downloaded into MS Excel spreadsheets for further sorting and analysis. The data were gathered remotely and after-the-fact, eliminating any form of bias and avoiding what is known as the Hawthorn effect (Franke and Kaul 1978), referring to the tendency of individuals to perform differently when their performance is being measured or observed.

All six hospital projects were constructed in California under the review and supervision of COSHPD. All projects were completed between 2009 and 2014, varied in total construction cost between $260 million and $550 million, and varied in total area between 28,000 and 60,000 square meters validated continuity of the data. No further information about the projects is provided in this study to keep the identity of the projects, the owners, the architects/engineers, general contractors, and subcontractors confidential. COSHPD generated data had several advantages over other possible sources of quantitative inspection data generated by architects, engineers, general contractors, and privately hired consultants. All healthcare construction projects were required to accommodate continuous on-site inspections by the FDD, thus normalizing the inspection data. The FDD's policies and procedures for inspections, data gathering, and record keeping were standardized across all hospital projects, required by law, and conducted over the entire construction process.

COSHPD quality control inspection data were obtained and analyzed from forty-one (41) different subcontractors spanning six different California hospital projects. The breakdown of the forty-one subcontractors by trade, number in each trade, and designated reference number is shown in Figure 1. In order for a particular subcontractor who worked on one of the six hospital projects to be chosen for this research, a minimum of 150 inspections conducted by a COSHPD inspector was required. This minimum number was used to distinguish between subcontractors who had a significant role in the project and those who were ancillary.

Framing & Drywall (7 each); FD1, FD2, FD3, FD4. FD5, FD6, FD7*

Electrical (6 each); EL1, EL2, EL3, EL4, EL5, EL6

Structural Concrete (5 each); SC1, SC2, SC3, SC4, SC5

Wet Mechanical (5 each); WM1, WM2, WM3, WM4, WM5

Fire Sprinklers (5 each); FP1, FP2, FP3, FP4, FP5

Dry Mechanical (4 each); DM1, DM2, DM3, DM4

Ceiling Panels (3 each); CP1, CP2, CP3

Insulation (2 each); IN1, IN2

Fire Stopping (2 each); FS1, FS2

Exterior Framing (1 each); EF1

Glass & Glazing (1 each); GG1

* FD7 exists because one of the six hospital projects used two framing and drywall subcontractors due to the size of the contract.

Figure 1: Subcontractors by trade, number, and designation.

Table 2 below shows a breakdown of the forty-one subcontractors, the hospital projects on which they worked, and the number of inspections that they conducted. Inspection success was later converted into percentages to normalize the comparison between subcontractors who had varying numbers of inspections.

Table 2: Subcontractors by project, designation, and number of inspections.

Hospital 1		Hospital 3		Hospital 5	
1. FD1	1536	20. FD4	3390	33. FD6	2622
2. FD2	771	21. EL3	3320	34. EL5	378
3. EL1	1023	22. SC3	343	35. SC4	772
4. SC1	571	23. FP3	519	36. WM4	1988
5. WM1	1002	24. DM3	1049	37. FP5	197
6. FP1	269	25. CP3	241	Subtotal	5957
7. DM1	835	26. IN2	1152		
8. CP1	262	Subtotal	10014	Hospital 6	
9. IN1	190	Hospital 4		38. FD7	4252
Subtotal	6462	27. FD5	4904	39. EL6	2138
Hospital 2		28. EL4	1819	40. SC5	1745
10. FD3	3775	29. WM3	1658	41. WM5	1802
11. EL2	5196	30. FP4	265	Subtotal	9937
12. SC2	462	31. DM4	525	TOTAL	61,070
13. WM2	2406	32. FS2	1886		
14. FP2	429	Subtotal	11057		
15. DM2	2011				
16. CP2	452				
17. GG1	340				
18. FS1	1503				
19. EF1	1069				
Subtotal	17643				

3.2 Subcontractor Survey

Data reliability is related to data source and is therefore inextricably linked to the position held by the person who completed the questionnaire (Oppenheim, 1992). An individual survey was sent specifically to the subcontractor's field project manager in-charge of the project and from which the above existing mined inspection data was obtained. The survey was returned fully completed by thirty-nine of the original forty-one subcontractors; two subcontractors were not available or unwilling to participate. The survey focused on the actual cost of a failed third-party quality control inspection. The survey questions were as follows:

SQ1 – What was your total subcontract amount?
SQ2 – How many man hours were required to correct an inspection failure?
SQ3 – How much in material costs were required to correct an inspection failure?
SQ4 – How much equipment cost were required to correct an inspection failure?
SQ5 – How many man hours were required for the re-inspection process?

Figure 2: Subcontractor Survey Questions

4. Results

4.1 Data Mining Results – Total Inspections

A total of 61,070 COSHPD inspections data points were analyzed from six hospital construction projects spanning forty-one subcontractors. Major subcontractors on a significant California hospital project could generally expect that nearly 1,500 inspections might be required of them on any particular hospital project. This piece of data may not particularly useful, knowing that the average number of inspections required for any particular subcontractor will vary greatly. Subcontractors of a particular trade, however, could benefit from the results shown in Figure 3, which identifies the average number of inspections broken down by subcontractor trade. Figure 3 brings into focus the wide variation in the number of inspections possible depending on the subcontractor trade. The values listed represent the number of subcontractors representing a particular trade, the mean number of inspections, the minimum, and the maximum number of inspections respectively.

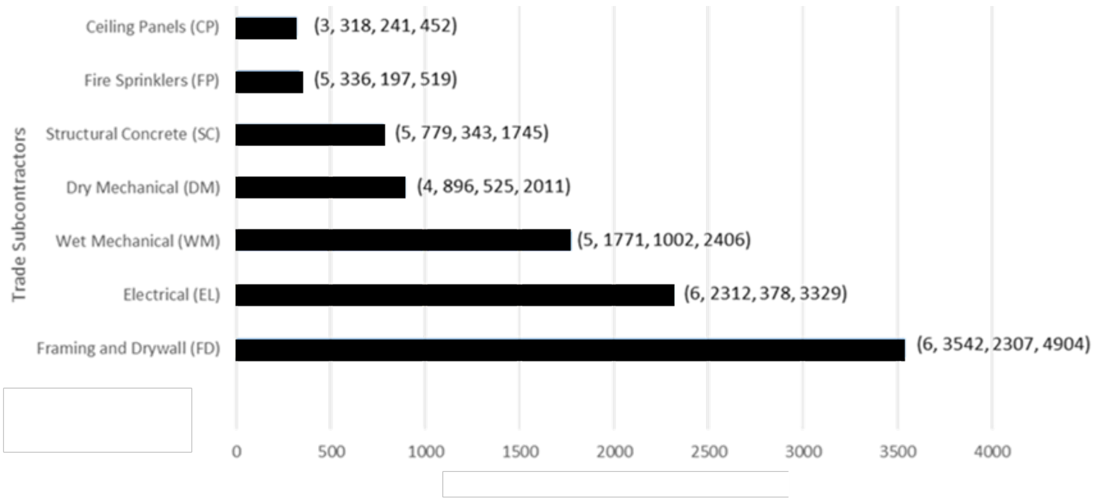

Figure 3: By trade and (number of subcontractor's, mean, minimum, and maximum number of inspections).

4.2 Data Mining Results – Failed Inspections

The percentage of COSHPD re-inspections (or failed inspections) versus total inspections revealed that 9.07% of all inspections conducted resulted in a failed inspection. The range of results was a minimum percentage (best subcontractor performance) of 2.02% and a maximum percentage (worst subcontractor performance) of 21.82%. As a result of a failed inspection, the work inspected was redone (re-work), a re-inspection was requested, and a new inspection was conducted by COSHPD. The overall re-inspection percentage number is based on over 60,000 inspection attempts with a standard deviation of 5.55%.

Subcontractors were then ranked based on percentage of failed inspections, ranking high achieving (low percentage of re-inspections) to low achieving (high percentage of re-inspections) as shown in Table 3. A re-inspection rate range of 2.02% to 21.82% was observed, as was a fairly even distribution of trade types along the spectrum. This would indicate that re-inspection rates had no particular correlation to the type of subcontractor trade being inspected.

Table 3: Ranking of subcontractors by percentage of re-inspections.

Subcontractor	Re-inspection Rate %	Subcontractor	Re-inspection Rate %
1. FD7	2.02%		
2. WM5	2.16%	22. WM1	7.98%
3. EL6	2.18%	23. EL2	8.33%
4. SC5	2.34%	24. DM3	9.06%
5. FD2	2.98%	25. DM1	9.58%
6. WM3	3.20%	26. FS2	9.86%
7. SC2	3.46%	27. FD4	9.88%
8. FD3	3.81%	28. IN2	10.07%
9. DM4	3.81%	29. FP2	10.96%
10. FD1	4.48%	30. FP3	11.95%
11. SC1	4.55%	31. IN1	12.11%
12. SC3	4.66%	32. FS1	12.38%
13. EL5	5.29%	33. CP2	13.05%
14. FD5	5.93%	34. GG1	13.82%
15. CP1	6.11%	35. CP3	14.94%
16. FP5	7.11%	36. EL4	15.28%
17. FP4	7.17%	37. WM4	17.71%
18. EL1	7.23%	38. FP1	19.33%
19. EF1	7.30%	39. WM2	20.28%
20. DM2	7.86%	40. SC4	21.76%
21. EL3	7.98%	41. FD6	21.82%

4.3 Survey Results

To determine the subcontractor's direct cost to correct each failed inspection (rework), questions SQ1-SQ5 (see Figure 2) were asked as part of a survey. The responses were analyzed and the mean amounts are shown below (Figure 4) based on an N=39.

SQ1 Total Subcontract Amount	$28,468,384 (US$)
SQ2 Man Hours to Correct	6.3 Man Hours
SQ3 How Much Material Cost	$238 (US$)
SQ4 How Much Equipment Cost	$96 (US$)
SQ4 Man hours to Re-inspect	3.8 Man Hours

Figure 4: Mean results from subcontractor survey.

Direct Cost of Quality (DCOQ) per failed inspection was calculated (see Figure 5) for this sample (N=39) subcontractors. The cost per man-hour rate, including workers' compensation insurance and overhead, was estimated at $80.00/hour (based on the 2015 RS Means Carpenter/Foreman/ Superintendent blended rate for California, USA).

Labor Cost Correct (6.3MH x $80/hr)	= $ 504
Material Cost Correct	= $ 238
Equipment Cost Correct	= $ 96
Labor Cost Re-inspect (3.8MH x $80/hr)	= $ 304
Subcontractor's Average Cost per Inspection Failure	= $1,142

Figure 5: Failed inspection calculation.

From the mining of inspection data results discussed earlier, it is estimated that significant subcontractors on California hospital projects averaged approximately 1500 inspections per project at a 9.07% inspection failure rate. Based on these numbers, a subcontractor could typically expect to incur (1500 x 9.07% x $1,142) = $155,369 of direct re-work expense (DCOQ) from a subcontractor's perspective. At an average subcontract amount of $28.5 million per project, the percentage of DCOQ for a substantial subcontractor working on a California hospital project is approximately ($155,369 / $28,500,000) = 0.55% Field Rework Cost (FRC). This percentage is lower than that found in other studies which calculated the DCOQ based on the entire construction project.

5. Discussion and Conclusions

Previous studies on the topic of construction quality have primarily focused on the cause of quality failures, the cost of quality due to rework, and identifying the reasons for project success. These studies are all from a primary stakeholder's perspective, most notably the general contractor. Interestingly, there were no studies found that examined the issue of quality from a subcontractor's perspective in an attempt to document inspection failures, improve inspection success, and decrease the DCOQ. This study assessed the construction quality of California hospital projects from the perspective of subcontractors in the field and through COSHPD third-party quality inspection data. The old adage, "you can't manage what you don't measure" (Deming 1986), is a rudimentary goal of this study. This research aimed to create measurements and benchmarks where none existed to assist subcontractors and project teams to better manage the quality inspection process on construction sites.

This study found that the DCOQ from a subcontractor's perspective was only 0.55%, far below the project wide calculations. While there is a wide variation when comparing these results, they may both be correct, because the total DCOQ for the total project with general contractor costs, mark-ups, etc. included may justify the higher percentage range as compared to the just subcontractors direct cost of rework. The motivation to decrease the additional cost of rework on large construction projects from a general contractor's and owner's point-of-view are clearly understandable at 3% to 6% of total project cost, especially when the significant indirect costs associated with poor quality are also considered. At 0.55%, and with very little additional indirect costs, what is the motivation for the subcontractors to decrease their amount of rework and DCOQ? Subcontractors may be very comfortable with a percentage such as this. General contractors and owners might find it difficult to motivate subcontractors to decrease this percentage further when it is such a small amount to begin with.

Gathering, analyzing, calculating, and benchmarking quality inspection data at a subcontractor level was unique to this study. For the first time, using our approach, subcontractors and the rest of the construction project team can utilize measureable quality inspection data to gauge the relative success of the quality obtained in the field. This new approach when applied early on in the construction process can alert project teams when a quality issue exists and action by management is required to rectify either the quality management process, quality assurance program, and/or the quality control program responsible for the relatively poor inspection results.

By applying this study, subcontractors could more accurately calculate the direct cost of rework due to failed quality inspections to determine the actual DCOQ for their particular trade and company. Depending on the results, a subcontractor can determine if taking corrective action for quality assurance is necessary or if the rework percentage is acceptable and simply a cost of doing business. General contractors and owners might choose to further motivate subcontractors financially to decrease rework and the DCOQ with various incentive programs if subcontractors are unwilling to take additional quality assurance action on their own. Future studies should look at the reason for these failed inspections and why they were not corrected prior to a formal inspection process. Indirect costs resulting from inspection failures such as lost productivity, acceleration costs, and work flow disruption is an issue which should also be further explored.

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A Study on the Factors of Completion Time for Road Construction Projects

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Abstract

Studies indicate that there is a relationship between project cost and construction time for different construction types. The purpose of this study is to validate the time-cost relationship model developed by Bromilow et al. in context with road construction projects in Florida. The model was extended to include contract types to determine whether the variable also has an effect on project duration. Data related to 235 road construction projects was obtained for the study. SPSS® program was used for analysis of the data. The statistical technique used for the analysis was stepwise linear regression. The results indicate that both actual construction cost and contract type have a statistically significant relationship with construction time for road construction projects in Florida, at the level of significance (p-value) of <0.0001. A prediction model of construction time was developed based on the results of the study. This model will be useful to both graduate and undergraduate students taking courses related to cost estimating and construction project scheduling, and also to professionals involved with the construction industry.

Keywords: Construction Time, Construction Cost, Contract Type, Road Construction, Regression Analysis

1. Introduction

1.1 General

Construction time for any type of project is related to a wide range of variables including construction cost. Time and cost have been typically used as important criteria for determining project performance globally. A relationship exists between the time taken for construction of a project and the cost incurred to complete it. Project cost has been identified as a correlate of construction time in many regions of the world (Bromilow et al., 1980; Choudhury & Rajan, 2008). In the construction industry, contractors usually use previous experiences to estimate the project duration and cost of a new project. In general, the more time it takes to complete an activity, the more human resources have to be engaged for the task, resulting in a higher project cost.

A correlation between completed construction cost and the time taken to complete a construction project was first mathematically ascertained by Bromilow et al. (1980). The authors analyzed the time-cost data for a total of 419 building projects in Australia to develop the model. The equation defining the mean construction time as a function of project cost was found to be:

$$T = K*C^{B} \qquad (1)$$

Where

T = duration of construction period from the date of possession of site to substantial completion, in working days

C = completed cost of project in millions of dollars, adjusted to constant labor and material prices

K = a constant indicating the general level of time performance per million dollar

B = a constant describing how the time performance is affected by the size of the construction project measured by its cost.

The model indicates that the duration of project time of a construction project is basically a function of its total cost. It provided a basis for all parties concerned with the construction procedure to establish a fairly accurate probable duration of a project in days, given the estimated cost of the project. The authors also analyzed the overruns on cost and time that provided a measure on the accuracy of the industry's time and cost prediction.

The model also indicates that relationship between duration of a construction project and time required to complete it is non-linear. A hypothetical scenario of such relationship, developed by the author, is shown in Figure 1. In order to perform data analysis using a linear model, the variables need to be transformed into their natural logarithms.

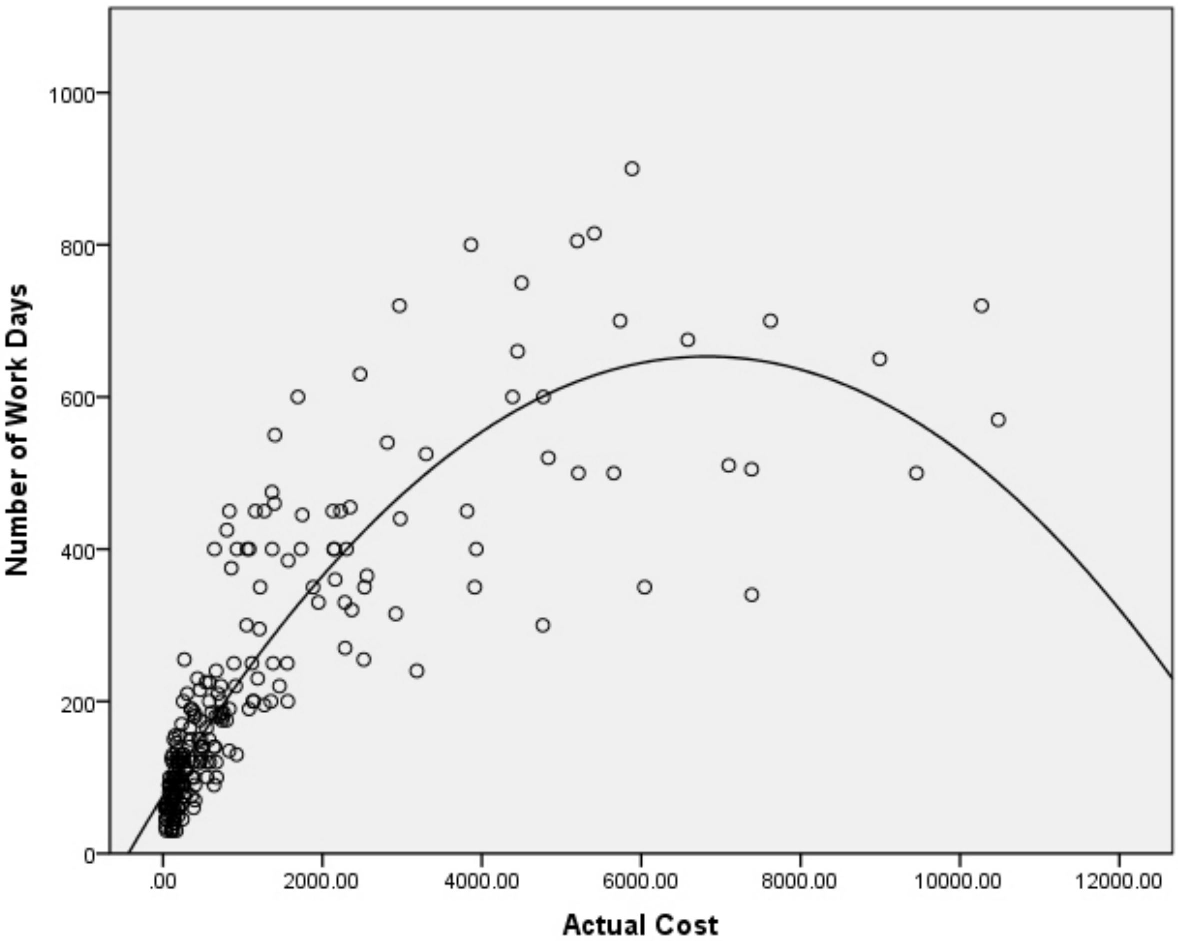

Figure 1: Non-linear relationship between construction cost and time

Several other studies have been performed around the world to make similar predictions for either a specific sector of construction or construction industries, in general. Ireland (1985) replicated the study to predict construction time for high-rise buildings in Australia; Kaka & Price (1991) conducted a similar survey both for buildings and road works in the United Kingdom; Chan (1999) investigated the effect of construction cost on time with particular reference to Hong Kong; and Choudhury & Rajan (2008) conducted a study on residential construction projects in Texas. Hoffman et al. (2007) used Bromilow et al.'s (1980) time-cost model to analyze data collected for 856 facility projects. They, however, included certain other variables such as project location, building type, and delivery method in the model.

Gritzka & Labi (2008) conducted a study on factors of time delay, specifically for road construction projects. Findings of their study indicate a statistically significant relationship between longer-duration projects and cost overrun.

All these studies found that the mathematical model developed by Bromilow et al. (1980) is applicable for prediction of construction time when the cost of construction is known.

1.2 Other Possible Factors of Road Construction

A critical issue in road construction that affect project delivery, experienced almost worldwide, is cost overrun (Bhargava et al., 2010). It generally results from factors that occur during various stages of life-cycle of a project. Studies on highway projects have been conducted by quite a few researchers to seek the extent of this particular problem.

Findings by several authors indicate that it is associated with project design, project environment, and project size (Akinci & Fisher, 1998; Hinze et al., 1992); project size, of course, is directly related to overall construction time.

Construction procurement is the process of obtaining services and supplies for efficient and timely delivery of the end product. The major project delivery methods include (1) Design-Bid-Build, (2) Design-Build, and (3) Construction Management at Risk. Studies indicate that project performance is affected by project delivery method (Choudhury & Pitkar, 2007; Ling et al., 2004; Chan et al., 2002).

The trend in the use of project delivery system is changing rapidly. Project delivery system has evolved over the years. The medieval master builder was hired by an owner to design, engineer, and construct an entire facility. This system was common until the early 20th century. With changing technologies, it was necessary to change the type of delivery system that gave way to the Design-Bid-Build method. As the specialization of services increased, it was found that the interaction during design phase was extremely poor which resulted in inefficient designs, increased errors and disputes, higher costs, and ultimately longer schedule. This led to the Construction Management at Risk delivery system to improve the interaction among parties concerned and to overlap the design and the construction phases. Eventually, it was found necessary for owners to resort to a single source Design-Build contracting (El-Wardani et al., 2006). There is an increasing trend toward the use of the Design-Build delivery method in the public sector (Choudhury & Pitkar, 2007; Tulacz, 2006; Yakowenko, 2004).

It is thus possible that project delivery method could play a role in construction performance time. The likelihood of an impact of delivery method on construction time of road projects was ascertained by including it in the time-cost relationship model.

1.3 Hypotheses

From a review of literature, it is hypothesized that

1. (H1) The mathematical model developed by Bromilow et al. (1980) holds good for prediction of construction time for road projects.
2. (H2) The actual completion time of road construction projects in Florida is affected by actual construction cost.
3. (H3) The actual completion time of road construction projects in Florida is affected by estimated construction cost.
4. (H4) The actual completion time of road construction projects in India is affected by contract type or delivery method.

2. Methodology

2.1 Data Collection

Data for 235 completed road construction projects undertaken by Florida Department of Transportation (FDOT) was obtained from secondary sources. All construction works were completed within last five years.

2.2 Variables

Actual Construction Time (TIME): It is the actual time measured for the completion of a road construction project. It was measured in days. This variable was labeled as LNTIME after being transformed into its natural logarithm.

Actual Project Cost (ACOST): It is the total cost of construction works of a road construction project. It was measured in units of 1000 US Dollars. This variable was labeled as LNACOST after being transformed into its natural logarithm.

Estimated Project Cost (ECOST): It is the total cost of construction works of a road construction project, estimated by FDOT prior to construction. It was measured in units of 1000 US Dollars. This variable was labeled as LNECOST after being transformed into its natural logarithm.

Contract Type (CONT): It is the type of contracting used for delivering a road construction project. This was a dummy variable consisting of two categories: (1) Design-Build (DB), and (2) Others. This variable was labeled as LNCONT after being transformed into its natural logarithm. It was assigned a value of 1, if the contracting method was DB; if not, a value of 0 was assigned.

3. Results

3.1 Analysis

The time-cost relationship model developed by Bromilow et al. (1980) defines only the relationship between construction time and actual construction cost. Since the present study hypothesizes relationships to exist also between (1) construction time and estimated construction cost and (2) construction time and contract type, the model had to be modified. Following model encompasses both the variables that may have an effect on construction time performance:

$$TIME = K*ACOST^{B1}*ECOST^{B2}*CONT^{B3} \qquad (2)$$

A stepwise linear regression analysis was used to perform the first step of analysis (see eqn. 3). It is a semi-automated process of building a model by successively adding or removing variables based on the *t*-statistics of their estimated coefficients. Therefore, the variables had to be transformed into their natural logarithms.

$$LNTIME = LNK + \beta_1 \, LNACOST + \beta_2 \, LNECOST + \beta_3 \, LNCONT + \varepsilon \qquad (3)$$

Where LNK = natural logarithm of K; β_1, β_2, β_3 = regression coefficients; and ε = error term.

The results show that two independent variables were retained by the model: actual construction cost (LNACOST) and contract type (LNCONT). Estimated contract cost (LNECOST), not being statistically significant at the level of 0.5, was were excluded. The results are shown in Table 1.

Table 1: Stepwise Linear Regression Analysis for LNTIME

Variable Retained	*Intercept (LNK)*	*Regression Coefficient*	*t*	*p<|t|*	*Critical Value of |t|*
Intercept	*1.827*		*15.976*	*<0.0001*	*1.96*
LNACOST		*0.529*	*29.976*	*<0.0001*	
LNCONT		*-0.131*	*-2.234*	*0.026*	
F-value of the Model = 459.471	*p>Model F=<0.0001*	*Model R^2 = 0.89* *Adjusted model R^2 = 0.80*			

3.2 Interpretations

The *F*-value of the model used for multiple regression analysis was found to be statistically significant at less than the 0.0001 level. This provides evidence that a relationship exists between construction time and at least one of the independent variables used in the model. The results indicate that construction cost (p>0.0001) and contract type (p>0.026) are correlated to construction time. The other variable, estimated construction cost, was not found to be significant at level of significance of 0.05; hence, it was automatically excluded by the statistical program from the model.

An important aspect of a statistical procedure that derives model from empirical data is to indicate how well the model predicts results. A widely used measure the predictive efficacy of a model is its coefficient of determination, or R^2 value. If there is a perfect relation between the dependent and independent variables, R^2 is 1. In case of no relationship between the dependent and independent variables, R^2 is 0. Predictive efficacy of this particular model was found to be moderately high with an R^2 of 0.89, and an adjusted R^2 of 0.80. It means that at least 80 percent of the variances in construction time of projects are explained by actual construction cost and contract type.

Based on the findings, research hypothesis (H1) regarding application of Bromilow et al.'s (1980) model for prediction of construction time for road projects could not be rejected; F-value of the model was statistically significant .Research hypotheses (H2) and (H3) related to relationships between actual completion time and cost of road construction projects (Figure 2) and actual completion time and contract types for road construction projects in Florida could not also be rejected; relationships of both these variables with actual construction time were statistically significant. However, hypothesis (H4) indicating a relationship between actual completion time and estimated construction cost for road projects in Florida had to be rejected, because relationship of this variable with construction cost was not found to be statistically significant at the 0.05 level.

The relationship between time and cost was found to statistically significant at the level of less than 0.0001. The relationship between time and contract type was found to be inverse at the level of less than 0.026. It means that construction duration was less using design-build type of contract.

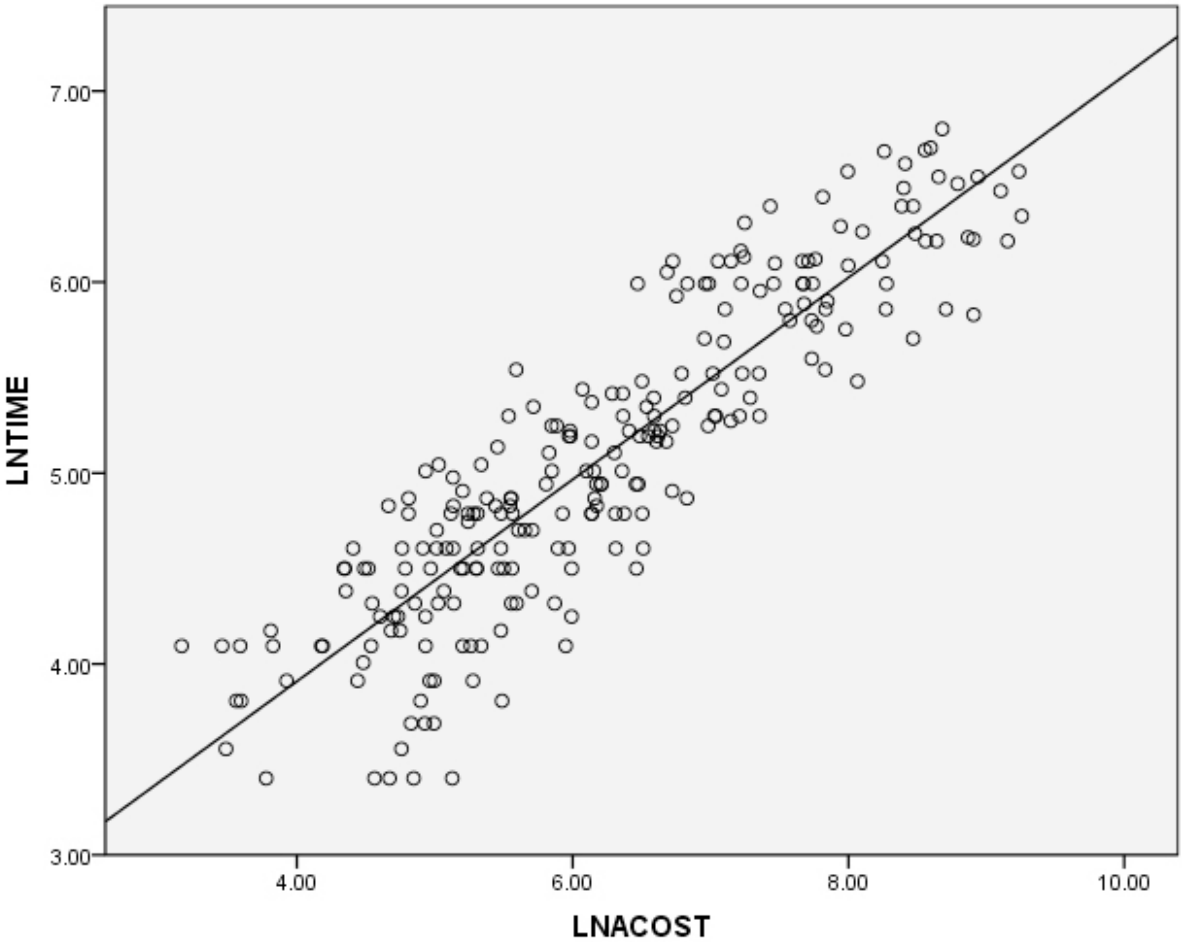

Figure 2: Relationship between LNTIME and LNCOST

The prediction model for road construction time in Florida was developed using results of the analysis. Bromilow et al.'s (1980) model was modified by adding contract type to the equation. The value of LNK and LNCONT were required to be transformed to K, using an exponential function [exp(LNK)] and [exp(LNCONT)] respectively, for expressing the model in its original form (Equation 4). The model may be expressed as follows:

$$TIME = 6.215*ACOST^{0.529} *CONT^{-1.31} \quad (4)$$

This model can be used to predict the road construction time in Florida when the gross floor area in known. For example, if the actual construction cost of a road project is, say $5,000,000, the predicted construction time for the project would be about 494 days.

4. Conclusions

The results of the study provide evidence that a modified version of the mathematical model developed by Bromilow et al. (1980) is applicable for prediction of time for road construction projects in Florida. Apart from cost, contract type was also included in the model.

The results of the statistical analysis indicate that for a road construction project in Florida, an increase in construction cost results in an increase in total construction time. The results also indicate that contract type has a statistically significant effect on actual construction time of the projects. It takes less time for completion of a road project in Florida using design-build method of delivery.

The model will be useful for students of construction science, taking courses in construction project scheduling. It will also be useful for all parties associated with the construction industry to predict the mean time required for the delivery of a road project. It provides an alternative and logical method for estimating construction time, both by bidders and clients, to supplement the prevailing practice of estimation predominantly on individual experience.

This study has been conducted using data for construction of road projects in Florida. The construction industry can benefit from the results of the study by applying the model in predicting construction time for similar projects. Such models may be developed by collecting historical data either from the owners or the constructors. However, the model documented in this study applies only for road construction projects in Florida and cannot be generalized beyond the sample size.

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Lean Sustainable Indices: A case for South African Public Infrastructure Sector

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Abstract

The interwoven nature of the goal of lean and sustainability points to synergy that can be created for industry, and societal benefits. The paucity of studies, which dwell on the impact of lean and sustainability on construction project performance is however notable. This is the case of public sector infrastructure projects (PSIP), which form the focus of this research. This exploratory study assesses the indices required for measuring the integrative implementation of lean and sustainability concepts in an infrastructure project. The study is qualitative in nature, based on interpretative theoretical framework that is grounded in lived experiences of project stakeholders. Emergent findings indicate that although the generic internal project key performance indices (KPI) of cost, time and quality is of major concerns to the stakeholders, indices required for integrative implementation of lean and sustainability are more broader in satisfying various stakeholders concerns, which would match business and environmental excellence, energy efficiency and optimum indoor environment, minimized resource consumption, minimized emissions, increase health and well-being, user productivity, reduced noise and dust pollution, stakeholders collaboration, and community social benefits. Such benefits include employment and enhanced industry competitiveness. It can be argued that a focus on these indices could lead to project delivery with limited impact in terms of sustainable development.

Key words: Construction, Lean, Infrastructure, Sustainability, South Africa

1. Introduction

The last decades witness a lot of innovation and transformation in its expedition for an improved built environment. Infrastructure development is crucial to drive the economy and advance civilization (Mirza, 2006). Achieving a sound and well-functioning infrastructure is essential for continuous economic growth, international competitiveness, public health and overall quality of life, as demanded by the current generation within the available social and natural context. However, this interrelationship between social and natural boundaries could alter the ecosystem. Environmental symptoms such as worsening climate change and huge emission of greenhouse gases (GHG), as a result of the depletion of natural resources because of the need to consumption is a global reality. As a result, sustainability has emerged in construction lexicon (Abidin and Pasquire, 2007).

The World Commission on Environment and Development (WCED, 1987) propounded the definition of sustainable development. The definition, which has been widely adopted by multiple agencies, says that sustainable development is meeting the basic needs of the present and the right for a better life without compromising the ability of future generations. The import of this definition is placed on the balance between social development, economic development, and environmental sustainability (Shen et al., 2007). Based on this, the primary goal of infrastructure development has now expanded from been mere economic viability to social and environmental concerns. Major infrastructure procurement now involves expert considerations regarding major spheres of sustainability. The triple bottom line (TBL) of economic, social and environmental dimensions qualifies for legislative, financial, and professional backings necessary for procurement success (Opoku and Ahmed, 2015). Infrastructure sustainability has grown from being technical based perspectives into social-political dimensions, attracting the attentions of multi-disciplinary experts, nations, and pressure groups in an attempt to negotiate the best way for sustainable development. This has been furthered by the recent adoption sustainable development goals (SDGs) by the United Nations (UN). The goals are premise on the need to build safe and resilient infrastructure, and combats climate change. The goals also include sustainable use of resources, promotion of inclusive and sustainable industrialization, which foster innovation.

This new concept focuses on the impacts of infrastructure development and resource use. The focus is on how efficient management can be brought to bear on energy consumption, dust and gas emission, noise pollution, waste generation, water discharge, water use, land use and pollution, and consumption of non-renewable natural resources, and its effect on the needs of current and future generations (Ghosh et al., 2014). Various researchers have shown that the construction industry and its activities have significant effects on the environment (Ding and Lanston, 2004; Griffith, et al., 2005; Low *et al*. 2009). Several work (Kibert, 1994; Hill and Bowen, 1997; Madu and Kuei, 2012) have proposed the thinking that underpins sustainability for the construction industry in order to engender wastes minimization and prevention of environmental hazards through basic principles of 5Rs (rethink, reduce, reuse, recycle and report) to achieves long-time economic and social benefits. Sustainability goals can only be achieved if construction activities are informed and directed by new thinking, new resources and expertise. Some of this comes in the form of innovative practice, tools and enhanced process models, but much will have to come from situated and contextual appreciations of sustainability goals and local practices in the industry (Pathirage et al., 2007).

Similarly, lean as a concept was developed as an industry process of eliminating waste by adapting production process in construction to enhanced performance (Howell, 1999; Forbes and Ahmed, 2011). Rybkowski et al. (2013) look at lean construction as respecting stakeholders in the value chain through a holistic pursuance of continuous improvement, while minimizing waste and maximizing value to the customer. Howell (1999) sees lean construction as a production process that mainly redresses project KPIs balance by 'increasing value while reducing waste' in construction. This production process is often anchored on waste reduction and normally practiced in the segregation of construction process breakdown of project life-cycle. Most works on lean construction have been premised on the five principles of lean thinking that serve as a pathway for continuous improvement. These principles are: value, value stream mapping (VSM), flow, pull, and perfection (Pasquire and Connolly, 2002; Terry and Smith, 2011). These principles are used to mitigate the current practices in infrastructure procurement that often hinders the attainment of the criteria for sustainability (Vieira and Cachadinha, 2011).

The interwoven nature of the goal of lean and sustainability points to a synergy that can be created for industry, and societal benefits. Construction industry can leverage on the synergy between lean and sustainability to achieve infrastructure development. Lean concepts align with sustainability concept of doing more with less. What is not clear though and is worthy of further investigation is; how can lean and sustainability indices be used to promote stakeholder engagements in the built environment? The paucity of studies which dwell on the impact of lean and sustainability on construction project performance is notable (Novak, 2012; Campos *et al.*, 2012). This is the case of public sector infrastructure projects (PSIP), which form the focus of this research. Monitoring progress towards lean and sustainability (LS) practices, thus, requires the identification of operational indicators that provide manageable units of information on economic, environmental, and social conditions that can be measured. A full disclosure of this new paradigm and the ability to fully map out its performance indices will be beneficial to the industry, and enhanced the process of continuous improvement and attainment of ecosystem equilibrium for sustainable development. The proposed will assist developers and others stakeholders gain a more comprehensive view of the lean and sustainability in the construction context.

2. Sustainability in Construction

Over the last three decades, sustainability concept has been growing in significance in the areas of developments in the built and natural environments (Edum-Fotwe and Price, 2009). After probing for answers to the challenge of sustainable development, most nations refocus their attentions on the construction industry. The construction industry is important to the achievement of the sustainable development agenda. The South African government has made progress in establishing policies that favour energy savings in the built environment. Appreciation of the major impacts of construction activities on sustainable development has led to the development of various management approaches and methods to guide construction participants in achieving better project sustainability performance in South Africa (Du Plessis, 2007; Thomson and El-Haram, 2011).

Kibert propose 7 principles to implement sustainable construction practice in 1994. These principles cover most aspects of the TBL and the concept of "doing no further harm" to the built environment. These construction principles speak to: conserving, to minimise resource consumption; reuse, to maximise reusable resources; renewing/recycling, to optimise renewable or recyclable resources; protecting, to conserve the natural environment; eliminate toxic materials, to create a healthy and non-toxic environment; economic benefits, to apply life cycle cost analysis; and technical, to provide quality products. Adopting these principles will ensure the reduction / elimination of adverse effects of construction activities on the built environment through efficient use of resources. The outcomes of sustainability principles could be regarded as a vital ingredient of improved competitiveness in construction industry (Opoku and Ahmed, 2015). Sustainable construction fosters interaction and protection of natural and social environments and ultimately helps to reduce energy usage, enhanced healthy and improved condition of living, and promote stakeholders productivity.

3. Lean in Construction

Stakeholders' concern about inefficiency in the construction industry is well known. The monumental wastes accompanying the use of resources (energy, water, materials, and land) have contributed immensely to climate change. Business as usual can no longer be sustained in the construction industry, if the industry is to assure biophysical sustainability while maintaining competitiveness (Womack and Jones, 2003; Holton et al., 2010). Lean offers an alternative that allows construction activities to thrive within environmental and social-economic constrains. Based on lean principles, major sources of waste, inefficiencies and pollution within the construction processes are identified and eliminated through collaborative approaches and processes to create value. For instance, planning, measurement, adjustment, and improvement ("Plan, Do, Check, Act") have also prove to be a veritable framework for value creation beyond specification (Ng et al., 2012).

Various lean principles and tools have been developed for use in construction with varying degree of success. San Martin and Formoso (1998) state that lean performance indicators include value chain efficiency, process efficiency, production flexibility, improved skills, material diversity, standardization, and optimization of components weight. Generally, the collaborative and continuous improvement principles inherent in lean practices made it not only a wastes reduction philosophy, but catalysts for business competitiveness, productivity and profitability. Lean principles engender effectiveness and efficiency in production processes by systematically examining the value chain for non-value activities through critical thinking and planning improved projects performance (Corfe, 2012; Novak, 2012).

4. Lean and Sustainability in Construction

The emergence of sustainability issues calls for a more innovative approach for the world to survive within the present constrains. The construction process generally contributes to the total energy use, GHG emission, and waste generation. Utilizing lean tools bring forth the predicted variable of efficiency and waste reduction, and the responsive variable of environmental benefit through reducing construction wastes at source, minimizing resource depletion, and preventing pollution. Integrative deployment of lean and sustainability could increase the pace of broader enhanced value (Larson and Greenwood, 2004; Ghosh et al., 2014).

Despite the sustainable construction drivers reported in the literature - resource efficiency, competitive advantage, reputation, increased productivity, reduced wastage, reduced materials cost, and preservation of natural environment (Yates, 2003; Zhou and Lowe, 2003) , the uptake of sustainability is still limited in the industry. This limitation may not be unconnected with the complex and fragmented nature of the construction industry. Common challenges perpetrating the limitation are the lack of understanding, perceived costs, and inadequate expertise (Opoku and Ahmed, 2015). However, lean reputation for promoting collaborative working arrangements, coordination, waste and cost reduction, and continuous learning and improvement serves as an opportunity for the industry to mitigate barriers to sustainable construction and create value beyond specifications.

The opportunity for value beyond the specifications has emerged as construction process with highly developed lean practices have reliably broken through the traditional project constrains and serve as catalyst for sustainability and enhanced added value in meeting the needs of sustainability (Nahmens and Ikuma, 2009; Novak, 2012). Lean practice covers a wide range of infrastructure procurement practices: planning and risk management, collaborative working, problem definition and solving, and value stream efficiency. These lean approaches demonstrate the value stream (benefits in terms of cost, time, and sustainability) for infrastructure sustainable development that span the project life cycle. It is on this premise that governments are urging the industry to leverage on lean thinking for real value delivery whilst simultaneously achieving improved competitiveness and the objectives set out in the strategy for sustainable construction (HM, 2009 cited in Corfe, 2013). It follows that lean thinking could form a central part of organisations' sustainability strategies, as it could deliver sustainability objectives.

Lean sustainable construction therefore can be conceptualized as 'a proactive approach to project delivery practice that meets a broader sustainability concerns of environmental, economic, social and technical perspectives by leveraging on available effective and efficient concepts to attain sustained productivity'. Sustained productivity here means to exceed the status quo of project delivery practice and achieve infrastructure beyond specifications. This has been achieved through efforts to enhance infrastructure project performance, reduce resource use and reduce costs through lean tools such as BIM, just-in-time, 5R, 5W (Scanlon and Davis, 2011; Ahuja et al., 2014).

5. Research Methodology

The aim of this study is to develop holistic indices of integrative implementation of lean and sustainability in terms of infrastructure development. The indices could allow a better understanding of stakeholders' way of assessing public infrastructure project performance. Within the construction context, the understanding of KPIs serves as benchmark for improved productivity, and it is vital to the success of project goals. To resolve this challenge, an exploratory study was conducted in Bloemfontein, South Africa. The study relies on interpretative theoretical framework that is grounded in lived experiences of project stakeholders (Creswell, 2013). Purposeful sampling in which the participants are selected according to a defining characteristic that makes them a role player was utilised in the study (Nieuwenhuis, 2007; Leady and Ormrod, 2010).

In particular, nine stakeholders in infrastructure development were interviewed in six different entities (department of works, project managers, consultants, policy administrator, community representative and the academia) with semi-structured questions that were initially sent to them by e-mail and a follow up telephone call was used to confirm the actual date of the interview for consistency. The interviews were conducted over a period of two weeks. Interviews, generally, were between 20 to 30 minutes in duration. At the start of the interviews, each participant was reminded of the research question and of the interview process. Each interviewee was then provided with a covering letter to read, and a confidentiality agreement to sign; on demand. This process was then followed by the actual interview during which the interview protocol was utilized as a guide. Each interviewee was asked about his / her experience and perceptions of infrastructure performance indicators related to: economic, environmental, and social conditions. All interviews were recorded and transcribed. The emerging findings were then collaborated with a comprehensive literature review to explore the phenomenon in South Africa. Nine interviewees took part in the exploratory study. The interviewees were two women and seven men between the ages of 30 and 56. The educational levels of the participants ranged from a national diploma to a doctoral degree, and construction industry experience ranged from 3 to 32 years (Table 1).

Table 1: The demographic of interviewee

Descriptions / *S/N*	*Highest Level of Education*	*Entities*	*Designations*	*Years in Industry*
1	*Bachelor's Degree*	*Works department*	*Project supervisor*	*3*
2	*Master's Degree*	*Consultant*	*Project manager*	*24*
3	*National Diploma*	*Project managers*	*Site agent*	*11*
4	*Bachelor's Degree*	*Consultant*	*Architect*	*26*
5	*Honours Degree*	*Project managers*	*Managing director*	*25*
6	*Doctoral Degree*	*academia*	*Senior Lecturer*	*19*
7	*Honours Diploma*	*Works department*	*Junior manager*	*11*
8	*Honours Degree*	*Community rep.*	*User*	*8*
9	*Honours Degree*	*Policy administrator*	*Director*	*32*

6. Research Findings and Discussions

The findings are herein presented and discussed in line with natural and social concerns about biophysical, economic, technical and social dimensions of sustainability in order to cater for the concern of different stakeholder. This provides a platform to integrate the primary data and the literature for meaningful interpretation for the right indices to emerge.

7.1 Indices for Biophysical Dimension

Most environmental concerns appears to be the highly researched sustainability dimension, some of the issues of the environment are predicated on the interaction between natural and social issues. Most interviewees suggest that resource use is a global issue as concerns for global warming are not localised. Sustainable resource use and environmental impact assessment are considerations in any developmental agenda, where the goal is to achieve sustainable extraction of fossil fuels and minerals resources at a rate lesser or equal to the slow replenishment of the inert resources, and to reduce the use of 4 generic resources of energy, water, materials, and land.

An attempt to maximise resource reuse and / or recycling, use renewable resources in preference to non-renewable resources, minimise air, land and water pollution, minimized emissions. So as to maintain and restore the earth's vitality and ecological diversity; and minimise damage to sensitive landscape in order to achieve the expected continuum (Shen, et al., 2007). Interviewees were unanimous in saying "we all know the rate at which we depletes the natural resources is certainly not sustainable, and a stable weather condition is not only good for our health, it also good for future planning". This echoes the current unpredictable nature of the biosphere and it impact on the environment. The interviewees express preference for facility with efficient energy, good indoor environment, and limited noise and dust pollution that can aid productivity.

7.2 Indices for Economic Dimension

Cost and value for money are the main determinants between internal and external stakeholders in any potential infrastructure development of scale. The management of the inherent trade-offs between these parties determine the viability of the project. Most interviewees agree with Shen et al. (2007) that intending user's affordability, employment creation; enhanced competitiveness, environmentally responsible supply chains, and the capacity to meet the needs of future generations are the main fulcrum for economic sustainability. Interviewee 5 says "yes, we all want to put up an energy efficient building or green building as you call it, but those technology are beyond the reach of common man", while interviewee 8 says "any user will like to rent a sustainable built environment because it ultimately reduces energy and maintenance costs of the properties". These quotes demonstrate the significance of energy use to the economics of the stakeholders. Other economic aspects mentioned by the interviewees relate to: having a competitive edge over their industry rivals through organizational learning, innovative ideas, technological advancement; improved productivity for enhanced profits; and stakeholder's collaboration for sustained harmony that engendered business and environmental excellence.

7.3 Indices for Social Dimension

The social dimension of sustainability has been growing in importance as a criterion for evaluating the viability of projects in the construction sector, especially in developing nations where basic needs of life and the right skills for quality job remains a challenge. Social sustainability in construction is mostly premises on the need for improve quality of human life through implementation of skills acquisition and capacity enhancement of the disadvantaged, to seek fair or equitable distribution of construction social costs, and to seek intergenerational equity (Shen, et al., 2007; Edum-Fotwe and Price, 2009). This social cost, according to the interviewees pertains to the health and well-being of the community. Most interviewees agree that "a lean sustainable project should be able to contribute to the community through local employment and improved skills development". A segment of the interviewees also echoes the need to match business goals with environmental excellence. This can only be attained through stakeholder collaboration and community involvement/development, proper site layout to reduce noise and dust pollution for work place harmony.

7.4 Indices for Technical Dimension

Quality is one of the traditional KPIs in construction management. Although relative in nature, it depends on technical competence and it outputs express 'value for money'. Sustainability in technical terms is to construct durable, reliable, and functional structures, which creates the built environment; humanize large buildings; and revitalize the existing urban infrastructure (Shen et al., 2007). Most interviewees agree with Emuze (2015) that the new model of sustainability must include regenerative, adaptive and resilient initiatives in order to achieve a broader sustainability agenda. The quality of the design, material selection, production process and the level of finishes most at times determine the functionality and the price clients are willing to pay for the products. Also, poor quality of work in projects may lead to reworks which certainly compromise other performance indices.

7.5 Indices for Lean and Sustainable Projects

The traditional KPIs have evolves overtime from the dated tripod of cost, time and quality. Projects success are now evaluated through performance measures to include critical factors of; health and safety and related sustainability criteria (Khosravis and Afshari, 2011; Kylili, Fokaides and Jimene, 2016). The broader sustainability indices have been widely reported (Shen et al., 2007; Edum-Fotwe and Price, 2009; Emuze, 2015) to encompass the natural and socio-economic aspects of infrastructure development and its effect on various stakeholders in the industry.

These cut across the project value chain in relation to processes, resources, leadership, people, financial, environmental and the entire ecosphere through project lifecycle. Lean principles as a waste reduction tools, is an effective ways of enhancing the various spheres of KPIs for infrastructure development (see sections 3 and 4). It can then be infer that indices for lean and sustainability (LSI) are those indices that can be seen as a standard of judgement by which lean and sustainable values can be measured. Hence, the LSI went beyond traditional indices to accommodate external inclusiveness that address industrial harmony and the need of future generations. As illustrated in Table 2, these indices set a benchmark for measuring project performance holistically and provide significant insights into developing a comprehensive base for future developments.

Table 2: Stakeholders project performance indices

Types / Indices	*Traditional*	*Lean (L)*	*Sustainability (S)*	*LSI*
Cost	✓	✓	✓	✓
Time	✓	✓	✓	✓
Quality	✓	✓	✓	✓
Health and Safety	✓	✓	✓	✓
Environmental responsible value chain		✓	✓	✓
Energy and resource consumption		✓	✓	✓
Pollution and emission		✓	✓	✓
Matching Business and environment		✓	✓	✓
Social cost/benefit			✓	
Industry competitiveness		✓	✓	✓
5R / Renewable resources		✓	✓	✓
Flexibility and adaptability		✓	✓	✓
Organizational learning		✓	✓	✓
Dispute	✓	✓	✓	✓
Stakeholders collaboration		✓	✓	✓
Employment and Skill development		✓	✓	✓
Continuous improvement		✓	✓	✓
Planning and risk	✓	✓	✓	✓

management				
Value stream efficiency		✓		
Technological advancement		✓	✓	✓
Affordability		✓	✓	✓
Indoor environmental quality			✓	

Adopting these new sets of performance measures as a base for planning and executing future projects could lead to evolution of sustainable built environment. To do so, a clear understanding of the LSIs, as a sub-set of biophysical, economic, socio and technical dimensions will be needed. This can come to fruition through further research and stakeholders' engagement in term of standardizing LSI measurement methods (Ali, Al-Sulaihi and Al-Gahtani, 2013).

7. Conclusions and Recommendations

The purpose of the research reported upon in this paper is to develop lean sustainability indices that are grounded in stakeholder's projects experience with the view of creating a consistent and holistic way of assessing public infrastructure project performance. The compilation of the indices is relevant as projects performance criteria are often hedged around the traditional KPIs and TBL of sustainability, measured both objectively and subjectively, in order to achieve success expectations. To sum up, the emergent findings indicate that although generic project KPIs of cost, time and quality is of major concern to the stakeholders, indices requires for lean and sustainability are however, broader and far reaching in engendering efficiency and effectiveness in infrastructure development. These include matching business and environmental excellence, energy efficiency and good indoor environment, minimized resource consumption, minimized emissions, increase health and well-being, user productivity, reduced noise and dust pollution, stakeholders' collaboration, community social benefits, and enhanced industry competitiveness. It can therefore be argued that a focus on these indices could benefit project delivery with limited whole life cycle impact in terms of sustainable development. The indices could provide all stakeholders the same information and knowledge of the overall goals, creating cooperation, coordination and better understanding of the key issues affecting the value chain, towards achieving better project performance.

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Status quo and future development of lean construction in Hong Kong

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Abstract

The current construction industry in Hong Kong faces severe challenges in relation to increasingly stringent regulations, aging workforce and skills shortages and their triggered high labour costs, and the transition of development from the fast-speed to sustainability-oriented mode. Lean construction has been recognised as an effective approach to improving productivity, hence offering a potential for the Hong Kong construction industry to prosper in the challenging circumstance. The aim of this paper is to examine the current practices and explore the future development of lean construction in Hong Kong. The research was conducted through 30 semi-structured interviews with established professionals in the industry. The results indicate a low level of awareness of the lean concept although some lean construction techniques were already embedded in practices implicitly. A wide range of benefits were identified, which were centred on reduced input, increased output and reduced impact, offering a potential for productivity improvement. However, challenges were also revealed at individual, organisational and industry levels, markedly people's mind-set and reluctance to change, a lack of demonstration of the benefits, and a weak knowledge base of lean. While some regarded lean as today's solution and therefore a must-to-have, others speculated an uncertain and dynamic future of lean construction in Hong Kong. Recommendations were identified for promoting lean construction in Hong Kong, fundamental to which was collaboration engaging government, industry and institutions.

Keywords: lean construction, productivity, industry development, Hong Kong

1. Introduction

The construction industry has long been criticised in many countries and regions for low levels of performance in relation to cost and time overruns, poor quality, disputes, and other problems leading to impaired efficiency and waste. It has also been argued as one of the weakest sectors in innovation, with piecemeal adaptation of modern technologies (Woudhuysen and Abley 2004). Much of the research in construction has attributed the lag-behind performance to the nature of the industry that is highly fragmented in structure and complex in operation, and has reached a consensus on the urgent need for reform and innovation in the industry (Dubois and Gadde 2002; Woudhuysen and Abley 2004; Goodier and Pan 2010).

Productivity is an essential component of industry performance which can be illustrated by a ratio between output and input (Park et al. 2005). The need for improving productivity is a great concern in the construction industry. In Hong Kong, the seminal Henry Report 'Construct for Excellence' (Construction Industry Reviews Committee – CIRC 2001) proposed 'an integrated construction industry that is capable of continuous improvement towards excellence in a market-driven environment'. More recently, the Hong Kong's Construction Industry Vision 2020 (Hong Kong Construction Association – HKCA 2012) has set the target of improving by 50% productivity by 2020 against 2012 benchmarks. However, in parallel with the ambitious goals, there are pressing challenges facing the Hong Kong construction industry to meeting these targets. One of the most significant issues is the ever increasing demand for manpower, accompanied with skills mismatch and the ageing labour force (Wong et al. 2015; Ng and Alan 2015). The great shortage of skilled labour poses significant risks to the fulfilment of a productive industry. In addition, safety is a thorny problem that the accident rate of the construction industry ranked the top among all sectors in Hong Kong (Wong et al. 2015). The impact of construction on the environment is also critical in Hong Kong, in terms of the large amount of carbon emissions and wastage demolition (Hong Kong Green Building Council – HKGBC 2014). To tackle these challenges and thrive in the dynamic circumstance, the adoption of modern technologies and innovative ideas is of great importance in the Hong Kong construction industry.

Lean construction has been widely recognised as an effective approach to improving productivity in the construction industry, e.g. in the UK (Egan 1998; Wolstenholme 2009), US (Salem et al. 2006; Song and Liang 2011), and Canada (Mao and Zhang 2008). Koskela et al. (2002) defined it as "a way to design production systems to minimize waste of materials, time, and effort in order to generate the maximum possible amount of value". Lean Construction Institute (2015) described it as "a new way to design and build capital facilities whilst the reliable release of work between specialists in design, supply and assembly assures value is delivered to the customer and waste is reduced". The many definitions and descriptions of the concept of lean construction in literature, albeit varying from each other, indicate the underlying common purpose of value maximization and waste minimization in construction projects. Along with the development of lean construction globally there have emerged numerous lean construction techniques and tools, with a trend attempting to address the emerging concepts and practices in the construction industry, such as building information modelling (BIM), sustainability, advance planning, and visualisation. For examples, Salem et al. (2006) studied six lean construction techniques: last planner, increased visualisation, first-run studies, huddle meetings, the five S's and fail-safe for quality. Song and Liang (2011) developed a vertically-integrated scheduling system tool for implementing lean thinking to improve project cost and time performance as well as reducing environmental impact of construction. Sadreddini (2012) described in detail two lean construction tools, i.e. collaborative planning and visual management, and considered them to be the first two commonly used to ensure quick wins and start a roll-out of lean and culture change. All these studies emphasise the importance of selecting and applying appropriate tools in a given situation.

However, the take-up of the lean approach in the Hong Kong construction industry appears to be low, coupled with few lean construction tools and technologies in use. Understanding of lean construction may reside with individuals in the industry and academic domains (e.g. Li et al. 2012), while such body of knowledge is fragmented and insufficient. Leung and Tam (2008) identified that the term "lean construction" is not commonly applied by practitioners in the Hong Kong construction industry. These factors not only expose the Hong Kong construction industry to risks and uncertainties when facing the rapidly evolving technologies and innovations, but hamper further take-up and future development of lean construction for achieving the construction industry vision and productivity improvement target.

The aim of this paper is thus to examine the current practices and explore the future development of lean construction in the Hong Kong construction industry. Following this introduction and methodology, the paper examines the perspectives of lean, the status quo of lean construction in Hong Kong, and achieved and potential benefits of and challenges for lean construction. It then explores the future development of lean construction in Hong Kong and identifies relevant recommendations, before conclusions of the paper are drawn.

2. Research Methodology

This research aimed to examine the lean thinking and applications in the Hong Kong construction industry. Semi-structured personal interviews were carried with established professionals in the industry. The interviewees were selected using the cluster sampling strategy, and covered the key stakeholder groups of lean construction in Hong Kong, e.g. developer/client, contractor, specialist contractor, architect, engineer, manufacturer and supplier, government, institution. Previous research (Warren 2002) argued that interview-based research should target between 20 and 30 interviewees for academic publication purpose. Therefore, this study targeted 30 interviews, achieved from 43 invited professionals with a response rate of 70%. Each interview took around 45 minutes, guided by a number of questions in three aspects: the status quo of lean construction in Hong Kong; benefits of and challenges for lean construction in Hong Kong; and future development of lean construction in Hong Kong.

The interviews were audio recorded with permission. The transcripts and notes taken during the interviews were analysed following the process of identifying codes, themes and patterns with the aid of NVivo software.

3. Results and Analysis

The background information of the 30 interviewees is provided in Figure 3. The interviewees together, by their primary affiliated organisations, covered all of the eight main stakeholder groups in the Hong Kong construction industry identified for this study, which were institution (30%), contractor (17%), consulting engineer (17%), developer/client (13%), government department (10%), manufacturer and supplier (7%), specialist contractor (3%) and architect (3%). The interviewees together also well covered various groups of stakeholders by their working experience. Nearly half of the interviewees (46%) had more than 30 years of experience in the construction industry, followed by those with 10-19 years of experience (20%) and then those with 20-29 years of experience and those with less than 10 years of experience.

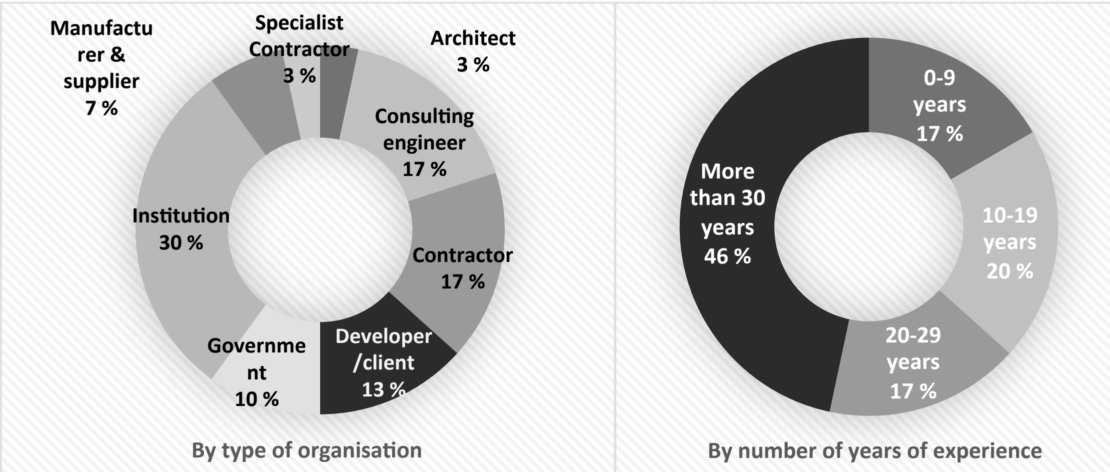

Figure 1 - The demographic information of the interviewees

3.1 Status quo of lean construction in Hong Kong

3.1.1 Understanding of the term “lean construction”

The term “lean construction” was still considered new and uncharted in Hong Kong. More than half of the interviewees (53%) were not familiar with the term. Some of those who knew about the term had not actively adopted the lean construction approach in their practices. Removing those interviewees from institutions (including universities) and consulting engineers (who were assumed to have devoted more efforts in knowledge exploration and exploitation and might have had more exposure to lean), only 12% (2 out of 16) were familiar with the term. It is worth noting that those stakeholder groups who are ignorant of lean are the main actors in the industry. These results suggest that the Hong Kong construction industry is not familiar with the term “lean construction”. The identified perspectives of the concept of lean are summarised below.

Lean construction is from lean production

Over one third interviewees (11/30) commented that lean has its origin in manufacturing such as Toyota automobile production. Applying lean thinking in construction was recognised as a result of cross-industry benchmarking. Hong Kong heavily relies on imported goods while most construction-related manufacturing facilities have been relocated to Mainland China. Therefore, manufacturing-based innovation like lean may not diffuse well in the construction industry. Thus, the limited awareness of lean explains the poor understanding of lean in construction.

Lean construction is to reduce waste in construction projects

It has been widely reported that applying lean in construction is conductive to the reduction of multifaceted waste in construction projects, including time waste, on-site construction waste, labour waste and other forms of wastages. This was a consensus among the interviewees. Some highlighted only certain kinds of waste, while others had a more comprehensive perspective covering all potential non-value-adding matters within the projects. Besides, it was also brought forward that the construction industry faces different wastage issues from manufacturing and has more on-site wastes. Therefore, although the concept of lean construction was recognized to have originated from lean production, the actual implementation of lean in construction operations is different.

Lean construction is to minimise resources in construction projects

As pointed out by some interviewees, an essential feature of lean is to finish the project with fewer resources in terms of budget, schedule, material, labour, land and other required assets. This perspective is in line with the fundamental lean idea that "lean is to maximise the value", but emphasizes only the value of the industry itself not the final customers. In Hong Kong's construction market, the supply, especially housing, has largely failed to keep pace with the demand, which results in a less attention from the industry on the value of end customers, compared to manufacturing or construction market in other competitive places, like Mainland China. These results suggest a missing link in connecting the interests of industry stakeholders and end users in the Hong Kong construction industry.

Lean construction is an integrated approach of life-cycle process management

Lean construction was also viewed as a pillar of project management, with a focus on the integration of processes. Most interviewees considered lean based on the beneficial targets, e.g. reduced waste and minimized resources. Therefore, this perspective offers a slightly different view that concentrates on the pathways to achieve lean. The integration of works at the project level, or more specifically, integrated project delivery (IPD), do put the lean principals into practice. Nevertheless, this perception was only proposed by a few industry experts in the interviews. Indeed, the construction industry is characterised as a competitive and loosely-coupled system (Dubois & Gadde, 2002), while market conditions in Hong Kong are even competitive (HKTDC, 2015). In this respect, the efforts to manage and improve industry performance are more often aimed at individual level rather than enhancing the total project performance, and the power and importance of collaborative integration have often been ignored in the industry.

Lean construction is an overarching theory of project management

Some participants argued that lean construction should be understood as an overarching theory of project management, which covers a range of principles, tools and techniques. They suggested that the lean concept should be promoted to help achieve a systemic understanding of lean for improving the multiple performance aspects of construction projects. It was argued that the promotion of lean can facilitate the application of lean tools and techniques. Based on these arguments, it was acknowledged that the promotion of the concept of "lean construction" should be important and valuable for the Hong Kong construction industry.

3.1.2 Relevant lean construction practices in Hong Kong

Although the term "lean construction" was not much used in the Hong Kong construction industry, relevant lean practices were identified for improving construction performance.

BIM: a promising but not well-applied technique in Hong Kong

There has been a global transition towards smart and virtual construction, and Hong Kong is of no exception. BIM as the most representative digital technology exerts a tremendous fascination on construction companies. All the interviewees agreed that BIM is an innovative and beneficial practice in the construction field. However, whether it is a lean approach is not clear. Some confirmed that BIM is useful and favourable to achieve lean with the powerful visualization and integration, but others argued that it can be a lean tool only if applied wisely and correctly, e.g.

> *"There is no button or promise in BIM to tell us when we do something not lean, so to me it's just a tool and whether it is lean depends on the user. If the user's mind-set is not lean but mean, I don't think BIM alone can create lean construction."*

The use of BIM in Hong Kong, although having been highly promoted, was still considered poor. The BIM use has been largely restricted to the design and planning stages. Some interviewee commented,

> *"Projects labelled with BIM may only exist in names, that they do have BIM consultants come periodically but may have no impact on the real construction works, resulting in a waste of time and resources rather than being lean."*

In this regard, the wide-spread take-up of BIM in Hong Kong would be slow and challengeable.

Low or zero carbon building (L/ZCB): a promotive but uncertain area in Hong Kong

L/ZCB is being promoted in Hong Kong. The first ZCB in Hong Kong has been developed with a collaborative effort across the industry, to showcase the modern energy-saving building technologies and raise the awareness of low carbon living in Hong Kong. However, the possibility of a wide take-up of ZCB in Hong Kong was doubted by some interviewees. One argument was lined in the uncomfortableness a zero carbon environment may offer in such a hot and humid city. Another was concerned with the uncertain feasibility of L/ZCB in the high-rise high-density urban environment of Hong Kong.

L/ZCB was considered not an approach for lean but a scenario for lean application. Whether or not the zero carbon blueprint is a feasible target in Hong Kong, lean techniques were recognized to play a crucial role in reducing carbon footprint and fulfilling building energy saving schemes.

Prefabrication/modular construction: a widely adopted approach in Hong Kong

Prefabrication and modular construction were agreed to be a long-term and well-adopted practice in the Hong Kong construction industry, especially in the public sector. Also, it was seen by almost all the interviewees as an effective lean approach itself and also a useful scenario for embedding lean strategies. Actually, the strength of prefabrication use in Hong Kong was the main supporting argument taken by the interviewees who commented,

> *"Hong Kong does not use the term "lean construction", but moves in the same direction to improve construction performance."*

While the use of precast units and modular construction is not new to the industry, there is still room for improvement and being much leaner, as noted by some interviewees. First, better planning is needed involving the usage prediction of precast units, logistics and on-site arrangement. Second, the extent of prefabrication use can be increased. It was reported that around one third of the concrete elements used for public housing in Hong Kong were prefabricated, but the extent for private buildings in the city was much lower. An increased use of prefabrication was therefore suggested. Third, some interviewees suggested that Hong Kong should bring back its precast yards from the Mainland due to the increasing land and labour costs in the Mainland, and time and carbon emissions in transportation.

Look ahead planning tools: an untapped method in Hong Kong

Unlike the other three themes which were widely known, only a few interviewees were well informed with look ahead planning. As look ahead planning is a specific lean approach, this finding is not surprising. It reveals that although interviewees have argued that the Hong Kong construction industry has applied lean practices without labelling the term, a gap still exists in applying some specific lean techniques. An even poorer awareness was identified of Last Planner System, which is one of the most important and far-reaching construction-specific lean techniques that covers look ahead planning as one step. This finding again suggests that advanced lean construction tools and techniques, with the potential to improve construction productivity, are still largely untapped in Hong Kong.

Other techniques undertaken for improving productivity

While employing a formal lean approach is rare in the Hong Kong construction industry, advanced practices to increase efficiency have been adopted in different firms for a long time. During the interviews, industry experts and researchers mentioned a number of other related techniques and methodologies for improving productivity. Examples of such techniques and methodologies include quality control, critical path method, knowledge sharing platform or knowledge transfer system, collaborative delivery methods, data management, design software, reuse of resources, and 5S.

3.2 Benefits of and challenges for lean construction in Hong Kong

A wide range of achieved or potential benefits were identified, which can be grouped under three themes in alignment with the industry-wide concern of improving productivity and competitiveness, namely, reduced input, increased output and reduced impact (Table 1).

Table 1 Identified benefits of lean construction in Hong Kong

Theme	*Identified benefit*	*Example quote*
Reduced input	• *Reduced cost* • *Saved resources* • *Reduced project schedule* • *Saved labour* • *Saved spaces*	*'Time and cost are the benefits since lean helps the management to reduce the resources and result in faster projects.' [from institution]* *'If use wisely, it can reduce the number of waste and the number of manpower.' [from developer/client]*
Increased output	• *Higher quality construction* • *Better customer satisfaction*	*'We use some machineries and prefabrications, so by using these lean construction tools or techniques or designs, productivity will be enhanced, waste has been reduced, and quality has been improved.' [from institution]*
Reduced impact	• *Reduced construction waste (reduced environmental impact)* • *Improved safety (reduced accidents)*	*'Reducing waste in landfill, which I think is a very big issue in Hong Kong' [from consulting engineer]*

Six themes of the challenges were identified, grouped at the individual, organizational and industrial levels, leading to the uncertainty and dynamics of its future development (Table 2).

Table 2 Identified challenges for lean construction in Hong Kong

Level	*Identified challenge*	*Example quote*
Individual level	• *People's mind-set* • *Reluctance to change*	*'Number one is the concept. People have to have that concept.' [from government]*
Organizational level	• *Lack of demonstration of the identified benefits* • *Lack of support from the leader* • *Lack of time to learn*	*'You need to convince all the big boss to approve of implementing such kind of approaches.' [from supplier]*
Industrial level	• *Lack of knowledge/training in the market* • *Constraints in the regulatory framework*	*'Also the policy, I mean the procurement, is not really conductive to innovation.' [from institution]*

3.3 Future development of lean construction in Hong Kong

The need for improving construction productivity in Hong Kong was made clear in the interviews, but whether or not to achieve that by promoting lean construction was considered to be uncertain. Some believed that lean is today's solution to tackling the identified challenges, such as labour shortage, environmental concerns and low productivity. Some argued for a dynamic future of lean construction development in Hong Kong, i.e. the future development of lean construction will be associated with uncertainties and diversity. The others considered that the adoption of lean construction may still be stagnant in Hong Kong in the near future. Overall, the future development of lean depends on what challenges exist and how such challenges can be solved, as well as the efforts exerted in the promotion among industry stakeholders.

A number of recommendations were identified from the interviews to addressing the identified challenges and promoting lean construction in Hong Kong. The recommendations are:

- There is an urgent need for more education and training on lean construction.
- Successful cases of utilising lean are highly required to promote and demonstrate the benefits of lean construction.
- Government policies and incentives for adopting lean are impactful.
- Collaboration is critical to utilising lean for improving productivity.
- The establishment of a lean construction organisation in Hong Kong should be useful.

Fundamental to all these recommendations is government-industry-institution collaboration.

4. Discussion

The results from the interviews reveal that lean construction as a philosophy is not well understood in the Hong Kong construction industry as a whole. Although some more established approaches and techniques (some being lean related) have been widely utilised for improving productivity, the adoption of modern lean tools and techniques is limited. The promotion of lean therefore has the potential to broaden the horizon of the industry and facilitate the take-up of innovation, boosting up construction productivity.

The identified benefits of lean construction are primarily of reduced cost, resources and time. These results echo the fundamental principle of lean in waste minimization that unnecessary and repetitive wastage in various forms can be eliminated by applying lean (Womack 1996). Higher quality was also identified, but only by a few interviewees, whereas better customer satisfaction was considered as another benefit by even fewer participants. This result is believed to be presumably due to the severe problem of housing shortage in Hong Kong (Yip 2014), which dilutes the customer focus in the marketing strategy of many construction companies. However, lean is a customer-centric philosophy (Howell 1999). This finding suggests that the little awareness of lean construction in Hong Kong might be attributed to the lack of customer value emphasis in the industry. Along with an increasing global concern on sustainability and low carbon, the Hong Kong construction industry is now exerting more efforts on waste management and carbon footprint reduction (Pan and Ning 2014). It was also considered that the approach of lean construction can be promoted in Hong Kong under relevant sustainability schemes with its beneficial effects on the reduction of construction waste and resource consumption.

Despite the many identified benefits, challenges for lean are thorny. The results show that a large proportion of construction practitioners in Hong Kong are quite conservative and accustomed to conventional methods of construction. Owing to insufficient labour in Hong Kong (Wong et al. 2015; Ng and Alan 2015), some seldom fear the unemployment crisis and do not see the necessity of applying lean approaches or other innovative methods. It was recommended that more education and training is required to address this ideology. However, as the lean philosophy is really culture and value-laden, education per se may hardly fulfil that purpose. Besides, as the construction industry is fundamentally profit-driven, to fully demonstrate the benefits of lean by using successful project cases will be very important to encouraging construction organisations to take up lean. In this respect, pilot projects demonstrating how lean can help to improve performance are highly recommended. However, due to the lack of knowledge and expertise in the Hong Kong construction industry, pilot cases may be difficult to be developed. Increasing the industry's knowledge base of lean is vital, but the key issue resides with how to build such a knowledge base in this lean-insulated area. Recommendations on government and institutional support and industry-wide collaboration are only effective when industry stakeholders have achieved a comprehensive understanding of lean. Thus, it might be a more effective way to establish a specific lean construction organisation in Hong Kong, which may draw lessons globally, explore lean knowledge attentively, and create a collaborative platform for lean projects formation.

5. Conclusions

This paper has examined the current practices and explored the future development of lean construction in Hong Kong. The paper concludes that lean construction as a philosophy is not familiar to the Hong Kong construction industry at large. Relevant practices, however, have been conducted. BIM and L/ZCB are emerging areas and have received increasing attention in Hong Kong, but still being partial or immature. Prefabrication is a long existing practice and yields great benefits in the Hong Kong construction industry. Look ahead planning tools which are specific for lean construction are still untapped in Hong Kong.

The paper also concludes that wide-ranging benefits of lean construction are available, markedly reduced input, increased output and reduced impact. Examples identified include minimised project input of money, materials, time, labour, land and other kinds of resources, maximised value of the project output in higher quality and customer satisfaction, and reduced impact of construction in terms of less environment related wastage and accidents. Co-existed with the benefits are a number of challenges at the individual, organisational and industry levels. Typical examples of the identified challenges include people's mind-set and reluctance to change, the lack of demonstration of the benefits, insufficient support from the leaders of construction organisations, and the paucity of knowledge and expertise of lean in the industry.

The paper further concludes that to address the challenges and accelerate the uptake of lean in the Hong Kong construction industry, recommendations are proposed in terms of policy promotion and incentives from the government, knowledge support from institutions and universities, and collaboration across the whole industry. The establishment of a lean construction organisation in Hong Kong should provide an effective way to explore the knowledge and facilitate the future development of lean construction in Hong Kong. Such organisation should aim to disseminate lean related knowledge, develop learning from international practices for the wide industry, provide a collaborative platform for government-industry-academia initiated pilot lean projects, and organise events to support stakeholder communications and engagement.

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Industry Practitioners Quality Perceptions of Built Environment Graduates at Entry Level in the South African Construction Industry

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Abstract

Entry level graduates in the construction industry have been criticised for failing to meet the expectations of the industry. Gaps have been reported between competences possessed and those demanded by industry. These deficiencies impact on the ability of the graduates to acquire employment, maintain the employment, progress in their careers and get a new job when the need arises. Information on the extent of the problem of deficiencies in factors that impact on employability is scanty, if not altogether missing. This research therefore sought to establish the perception of employers in the South African construction industry on the level of preparedness of university graduates entering construction practice. A quantitative survey design approach was used. Data were collected through a structured questionnaire circulated to a purposively selected strata of general contractors registered with the Master Builders Association in the construction industry in South Africa. Descriptive statistics, reliability coefficients and the Kruskal Wallis test were computed and used to identify skills, knowledge, competences and attributes which employers felt were lacking in entry level graduates. The results show that the employers are not satisfied with the quality of graduates from universities in South Africa. Graduates are found to be deficient in knowledge of construction, financial aspects of construction, problem solving, professional practice, oral communications skills, written communication skills, health and safety, self-directed learning, ethics, team working, punctuality, legal and risk aspects of constriction, reading and understanding of documents and professional conduct among others. Attributes found to be deficient include negotiation skills, vision, practicality, entrepreneurial attributes, leadership, forward thinking, critical thinking, problem solving, and communication skills among others. On a positive note, graduates were rated fairly well in the desire to learn and information technology skills. The results suggest that employers are very highly expectant of the skills, knowledge, competences and attributes which graduates should bring with them to construction practice from the university. However, while it is important that graduates possess the relevant skills, knowledge, competences and attributes, the employers perception of the relevant extent to which graduates need to demonstrate these at entry level may be overrated.

Keywords: Built Environment Graduates, South African Construction Industry, Graduate Quality, Construction Education, Industry Perception

1. Introduction

The extent to which graduates entering the construction job market are competent for practice has come under question on several occasions. Several deficiencies have been reported including failure to apply practical construction knowledge, absence of problem solving skills, poor communication skills among many other skills critical for the efficient functioning of construction industry practitioners (Aryakwa et al., 2011; Love and Haynes, 2011). Similar deficiencies have been reported in some sections of the South African construction industry (Smallwood and Emuze, 2011).

These deficiencies impact on the ability of the graduates to acquire employment, maintain the employment, progress in their careers and get a new job when the need arises. The ability to achieve these is described as employability. Information on the extent of the problem of deficiencies in factors that impact on employability is scanty if not altogether missing. For example, the British Council (2014) noted the severe lack of information on employability skills that graduates possess and that while employer perspective surveys are usually sources of such information, even these are often absent in some countries. It is consequently difficult to compare employability information across contexts and through time (Ibid). For Sub-Saharan Africa, the absence of such information creates challenges for evidence based policy. The absence of evidence is in fact a global challenge with only a small number of high-income countries having adequate data on employability (Ibid).

This research therefore sought to establish the perception of employers in the South African construction industry on the level of preparedness of university graduates entering construction practice. Three measures were used to assess the level of graduate preparedness. Firstly, a single item measure, were respondents were asked to rate their extent of agreement, was used. Secondly, respondents were asked to rate several items which comprise of skills, knowledge and competences desired in construction graduates and an aggregate score was computed from the items. Thirdly, respondents were asked to rate attributes which make a good construction graduate. In achieving the objective, the paper first presents a background to the research by reviewing literature on deficiencies and employability of construction graduates generally and in South Africa in particular. The methodology adopted for achieving the objective is then presented and the results analysed and discussed after which conclusions are drawn.

2. Background

There has been widespread concern about the extent to which university graduates are ready for the workplace. The construction industry has equally expressed displeasure at the quality of graduates entering the industry. For example, while analysing the perception of the Ghanaian construction industry on the performance of industry entry level graduates, Ayarkwa et al. (2011) noted that graduates lacked practical building knowledge, problem solving skills, communication skills (inter-personal skills in generally) among several other skills and competences. Love and Haynes (2011) equally noted the absence of all these skills and competences in a survey of construction manager and construction companies in Australia.

Shafie et al. (2014) also reported a gap in the competences of construction graduates in Malaysia.

The competence gaps identified among the construction graduates have an effect on the employability of the graduates. Employability has been defined as gaining employment, maintaining employment and obtaining new employment if required (Lees, 2002 citing Hillage and Pollard, 1998). Harvey (1997, cited in Lees, 2002) defined employability as the propensity of graduates to exhibit attributes that employers expect will be necessary for future effective functioning of their organisation. Employability and employment differ in that employment is only about having a job while employability is possession of the qualities needed to get a job and maintain and progress in the workplace (Lees, 2002; British Council, 2014). Employability therefore depends on the possession of relevant knowledge, skills and attributes and how these are used and presented to potential employers (Lees, 2002).

Copper and Lybrand (1998, cited in Lees, 2002) suggested that employability skills fall in four broad areas of traditional skills, key skills and personal attributes, knowledge of organisations and how they work. Quite similarly, Zou (2008) classified the employability attributes into three categories of attributes, skills and knowledge (ASK) shown in Figure 1. Employers are generally satisfied with the disciplinary knowledge of graduates but perceive significant weaknesses in information technology skills, reliability and transferable skills such as team working and problem solving (British Council, 2014).

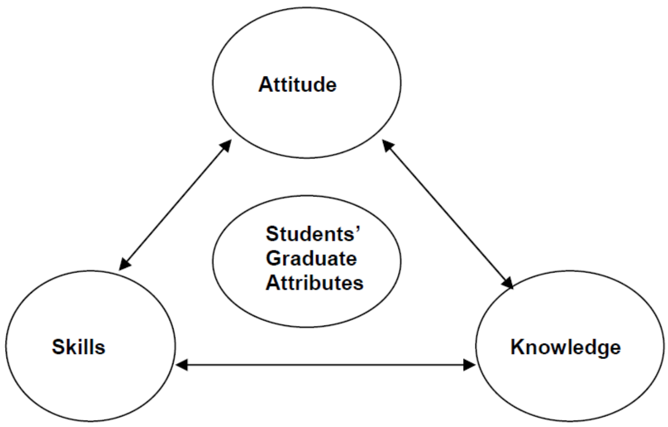

Figure 1: ASK Acronym for Graduate Attributes (Zou, 2008)

The range of skills, competences and knowledge areas identified as important for construction graduates is very large. While assessing employers expectations of the performance of construction graduates, Davies et al. (1999) found that strong interpersonal skills, team players who can also lead a team, information technology, language ability, good commercial awareness, problem solving skills among others were the skills employers expected from graduates. Shafie et al. (2014), while assessing views of employers and expectations of soft skill competences of quantity surveying graduates in Malaysia, identified communication skills, problem solving skills, leadership, team work, professional ethics and moral self-confidence as skills necessary for quantity surveying graduates. Technical skills like measurement, contractual aspects and project management among other competences are also necessary for a well prepared quantity surveying graduate (Ibid). Adams (1998) established that important topics for contractors in developing countries included accounting and financial management, entrepreneurial studies and project management among many others. Ahmed et al. (2014) identified five skills as important for construction management programmes and these are health and safety regulations, interpreting contract documents, listening ability/giving attention to detail, knowledge of building codes and regulations and time management. Acheampong (2013) and Sedighi and Loosemore (2013) also reported deficiencies in construction graduates.

Inadequacies in the relevant skills, knowledge, competences and attributes desirable in construction graduates have been reported in the South African construction industry. For example, while assessing the performance of diplomates and graduates entering the South African construction industry Smallwood and Emuze (2011) noted that the perception of industry is that the performance is almost inadequate in every learning outcome. The biggest gaps were found in project and site management, construction technology and skills, knowledge of the importance of key issues in construction, communication, people skills, leadership, problem solving and team work. In a survey on the difference between perceptions of importance attached to different skills by graduate employers in South Africa and the employers' level of satisfaction with the actual skills of graduates the British Council (2014 citing SAGRA Survey, 2013) also reported deficiencies in graduates employability albeit not specific to the construction industry. Significant deficiencies were reported in all skills surveyed including willingness to learn, team working, problem solving, interpersonal skills, commitment, proactivity, oral communication, flexibility, planning, numeracy, self-awareness, self-promotion, customer orientation, leadership, networking and business acumen. The graduates were perceived to be well prepare in IT/Computer literacy and foreign language.

Producing graduates who are employable requires the delivery of a university academic experience which imparts the relevant knowledge, skills and attributes that define employability in any particular field. Lees (2002) posited that it is likely that employer's criticisms of the weaknesses of graduate recruits are not necessarily resulting from failure in the curriculum but rather a failure in the transfer process. Lees further suggested that chosen teaching methods assist students to develop the employability skills to varying limits. Ahmed (2014) concluded that an integrated curriculum presenting the distinct parts of the construction process synergistically in a project environment is likely to equip graduates with better construction project management skills.

Notwithstanding the literature suggesting that graduates lack employability skills, Davies et al. (1999) concluded that graduates are actually not as poorly-prepared for the workplace as would be suggested by anecdotal evidence from employers. The British Council (2014) also noted that there is rather weak evidence suggesting that there is a gap in skills between the skills which the graduates possess and the ones that are required in the job market.

3. Research Methodology

A self-completing questionnaire was favoured firstly because the survey was preliminary and conducted to validate the extent of the problem of inadequately prepared graduates in the South African construction industry and since a census was not possible due to the very large number of construction industry practitioners. Graziano and Raulin (2007) suggest that it is appropriate to conduct a survey rather than a census unless the population of interest is small.

3.1 Population and Sampling Technique

Practitioners in the South African construction industry including Quantity Surveyors, Construction Managers, Construction Project Managers, Civil Engineers and Architects were targeted for inclusion in the sample. The respondents were drawn from a purposive sample of Master Builders Association (MBA) members in two of their regions. The selected regions were MBA Kwazulu-Natal (KZN) which covers the province of KZN and MBA North which covers Mpumalanga, North West and Limpompo districts of South Africa. While the MBA registers contractors of different specialisation, only contractors registered in the general contractor category who had valid email addresses on record were targeted for inclusion in the sample because they are more likely to employ graduates of Quantity Surveying, Construction Management and Architecture. While a random sample including all the different MBA regional offices would be more appropriate for external validity and therefore generalisation (Bryman and Bell, 2003), a purposive stratified sampling technique was instead favoured because of the exploratory nature of the research and the convenience of dealing with the selected MBA offices. Greenfield (2002) suggests that it is acceptable to use a non-probability sampling technique when access to elements in a population is prohibitive. However, it should be noted that the resulting sample may contain bias and therefore affect external validity and consequently reduce the power of generalisation (Bryman and Bell, 2003).

3.2 Survey Instrument and Data Collection

The questionnaire was designed to investigate the respondents' perception of the level of preparedness of the graduates from traditional South African universities and universities of technology whom the respondents had worked with. The questionnaire also sought to establish the extent to which the university education programme prepared graduates for specific educational attributes. In achieving these objectives, two scales were prepared. The first scale had 31 items with phrases about characteristics of graduates which were measured using a five point Likert scale with 1 = "Strongly Disagree", 2 = "Disagree", 3 = "Neutral", 4 = "Agree" and 5 = "Strongly Agree". The characteristics ranged from personal attributes to knowledge possessed by the graduates. The second scale was used to measure the extent to which university educational experience impart a range of attributes desirable in graduates using 22 attributes.

3.3 Implementation

The survey instrument was circulated to the target sample as an e-mail attachment by the MBA using their register of general contractors with a letter explaining the survey, its use and noting that participation was completely voluntary, results would be aggregated and therefore no individuals would be linked to any specific response and that respondents had the right to accept or refuse participation. While the use of questionnaires attached to e-mails is not yet common place, web-based survey instruments are becoming common place. Denscombe (2006) and Calbring et al. (2007) concluded that there is little evidence of a mode effect linked to web-based questionnaires compared to paper based ones. While a questionnaire attached to an e-mail is different from a web-based survey, they share a number of commonalities including the electronic nature of the interface as opposed to a paper interface and the use of the internet to communicate the responses among others. It can therefore be assumed that the two modes of survey dissemination should share similar advantages and disadvantages and can be concluded also that evidence suggests that the use of e-mail in surveys does not create any errors or biases that can be attributed to the mode of questionnaire administration.

4. Results and Discussion

The respondents were general contractors registered with the MBA KZN and MBA North who employ university graduates in construction. A total of 55 responses were received and analysed.

4.1 Graduate Preparedness

Table 1 indicates that the construction industry practitioners do not feel that construction graduates entering the South African construction industry are adequately prepared for the construction industry practice. The average score of 2.40 from the scale ranging from 1 through to 5 with 1 being strongly disagree, 2 being disagree, 3 being neutral, 4 being agree and 5 being strongly agree that the graduates are well prepared for construction practice indicates that the employers are not satisfied with the work readiness of the graduates upon entering the construction industry practice. This finding is consistent with other findings from South Africa such as from Smallwood and Emuze (2011) and also from the British Council (2014) and Shafie et al. (2014) and Aryakwa et al. (2011).

Table 1: Descriptive Statistics for "Graduates are well-prepared for immediate engagement with the world of work"

	N	Mean	Std. Deviation
Graduates are well-prepared for immediate engagement with the world of work	55	2.400	0.852

Rather than rely on a single item measure of the concept of industry perception of graduate preparedness, the 31 item scale was analysed. Firstly, the 31 items were tested for uni-dimensionality and to find the factors which consistently measure the same underlying construct. Cronbach's alpha was used and a resulting score of 0.908 was achieved after deleting some items so as to achieve the highest possible reliability index shown in Table 2. Cronbach's alpha measures the reliability of a data set which represents the degree to which the observed values measures the 'true' value and is thus error free (Hair et al., 1998). Weimer (1987) defines reliability simply as the probability that the estimate is correct. The computed Cronbach's alpha of 0.908, shown in Table 2 suggests that there is a 90.8% probability that the error of the estimate is at most 0.05.

Table 2: Reliability Statistics

Cronbach's Alpha	N of Items
0.908	18

The descriptive statistics of the 18 selected items measuring the construct of graduate preparedness are shown in Table 3. Based on the mean scores, respondents felt that graduates have a desire to learn as indicated by the mean score which tends towards the agree score of four. The desire to learn new things is contrary to the report by the British Council (2014 citing SAGRA Survey, 2013) on the employability of South African graduates who were reported to be reluctant to learn. However, the reported survey was aggregating results from different disciplines. The findings here therefore suggest that the construction graduates differ in their propensity towards learning new things as compared to the rest of the South African graduate population.

The rest of the items have mean scores tending towards three indicating that the respondents do not feel that graduates perform well in these areas. Other findings have indicated deficiencies in most of these areas. For example, Ayarkwa et al. (2011) found that graduates lack practical building knowledge in the Ghanaian construction industry consistent with the item indicating that graduates have inadequate knowledge of construction. Graduates lack the ability to define and solve problems consistent with the item indicating that graduates are unable to propose solutions to problems and substantiate and justify their position (Ibid).

Table 3: Graduate Preparedness Descriptive Statistics

	N	Mean	Std. Deviation
Graduates demonstrate a desire to learn new things	36	4.056	0.754
Graduates are able to work in a multi-cultural environment	20	3.650	0.813
Graduates are able to work in a team	55	3.455	0.835
Graduates are able to work methodically to finish an assigned task	12	3.417	0.996
Graduates conduct themselves ethically at all times	55	3.382	0.757
Graduates are able to learn on their own/autonomously	20	3.250	0.786
Graduates are knowledgeable about health and safety	12	3.167	0.835
Graduates are technically well-skilled	55	3.164	0.996
Graduates are assertive and willing to accept responsibility on projects	20	3.150	0.875
Graduates understand consequences of their actions	20	3.150	0.988

Graduates are able to communicate effectively in writing	55	3.127	1.139
Graduates are assertive	12	3.083	1.084
Graduates are able to communicate effectively orally	55	3.055	1.061
Graduates are respected by their seniors/those they report to	12	3.000	0.953
Graduates possess an adequate set of skills for professional practice at entry level	20	2.750	1.020
Graduates are able to propose solutions to problems and substantiate and justify their position	55	2.673	1.037
Graduates understand the financial aspects of construction	12	2.667	1.231
Graduates have adequate knowledge of construction	55	2.618	0.972

Table 4: Graduate Preparedness Descriptive Statistics

	N	Mean	Std. Deviation
Average	55	3.157	0.633
Valid N (listwise)	55		

While a total of nine items were not considered in computing the aggregate score of Graduate Preparedness, they were notwithstanding individually compared with the computed Graduated Preparedness score in order to identify any trends among the deleted items. The average scores of each of the deleted items are shown in Table 5. All the deleted items fall below the agree point except for the item “Graduates are able to use technology and software packages” to which the respondents agree that the graduates are well prepared to do. This finding is consistent with Ayarkwa et al. (2011) on construction graduates in Ghana and with the British Council (2014 citing SAGRA Survey, 2013) on South African graduates generally who found that the computer literacy of graduates was acceptable to employers.

Employers feel that graduates are not well prepared in the rest of the items shown in Table 5. Most of the deficiencies are consistent with several other findings.

Table 5: Descriptive Statistics

	N	Mean	Std. Deviation
Graduates are able to use technology and software packages	12	4.083	0.515
Graduates conduct themselves ethically at all times	55	3.381	0.757
Graduates are able to defend themselves in terms of a position they take which might be different	12	3.250	0.754
Graduates always conduct themselves professionally	55	3.182	0.905
Graduates respect authority	12	3.167	1.030
Graduates demonstrate sensitivity to needs of others they interact with at work	20	3.150	0.671
Graduates are able to read and understand documents	12	3.000	0.853
Graduates understand the legal and risk aspects of construction such as standard forms of contract	12	2.667	0.888

Graduates understand punctuality and are punctual themselves	12	2.583	0.669
Valid N (listwise)	12		

4.2 Graduate Attributes

Respondents were asked to state the extent to which they agree that the university experience offered to graduates imparts in them attributes desirable in a graduate. The resulting reliability index for the construct of graduate attributes is shown in Table 6. The attributes of the graduates exhibit a high level of internal consistency.

Table 6: Reliability Statistics

Cronbach's Alpha	N of Items
0.934	22

The descriptive statistics for the scale of graduate attributes are presented in Table 7. The mean scores range from 3.40 to 2.40 indicating a general disagreement that the graduates possess the desired attributes.

Table 7: Graduate Attributes Descriptive Statistics

	N	Mean	Std. Deviation
Employable	46	3.435	1.128
Knowledgeable	46	3.413	0.777
Responsible	45	3.356	1.004
Adaptable	46	3.304	0.963
Socially responsible	46	3.283	0.958
Lifelong learner	46	3.283	0.981
Planner	46	3.239	1.099
Pro-active	46	3.217	1.073
Independent thinker	46	3.217	1.073
Skilled professional	45	3.133	1.057
Culturally aware	45	3.133	0.991
Communicator	46	3.130	1.024
Problem solver	46	3.087	1.029
Critical thinker	46	3.087	1.112
Informed	46	3.087	1.112
Human skills	46	3.044	0.918
Forward thinker	46	3.000	1.174
Leader	45	2.911	0.949
Entrepreneur	46	2.848	0.942
Practical	46	2.848	1.010
Visionary	44	2.773	1.138
Negotiator	46	2.413	0.909
Valid N (listwise)	41		

A new variable measuring the graduate attributes was computed from the mean scores of all the individual items investigated. The resulting descriptive statistics for the aggregate variable are presented in Table 8 which also shows that the respondents are not altogether satisfied with the university graduates entering the construction market.

Table 8: Descriptive Statistics

	N	Mean	Std. Deviation
Graduate Attributes	47	3.117	0.692
Valid N (listwise)	47		

4.3 Associations among the Variables

In order to identify any relationships among the variables, the variables were tested for associations among them. Firstly, a normality test was performed to establish whether to use parametric or non-parametric tests of association. The Kolmogorov-Smirnov statistic is used to test for normality for a sample size exceeding 2000. The Shapiro-Wilk test (shown in Table 9), which tests the null hypothesis that the data are drawn from a normal distribution for a sample size not exceeding 2000, suggests that the "Graduates are Well-prepared for Immediate Engagement" data does not follow a normal distribution while the "Graduate Attributes" data and "Graduate Preparedness" data follow a normal distribution. Since one of the variables does not follow a normally distributed, non-parametric tests were preferred.

Table 9: Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Graduate Preparedness	0.114	47	0.157	0.955	47	0.066
Graduate Attributes	0.069	47	0.200*	0.983	47	0.738
Graduates are well-prepared for immediate engagement with the world of work	0.274	47	0.000	0.865	47	0.000

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

The Kruskal Wallis test, a non-parametric test exploring differences in mean scores, was computed to establish whether the mean scores of the computed "Graduate Preparedness" variable differ significantly with the single variable item which inquired whether "Graduates are well prepared for the immediate engagement with the world of work". The resulting chi-square statistics ($c^2(2, N=55)=13.165$, $p=0.001$) and the Spearman's rho correlation statistics ($r=0.629$, $N=55$, $p=0.000$) suggest that the two variables are associated with a fairly strong positive correlation.

The Kruskal Wallis test statistics were also computed relating the computed variable of "Graduate Preparedness" with the computed variable of "Graduate Attributes" to establish whether the two variables are also associated. The resulting chi-square statistics ($C^2(3, N=47)=20.817$, $p=0.000$, and Spearman's rho correlation statistics ($r=0.764$, $N=47$, $p=0.000$) suggest that the perception of graduate preparedness is strongly associated with the perception of the attributes possessed by the graduates with a very strong correlation coefficient.

The three measures used to assess level of preparedness of construction graduates for construction practice all correlate strongly and significantly with each other at an alpha of 0.001. The significant and strong correlations, which confirm that the three measures are related, confirms that the three measures are all valid measures of the perception of the respondents about the level of preparedness of the graduates and also validate the internal consistency of the instrument. The internal consistency of the instrument is also validated by the high Cronbach's alpha of the three measure shown in Table 10.

Table 10: Reliability Statistics

Cronbach's Alpha	N of Items
0.802	3

5. Conclusions

Employers in the South African construction industry feel that construction graduates entering the construction practice are inadequately prepared by the university education experience they are offered consistent with other findings from the South African construction industry and also from other countries surveyed. All three variables used to assess the perception of employers of the level of preparedness for construction graduates entering the South African construction industry consistently demonstrate that employers feel that university graduates are not adequately prepared for practice.

Skills, knowledge and competences perceived to be lacking in the graduates include knowledge of construction, financial aspects of construction, problem solving, professional practice, oral communications skills, written communication skills, health and safety, self-directed learning, ethics, team work, punctuality, legal and risk aspects of construction, reading and understanding of documents and professional conduct among others. Attributes found to be deficient include negotiation, vision, practicality, entrepreneurial attributes, leadership skills, forward thinking, critical thinking, problem solving, and communication among others. On a positive note, graduates were rated fairly well in the desire to learn and IT skills.

While the scenario regarding the extent to which graduates of construction programmes from South African universities based on the findings of this research looks rather bleak, it is worth noting that the research is based on the perception of employers about the graduates. The results therefore also point to a very highly expectant set of employers who may not adequately appreciate that university programmes need to provide a firm theoretical grounding for the graduates to develop into a career of choice within the industry. Therefore, while it is important that graduates possess the relevant skills, knowledge, competences and attributes, the employers perception of the relevant extent to which graduates need to demonstrate these at entry level may be overrated. Also worth noting is that other research has established that there is in fact weak evidence suggesting that there are gaps between competences possessed by graduates and those required in the job market.

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Factors Affecting Condition-Based Maintenance in Petroleum Pipelines Operation in Nigeria Oil and Gas Sector

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Abstract

This research paper investigates how maintenance performance measurement is utilised to measure Condition-Based Maintenance (CBM) in petroleum pipelines (PPs) in the Oil and Gas (O&G) industry. The paper is written using the findings of an extant literature review. The paper reviews various concepts of performance measurement (PM) and issues in relation to CBM in the O&G Industry. The paper discusses in-depth, the use of performance measurement in Condition-Based Maintenance in the Oil and Gas industry. The findings highlight the importance of performance measurement in CBM as a system that ameliorates pipelines maintenance and synergises O&G workforce to achieve a well-defined work procedures in CBM. This paper identifies performance measurement as a possible sub-system of strategic maintenance in petroleum pipelines (PPs). Performance measurement is in fact a return to the fundamental concept of CBM, and is a means of ensuring that the lifecycle of PPs is well managed and maintained. Based on the findings of this study, the paper develops a conceptual model for measurement of efficiency of actions in condition-based maintenance in pipelines. In order to improve workers performance, motivation, good information management, collaboration, and

Keywords: Condition-Based Maintenance (CBM); Performance Measurement (PM); Oil and Gas (O&G); Petroleum Pipelines (PPs), Strategy

1. Introduction

1.1 Condition-based maintenance in pipelines

The nature of maintenance work in the Oil and Gas (O&G) sector has change in recent decade from strictly preventive or corrective maintenance to condition-based maintenance as a result of huge increase in the number of petroleum pipelines (PPs) to be maintained. The term condition-based is used to discuss and interpret problem, situation and circumstances causing a particular or whole section of PP disorder, and assist management to decide the maintenance action to be performed. Facility maintenance in the O&G sector require improvement in the strategic and operational function. Because Oil and Gas (O&G) is considered as the backbone of the global economy, which involve a rigorous operation such as: exploration/extraction, refinement, transportation, and marketing of the petroleum products often by petroleum pipelines (PPs) (Duncan and Wang, 2014). There are several ways in which O&G can be transported, e.g. ocean moving vessels, tankers, rail transportation and pipelines. Yet, PPs remain the easiest, economical, resilient and robust way of transporting O&G in the petroleum industry (Ai-Khalill, 2005; Anifowose, 2012; Duncan and Wang, 2014; Shafiqur and Al-Hadhrami, 2014). PPs profitability cannot be overemphasised as it tends to be an indispensable component in the O&G industry (Ossai 2012; Bandinelli and Gamberi 2011). PPs can be defined as an integrated tube used to transport O&G liquid to demand point.

Despite the profitability or value in the use of PPs, PPs has not been without flaws. Equally, industries using pipe either as a storage facility or as a source of transporting O&G may face different challenges (Enyiche2 2011; Qian et al., 2011; Anifowose et al. 2012). Many of the challenges often occur as a result of improper maintenance, vandalism, corrosion or rupture and ageing. For example, ageing pipelines, i.e. those pipelines near the end of their useful remaining life or exceeding their original design life (Anifowose et al. 2012; Ossai, 2012). There is an increasing requirement around the world to defer their replacement or extend their remnant life (Clausard, 2006; Okamoto et al., 1999). Problem within this ageing PPs if unnoticed, can lead to catastrophic consequences at the time of deterioration (Bogue, 2013; Barabadi, 2014). Some example of major pipelines incidences in Nigeria alone include: such as, the 1998 Jesse pipeline explosion in Nigeria that almost claimed an entire village, burning to death over 250 people; the Ijegun 2008 PPs explosion in Nigeria damage more than 15 homes and 20 vehicles as construction workers incidentally broke the underground PPs; and, the 11th July 2015 PPs explosion in Bayelsa State Nigeria killing 12 workers, the 27th March 2016 O&G pipelines explosion killing operators (Aroh et al., 2010, The Guardian, 2015, Punchng.com, 2016). Consider: “it is such examples as the above that necessitate an improvement in the level of PPs”

1.2 Maintenance concepts and Strategies

Certainly, improved maintenance concepts and strategies could guarantee O&G pipelines robustness and reliability. Literature indicates that, improved maintenance has the capability to influence resources or maintenance operation in several monitoring levels (Alabdulkarim et al. 2014; Prajapati et al., 2012). On the other hand, inadequate maintenance plan may trigger system deterioration and cause disaster (Aboelmaged, 2015). In contrast, Dey et al. (2004) argue that most pipeline workers ensure that during the installation PPs, safety provisions are created to provide a theoretical minimum failure rate for the life of the pipeline. Kadafa (2012) argues that, despite the safety provision in place, several failures have been inevitable in PPs operation. Hence, strategic maintenance is important in the improvement of PPs maintenance. It can reasonably be argues, therefore that issues of strategic maintenance cannot be overlooked in the process of pipelines maintenance. Also, the role planning and adequate implementation play in the achievement of pipelines maintenance projects or the methods by which they are obtained is well documented in the "literature review". See (Oliver Schwarz 2005; Paranjape et al. 2006; Greenough and Grubic 2010; Prajapati et al. 2012; Platfoot 2014; Goyal and Pabla 2015). Beside the practice of CBM, there is a need to understand other maintenance function and what constitute pipelines maintenance and how to perform the assigned task successfully and this is discussed in the next section

2. Maintenance Types and Practice

The oil and gas (O&G) industry often practice several pipelines maintenance types in order to prevent pipelines from failure (Achebe et al., 2012; Agbakwuru, 2011; Gomes et al., 2013). Most of the maintenance practice include: preventive maintenance, corrective maintenance, turn around maintenance, reliability centre-maintenance, total productive maintenance, risk-based maintenance, shut-down maintenance, opportunistic maintenance, computerised maintenance management system, total quality maintenance and condition-based maintenance (Bousdekis et al. 2015; Fraser et al. 2015). However, preventive and corrective maintenance describes a wide range of activities designed and performed in order to improve the overall reliability and availability of a system (Moghaddam and Usher, 2010). Regardless of the specific pipelines system, preventive and corrective maintenance activities can be categorised in one of two ways, which is either repair or replacement (Öhman et al., 2015; Platfoot, 2014; Van Horenbeek and Pintelon, 2014). Preventive maintenance has been derived from a level of repair analysis to determine the maintenance allocation for a given system or subsystem (Prajapati et al., 2012). Corrective maintenance if often referred to as run to failure practice or maintenance task performed after failure has occurred or in the process of occurring. Corrective maintenance constitutes repair, refurbishment or replacement of sectional breakdown, or other remedial work to restore pipelines system to its original state as it was in new condition (Prajapati et al., 2012; Reza Golmakani and Fattahipour, 2011).

Equally, opportunistic maintenance, RCM, risk-based maintenance and other maintenance types are often seen as extra maintenance activities performed to enhance the overall performance O&G facility. Their activities consist of inspection, cleaning, lubrication, adjustment, alignment, and replacement of O&G pipelines facility that is wear-out or faulty. However, aforementioned maintenance types are usually done to elongate PPs lifespan or retain their serviceability (Al-Khalil et al. 2005; Liu et al. 2010; Sahraoui et al. 2013; Duncan & Wang 2014). Despite the numerous maintenance types, corrosion, sabotage, improper maintenance still persists. The prevailing issues in the Nigerian context are corrosion attack, improper maintenance and sabotage. Corrosion fatigue consists of cracking of material due to changing cycle, stress or as a result of corrosive environment. Improper maintenance issues may occur as a result of poor management, sociotechnical inordinate behaviour, social factors, and lack of motivation, poor communication within upstream and downstream section, lack of technical knowhow and the use of low quality materials. Sabotage involves third party meddling and obliteration of pipelines reliability (Bagkavos, 2008). However, this study assumed that sabotage and obliteration caused by third party may prompt corrosion outbreak and other unwanted issues in pipelines maintenance. These issues often interrupt the firm approach in the practice of preventive or corrective PPs maintenance activities in the Nigeria O&G sector.

Prajapati et al., (2012) argue that, adopting strictly preventative or corrective maintenance approach leads to inefficiencies in the use of manpower, subsequently causing downtime of PPs systems, economic loss and other wastefulness. At the heart of any pipeline integrity management system (PIMS) is having an understanding of the likely condition of a pipeline and confidence in the data generated from any inspection programme conducted to validate this understanding (Clausard, 2006; Fink et al., 2004; Okamoto et al., 1999). Based on the data generated on PPs inspection programmes, an Operator can go forward and make decisions related to the current and future integrity of a pipeline, remaining life assessment with the help of condition-based maintenance philosophical viewpoint to appropriate corrective and preventive maintenance action (CAPA) and to monitor activities that will improve pipelines performance.

CMB can be defined as an instrument that managers use to underpin efficiency and effectiveness of action in pipelines maintenance by helping managers to deal with issues related to functional safety, environmental and operational failure modes. CBM helps managers to plan and formulate a workable strategy through historical and current data (Al-Najjar, 2012; Fraser, 2014; Prajapati et al., 2012). In this instance, CBM seeks to discover the root cause of the failure and performs the detailed analysis of the reliability of the system components and the system as a whole (Al-Najjar, 2012; Bousdekis et al., 2015; Prajapati et al., 2012). Bousdekis et al. (2015) argue that, CBM can only detect emerging failures before their occurrence through diagnostic and prognostic techniques. CBM uses condition monitoring techniques to assess, control and investigate pipelines whether a problem exists and to determine the life cycle usefulness before failure occurs (Garg and Deshmukh, 2006; Prajapati et al., 2012).

Furthermore, Prajapati et al. (2012) state that, CBM enables the automotive, aerospace, military, and other industries to understand values of maintenance network bandwidth, data collection and retrieval, data analysis, and decision support capabilities for large data sets of time series data. In contrast, CBM forms the basis of all types of maintenance (Zhou et al., 2015). For instance, CBM function can be done either as in preventive/corrective maintenance, or condition monitoring. Consequently, the real uptake and implementation of CBM often improve the maintenance concept in the O&G industry. As a result, a comprehensive maintenance definition should embrace the CBM philosophical view. Taking this into consideration, maintenance is defined as a process of assessing assets condition and to know the current state and improve its condition using CBM elements to determine the necessary maintenance either about preventive, corrective, reliability centre maintenance or other maintenance actions needed to underpin or improve PPs condition monitoring in order to possess the assets.

Moreover, the effectiveness of CBM requires a comprehensive maintenance management system. Being that the enterprise-wide information management and business planning has become a norm rather than an exception (Garg and Deshmukh, 2006). Combined with a review of the pipelines maintenance management activities, e.g. review of internal and external issues in pipelines maintenance and management, CBM monitoring correlation with the inspection findings, will enable the integrity management strategy to proactively diagnose the likely causes of corrosion and discuss other related issues. On this basis, individual maintenance performance can be improved using lesson learned in order to obviate unwanted event that may decline PPs performance. Based on the determined corrosion or sabotage rates, accurate monitoring and prediction of future repair together with mitigation requirement can be determined via CBM historical data.

The search for materials and identification of issues using extant literature involved a rigorous process of selecting materials from databases such as: Emerald Insight, Google scholars, Science direct and Scopus. Performing combination of key words like performance measurement approach in pipelines integrity management, performance measures in condition-based maintenance in pipelines, maintenance performance measurement in the O&G industry result to many qualitative and quantitative materials. Applying the grounded theory approach, the materials gathered were narrowed down and focus on qualitative materials pertinent to this study. The Glaser and Strauss 1960s approach enable this study to perform constant comparison of different pipelines issues and incidences, to assess individual perceptions about pipelines maintenance, the role performance measurement plays in the maintenance of PPs. Also, the grounded theory approaches enable a clear identification of the key issue affecting CBM in pipelines. The process of identifying the discrepancies, contradictions, gaps in the CBM in pipelines activities and to formulate the emerging consensus that will improve the maintenance process also involve another rigorous process.

The practical relevance about grounded theory is that researchers do not know the outcome, until it emerges by investigating issues. However, the procedures of assessing worst-case hypothetical conditions and for the analysis of the consequence of any given pipelines failure are beyond the scope of this paper. Besides, pipelines failure and maintenance hypothetical characteristics and consequences vary with each pipelines sizes, also the environment vary were pipelines operation are done on daily basis (Anifowose et al., 2012; Okoh and Haugen, 2014; Shukla and Karki, 2016; Sylvestor et al., 2004). Pipelines failure and related issues tends to be a global problem. Though, several rules and regulation are in place to ensure adequate performance of CBM in pipelines. But, in the current time, the full benefits of CBM in pipelines maintenance can be realised through performance measurement plan do check act (PDCA) model, a techniques that enable managers to assess the effectiveness and efficiency of action in facility maintenance engineering/management. Undoubtedly, performance measurement approaches has enable some industries to outperform their equals in business. The next section will be discussing the intrinsic values about performance measurement

3. Performance measurements

There is a need for manager to analyse CBM activities in PPs and how to utilise the full benefits of CBM in PPs maintenance. Equally, literature review justified the need to perform measurement with an adages “you can’t manage what you can’t measure and what get measured gets done” these elements underpin PPs maintenance managers to safeguard working environment. The change in the operating context cause maintenance managers to concentrate on effectiveness of actions within PPs routes. Performance indicators are needed to give maintenance managers in charge of operation a qualitative information on the extent to which these goals are reached and the next actions to take to improve CBM operations. Performance indicators are a means to achieve maintenance control, so that maintenance costs can be reduced, productivity can increase, safety of the process can be achieved and environmental regulations can be fulfilled (Arts et al., 1998). For instance, in the UK, Liyanage and Egbu, (2008); Njuangang et al., (2015) develop some key performance measurement improvement concept to underpin the improvement of hospital facility maintenance management. Similarly, Parida et al., (2015) exemplify the importance of performance measurement across industries, whit emphasis on performance indicators, leading and lagging indicators, and the identification of “performance drivers and killers”, in maintenance operation. Moreover, performance measurement often involves a comprehensive approach linking strategy to action, motivating employees, supporting budget and controlling resources in order to overcome the strictly approach to the traditional practice of the engineering maintenance management in the industries. In this aspect, performance measurement allows benchmarking process to be performed in order to eliminate the out-dated management style, which does not support the current technological improvement in pipelines maintenance (Al-Najjar and Kans, 2006; Kutucuoglu et al., 2001; Lee et al., 2013; Simões et al., 2011). Another area to be addressed through performance measurement is the sociotechnical inordinate behaviour, a factor that often limit the effectiveness of action in pipelines maintenance. In fact, social issue can significantly influence maintenance performance. For example, pipelines conflicts between department and poor collaboration might prevent operators from passing on important information.

Inadequate information often result to neglect or abandonment of PPs maintenance in long-distance location. Most time, it lead to corrosion attack, leakages and environmental depredation. Also, causing counter accusation, political oversight and communities meddling due to environmental depredation. Though, literature indicates that issues like this can only be overcome through performance measurement. Hajjari, (2012) explain that, at the organisational context, maintenance contains several aspects that can affect the maintenance activities and cause undesirable adverse effect in maintenance processes. Therefore, performance measurement is required to refine the maintenance culture and to lead in the process of planning and monitoring maintenance. Performance measurement approach can be used to determine assigned job and monitor the efficiency and effectiveness, improve communication system, improve decision-making process and assess workers behaviour. Even in the decommissioning process when a particular route or section is no longer viable or required performance measurement can support CBM activities to achieve success in the operation.

Performance measurement practice can be plausible when management utilised the key performance indicators to assign task and monitor individual performance. Individual performance can also be monitored through a defined work order model as shown in table 1. The essence of work order is to guide operators about the maintenance activities/action and together with the role individual must perform in order to achieve target.

Table 1: CBM detailed work-order guide (source: (Platfoot, 2014)

PM function	Condition based maintenance pipeline work-order Mandatory	Documentation guide
Elements in work order	Date work requested, KPI to prioritise work; status of work, open, approved, work in progress, completed or cancelled, area to be worked on/location of work, specification of work to be done	Date work closed; date work scheduled commence, actually date work commenced, amount of resource/crew, summary of maintenance job plan
Work description or specifying the type of work	Work order type; priority of work order (e.g. emergency, periodic inspection, constant monitoring etc.).	Maintenance activity type; priority of original request Total
Cost of work	Actual amount/Prorated	Total cost (estimated and actual), labour hours (estimated and actual), materials and other miscellaneous costs/ coherent cost code
Performance evaluation	Monitor performance	Recommend

Applying the performance indicators or maintenance performance indicators according to (Parida et al., 2015), the work order can be fully defined and utilised. The issues of vagueness and inadequacy about measures can be obviated through this method.
Given a clear focus in the measurement of efficiency and effectiveness of pipelines maintenance within the upstream and downstream pipelines distribution network. In this aspect, performance measurement indicators enable managers to compare the actual operating conditions with a specific set of reference conditions and to ensure managers achieve target in the following ways:

- Establish solid technical justification for using the set objective and articulate the reason for not using other objective for assessment techniques to assess the pipeline section (Nidd et al., 2007).
- Establish active data management system to ensure security of data that will allows integration and manipulation for further improvement (DeWolf, 2003)
- Ensure that all data provided are sufficient for long-term planning and helping to achieve acceptable statistical conclusions (Nidd et al., 2007)
- Monitor the technical function to ensure that the collected data and results are accurate within acceptable industry tolerances.

- Ensures that all personnel involve are fit-to-work, trained and qualified and all certifications are documented, perhaps organise periodic medical check-up for workers.
- Ensures that CBM activities are achieved in a timely manner.

Literature indicates that, performance measurement and CBM support decision-making. Amalgamating the two elements will holistically address facility maintenance issues without discrepancy and helping to incorporate and regulate the relevant maintenance elements into the organisational management cycle. In the aspect, Armstrong (2006) exemplifies five basic performance measurement elements, which includes: agreement (i.e. incorporating operators to synergy in order to achieve organisational goals), measurement of efficiency and effectiveness, quality data collection and feedback, positive reinforcement and dialogue performance output. In this aspect, performance measurement can be fully utilised in CBM in pipelines as shown in figure 2.

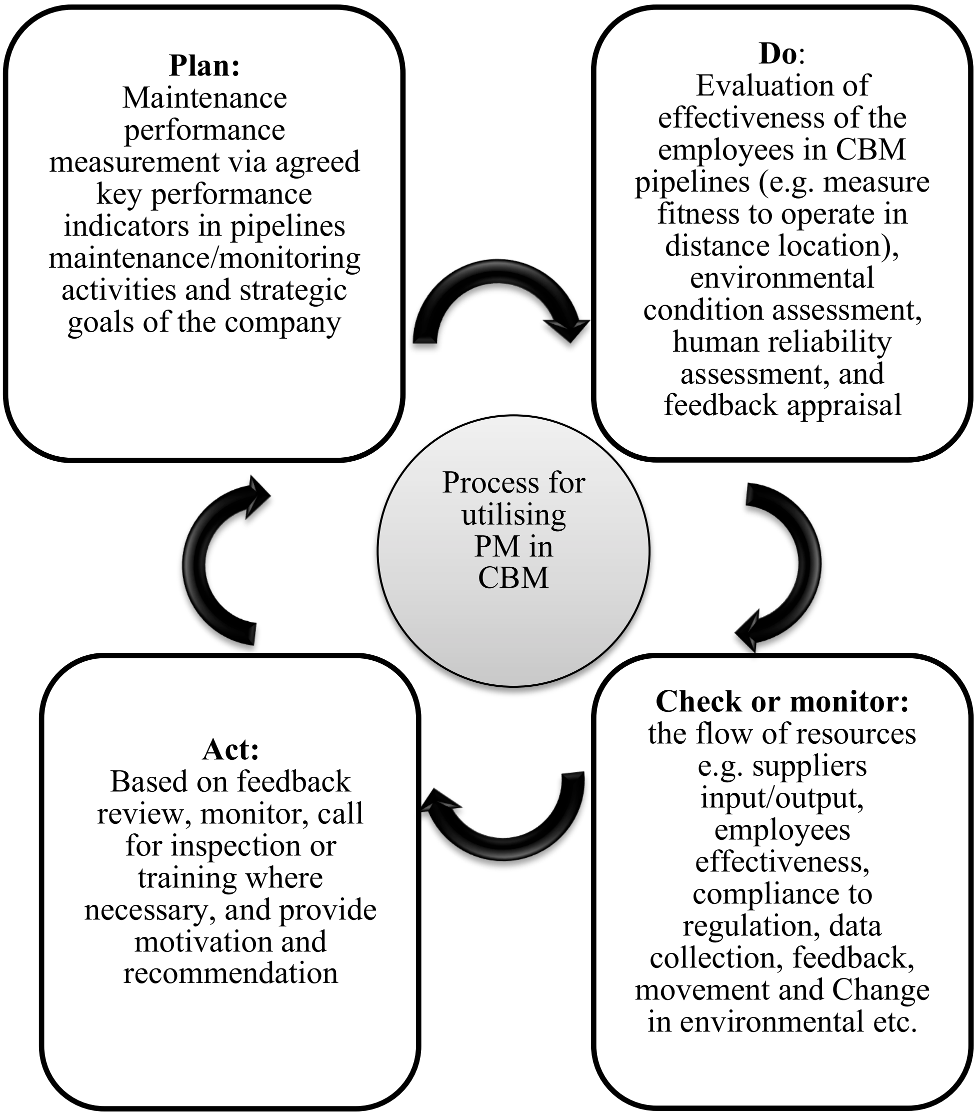

Figure 1: Condition-Based Maintenance Plan-Do-Check-Act model

In addition to the work-order as discussed in Table 1 above, measurement of performance can be realised through the PDCA model. The PDCA facilitate the work-order procedure, by help operators to understand their role in the pipelines integrity management programme before the performance of that role can be fairly assessed (Huprich, 2008; Kutucuoglu et al., 2001b; Parida and Chattopadhyay, 2007; Simões et al., 2011). Though, individual or maintenance team goals should to be defined before the commencement of work, to enable the field supervisor aligns the operators' objectives with the organisational goals (Huprich, 2008).

In pipelines maintenance, operators' role cannot be overemphasised, because they provide continuous assessment and feedback for the improvement of goals and to determine individual performance in PPs maintenance. In this form, PDCA can positivity influence measure, to determine safety compliance and ensuring adequate maintenance within the upstream and downstream sector is achieved. The PDCA justify the link between CBM and performance measurement as a single entity, their separation may result to catastrophic effect in pipelines maintenance. The union are power for decision-making in pipelines maintenance. Also in terms of monitoring, repair, replacement and improvement and decommissioning of pipelines system. Based on the different categories of issues discussed, the study can conclude that the identified issues can be used in extracting new performance indicators for condition-based maintenance in pipelines (i.e. extra indicators has been added to extant performance measurement indicators that is currently in operation for driving the performance of pipelines maintenance plan). Further research may consider defining contextual issues using real case scenarios for deriving performance measurement in pipelines maintenance project.

4. Conclusion

This paper exemplifies the importance of performance measurement and how to utilised performance measurement in condition-based maintenance in pipelines in various way. For instance, the application of plan-do-check-act (PDCA) and work-Oder in complex pipelines maintenance job and to monitor issues opposing pipelines performance. Another reason for this research is to establish plausible performance measurement method that will underpinning pipelines integrity management and justify values created by means of utilising performance measurement indicators for the improvement of facility maintenance and environmental protection at workplace.

The study also demonstrates the influence of using grounded theory to critically examine issues that requires improvement. It is clear that the combination of CBM and performance measurement is beneficiary and valuable, it rewards pipelines deficiency positively they merge corrective, preventive, and condition monitoring types of maintenance to address pipelines issues in a logical manner. As the research develops, the details of the model will be expended, and further study will be exploring issues relating to maintenance model being implemented that is designed for use within pipelines maintenance management involving life project scenario.

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Research Roadmap for Safety and Health on Construction Sites

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Abstract

The proceedings paper details the initial roadmap process, data collected, and summarizes steps forward for the Working Commission on Safety and Health in Construction (W099) to produce a complete research roadmap. A preliminary consultation report was developed in 2013. Data collection included an initial web-based survey sent to W099 members and registered W099 2015 conference attendees. The survey was completed in August before the September conference. At the conference special plenary sessions were organised to define and shape the research roadmap and goals. Seven brainstorming sessions were held around themes important to the CIB W099 and building off the survey results. The sessions were audio recorded, transcribed, and summarised. Future directions for finalisation of the roadmap are discussed with the goal of validating the roadmap during a workshop at the 2016 Word Building Congress.

Keywords: Roadmap, research, safety, health, construction.

1. Introduction

Occupational health and safety (OHS) is the science of the anticipation, recognition, evaluation and control of hazards arising in or from the workplace that could impair the health and well-being of workers. (Finneran and Gibb, 2013). Occupational health and safety is both an interdisciplinary and a multidisciplinary science clearly connected to and built on many other disciplines (Aven, 2014). Aven further contends safety science is also a discipline in itself. A 2014 Special Issue of the journal *Safety Science* sought to define, better understand, and operatinalise safety science. Various leading safety researchers provided input. Hollnagel (2014, pg. 24) for example, writes that "the object of safety science is accordingly how people are able to provide the required performance under expected and unexpected conditions alike." Hale (2014, pg. 67), discussing research in safety science comments that "Practitioners and their financial masters are too willing to follow safety intervention fashions and to accept anecdotal evidence that something will work, rather than asking for that more rigorous levels of proof to raise the probability that their investment is worthwhile."

Globally, construction is one of the most hazardous industry sectors with many thousands of workers being killed and seriously injured each year. While some regions have been making progress over the years there is still a long way to go to reach the vision of an industry where people return home at the end of a shift healthier than when they arrived (Finneran and Gibb, 2013).

There exists a great need to frame a research and practice oriented path forward in construction safety and health. CIB W099, the Working Commission on Safety and Health in Construction, is taking up this challenge alongside many CIB Working Commissions with the goal of positively affecting the global construction community. This proceeding paper is not a research roadmap. Rather, this is the summary of the initial discussions about the development of the CIB W099 research roadmap. Therefore, the paper does not contain a critical analysis of all the data.

2. Background

The goal of CIB W099 is to complete a research roadmap to better engage with and impact the global construction industry. The Roadmap has four specific aims:

1. To identify research which is important in construction safety and health.

2. To identify research gaps in the field of construction safety and health.

3. To suggest research priorities in the field of construction safety and health.

4. To identify ways that CIB W099 can contribute to these research priorities in the next 10 years.

3. Methodology

The W099 research roadmap is currently in process and is building off a preliminary consultation report (Finneran and Gibb, 2013). This proceeding paper reports on the data collected through December 2015 and specifically two sources of data. The first was an on-line survey taken in August before the most recent W099 conference and meeting in Belfast. The survey was sent to W099 members and registrants of the September Belfast W099 conference. They were asked to forward the survey on to colleagues and encouraged specifically to send to colleagues in industry and governmental agencies. The second data source wee the brainstorming sessions held at the Belfast W099 conference which followed up on the on-line survey summaries.

On-line Survey

In the survey we asked almost primarily opened ended questions to allow respondents to write freely and express their ideas around the questions. The questions were generally around three main themes. In addition we asked demographic information and also listed construction safety and health publications to determine their importance, via a Likert scale, to respondents' research.

Firstly, we assessed research and practice priorities in the respondent's country by asking the following two open-ended questions.

> What are the top three construction health and safety practice issues in your country?
>
> What are the top three construction health and safety research priorities in your country?

Secondly, we followed up on the three main findings from the Finneran and Gibb (2013) consultation report. We restated those three main findings and asked the respondent to list up to three additional topics deserving of research in each area. The language is below.

The 2013 CIB W099 Consultation Report surveyed industrialists and researchers from leading regions and identified three areas that were seen as key to moving from the current situation to the ideal OSH state.

The first was: "More responsible client behaviour – to adopt procurement approaches that support the integration of health and safety into project decision making and drive this so that it happens.

The second was “Health and safety becomes a professional responsibility of everyone in the industry. At the moment it is perceived to be the health and safety professional’s job. Health and safety professionals are generally not architects, engineers etc. They don’t make decisions. They act as advisors. The decision makers need to step up and take professional responsibility.”

The third was "Closer and more effective links between industry and academia. There is a need for a more evidence-based approach to construction health and safety. Companies need to know with certainty what works and what doesn’t. Managers are easily persuaded when there is evidence but skeptical when there is none."

We asked three questions, one for each main finding. For example, for main finding #3 we asked the question in this manner: What topics do you feel are the most deserving of priority research in the area of “Closer and more effective links between industry and academia”? Please list up to 3 topics.

For each question in this section we reiterated the definition of research priority. “Priority research” is defined as an area of research that requires priority funding and scientific interest in order to advance the construction safety and health in the coming years. When listing your topics, please be as specific and explicit as possible.

Thirdly, we asked open ended questions assessing what the future of CIB might look like. Those questions were as follows.

> What other Construction Safety and Health topics are important and should be included in future analysis and discussions in preparation of a Research Roadmap? Include as many as you like. Include Health and Safety topics (ergonomics, etc.), type of construction where there might be a need (housing, etc), or general construction industry issues (small and micro organizations, etc).
>
> What should CIB W099 be doing to better support your research and practice in construction safety and health?

Brainstorming Sessions at W099 Belfast Conference

The results of the survey were presented at the W099 conference in Belfast in September 2015 and discussed with the attendees. Attendees were broken into 6 brainstorming group with leaders assigned. Groups were assigned one of the following questions.

1. How well does education, training, and professional development prepare design professionals in the provision of inherently safe(r) designs?
2. How can the research into safety and health deliver improvements in workers conditions and their quality of life?
3. What progress towards achieving vision zero is likely to be brought about from current OHS research across all jurisdictions?

4. What are the opportunities for creativity and innovation in the delivery of safe design?
5. How can gender equality, cultural diversity and inclusivity be promoted in the design of safe(r) workplaces?
6. Are the ethical and moral challenges understood around the globe and addressed appropriately in OSH research projects?

In addition all Groups discuss these two questions:

1. Future scenario: The roadmap will unfold a vision on where we want to be in the future, e.g. in ten years' time including the stakeholders' opinions on required/envisaged future systems, processes and technologies, preferred future practices and skills etc.
2. Development strategy: What is needed in terms of knowledge, information, tools, concepts and applications to enable the respective systems, processes and technologies to develop from where we are today to where we want to be in the future?

Groups were allotted 50 minutes to discuss these questions. All discussions were audio recorded and transcribed into MS Word for analysis. Each group leader gave a report on the closing day of the conference.

4. Results and Discussion

On-line Survey

An overwhelming majority of the 48 survey respondents (39) came from academia. See Table 1. We were hoping to receive more responses from industry and government agencies. This limits the results of the survey. However, as will be noted later, stronger ties with industry and governmental agencies are important goals for W099. Table 2 shows there was a decent spread of respondents from across continents; the majority were from Europe. Noticeably absent for the survey were South American respondents. W099 has historically not had good attendance at its conferences and meetings from South America. Finneran and Gibb (2013) analysed authorship from past CIB W099 conferences and noted South America was very much underrepresented at the conferences. However, where the conference was held in Brazil in 2003 the majority of papers were from that region. One action being discussed within W099 leadership is targeting South America for a regional construction safety and health workshop or conference by 2020.

Table 1: Survey Respondents – Employment

	N	***%***
Academic	*39*	*81.2*
Industry	*5*	*10.4*
Government	*2*	*4.2*
NGO	*2*	*4.2*
Total	*48*	*100*

Table 2: Survey Respondents – Continent

	N	***%***
Europe	*21*	*43.8*
Africa	*10*	*20.8*
Australia	*5*	*10.4*
Asia	*5*	*10.4*
North America	*5*	*10.4*
Missing	*2*	*4.2*
Total	*48*	*100*

In the initial part of the survey we asked about respondent's top three research and practices in their country. Tables 3 and 4 summarize the top findings. Safe design emerged as one of the top priorities in both questions indicating the need to better understand this concept which many believe has promise to positively affect construction worker safety and health. Work at height was the top priority for practice whereas reducing falls was important for research but not listed very high. This might indicate a gap in research to practice for reducing falls from working at height. Health related issues and small and medium organizations showed up in both lists indicating possible areas to explore.

Table 3: What are the top three construction health and safety practice issues in your country?

Practice Issues	***Number of times mentioned***
Work at height	*11*
Safe Design	*9*
Client awareness / role	*7*
Health related hazards	*6*
Small and micro organizations	*6*
Safety culture	*5*
Motor Vehicle accidents	*4*
Language / literacy / foreign workforce	*4*

Table 4: What are the top three construction health and safety research priorities in your country?

Research Issues	***Number of times mentioned***
Safe Design	*11*
Cost benefit Analysis / business case for safety	*6*
Skills, competency, and training of workforce	*5*
Leadership / culture	*5*
Occupational health	*4*
More effective regulation	*4*
Better statistics, more rigorous research	*4*
Small and micro organizations	*3*
BIM potential	*3*
Supply chain	*3*
Reducing falls	*3*
Musculoskeletal disorders / human factors	*3*

In the second part of the survey we followed up on the three main findings from the Finneran and Gibb consultation report. The first question had to do with "more responsible client behaviour". Many comments had to do with demonstrating that safety and health does not cost more or demonstrating the cost-benefit. Some extended the thinking from green buildings which initially had the cost barrier but now eventually is viewed as cost effective. Some key comments include:

- Prove that S&H does not increase construction costs / Produce safer but also faster and with less initial costs - prefabrication?
- Money! The analogy with regards to green building can be extended further. Green buildings generally speaking cost a lot more than the alternative, if the client wants it then they pay for it as it has some intrinsic benefit to them.
- Focus on OSH prominently within the general subject of CSR. Putting it within CSR gives it a larger dimension and makes more of an impact.
- OHS is not a priority - it is pushed downstream - how to make it a priority upstream and educate developers they can be an influence.
- Learning from exemplar clients re their influence on construction H&S

The second point from the consultation report asked respondents to consider how "Health and safety becomes a professional responsibility of everyone in the industry. At the moment it is perceived to be the health and safety professional's job. Health and safety professionals are generally not architects, engineers etc. They don't make decisions. They act as advisors. The decision makers need to step up and take professional responsibility." Some interesting responses questioned education and the role of the traditional OHS professional and a few are provided below.

- Broad-based multi-disciplinary H&S Undergraduate Education that ensures that all graduates understand that H&S is their responsibility.

- Research into the efficacy of health and safety professionals. Some national bodies run into tens of thousands of members. Does this contribute to a positive outcome or does it negate the ability all professionals (and employees) to exercise their responsibilities for safety and health?
- Supervisor education and OHS integration needs to be improved.
- This is a self-perpetuating myth. We all know that it is everybody's responsibility, but H&S specific professionals earn their money by trusting that very few others actually care and think they can immediately transfer risk and responsibility to the person with the title for responsibility.
- What is the paradigm of the "safety professionals" and how they are in conflict with the other professions?
- In the UK, the bold move made by the Regulators was to embed the old CDMC role in the new Principal Designer role. This should move the responsibility from the 'consultants' to the lead designer, PM or D&B Contractor. A before and after survey of this change (intervention) would be interesting.
- I agree with the statement in quotes above. I have reservations about the proliferation of OSH specialists because surely it should simply be embedded in the everyday work of managers and supervisors? More research on how OSH is actually seen by managers and supervisors would be helpful.

The third and final main point from the consultation report asked respondents to consider ideas for closer and more effective links between industry and academia. Many of the responses indicated the difficult nature of this problem. Some of the more interesting responses are highlighted below.

- There is a need for a more evidence-based approach to construction health and safety. Companies need to know with certainty what works and what doesn’t. Managers are easily persuaded when there is evidence but skeptical when there is none.
- Meaningful links between academic and industry are difficult to achieve, even when both parties are keen. As a construction site manager who became an academic, I have always striven to work with the industry, but this has been challenging because academia is driven by different career determinant from industry. Perhaps we need some good research to tell us what works and what doesn't when trying to make links?
- Evidence of safety is really problematic – because it's a non-event! So perhaps a way of exploring/researching/framing this that is readily understood by practice that doesn't need stats or other traditional measures of 'impact'?
- I cannot say what deserves of priority research but how research is conducted by the universities seems all too often to be in respect of the needs of students to get a masters of PhD with little reference to the needs of the industry generally. This results in similar or even repeat research projects being carried out year after year. Maybe a priority research project is into research projects themselves to ascertain their relevance, innovativeness, dissemination and standard of research.

Respondents were asked about the importance to the following publications to their research. It was good to see the W099 conference proceedings ranked second. Table 5 summarizes those results.

Table 5: Importance of publications

Publication	***Ranked Importance***
Safety Science	*4.73*
CIB W099 conference proceedings	*4.63*
Construction Management & Economics	*4.55*
Journal of Construction Engineering and Management	*4.55*
Engineering, Construction and Architectural Management	*4.18*

The final two questions of the survey were open ended asking respondents what else could be done by CIB W099. The first of those questions asked "What other Construction Safety and Health topics are important and should be included in future?" There was a variety of answers including looking at organizational issues, psychological issues, nanomaterials, residential construction, and new concepts such as Safety-II. One of the most interesting responses sums it up with "Ask industry what it wants, ask the workers on site what they want, ask those who work, live and play within or on or under the things that we construct. I mean really ask, with a passion simply to eradicate work place and home death and serious health issues caused by preventable circumstances."

The final question asked respondents to assess W099 and give advice, "What should CIB W099 be doing to better support your research and practice in construction safety?" The most popular advice centred on W099 being a venue to ensure collaboration among researchers from different countries, and engage in meaningful collaboration between conferences. Specific quotes included:

- The standard of research is inconsistent, judging from papers submitted to W099 conferences. Some are of a high standard and others are, in my opinion, barely meet degree level standards much less PhD standards.
- CIB W099 like many academic commissions/groups needs to live outside of its own membership and make a real and meaningful impact beyond the publication of its proceedings.
- More interaction between conferences.
- Try to enhance more collaboration between researchers from different countries - measure the amount of co-authored papers by researchers.
- Increase the number of developing countries' researchers at conferences. It's the same group of countries attending.
- Have a review of the proceedings of CIB W099 over the last five years and as a panel of people both academic and industrial to mark each paper for its relevancy and impact on

real life. How likely is it that lives have been directly saved or improved by the outcomes of the research?
- Organize more regional conferences.

Others were complimentary:

- I think W099 works really well! A communicative, welcoming, open and sharing group of researchers who are most willing to help and support each other. The annual conference is very good for ensuring a vibrant network, so nothing much to add here.
- Continue as you are. The aims and programme are excellent.

Brainstorming Sessions at W099 Belfast Conference

In essence it was hoped that this was a turning point conference. Each attendee has thoughts about the future of construction OHS, and now W099 must put these thoughts into action. The pre-conference debate featured four academics against four local construction industrialists examining the value and relevance of research. A Day 1 plenary session entitled "Bashing the heads of Bunny Rabbits" explained the story of the eradication of smallpox and served as an inspirational example of achieving what seemed to be an insurmountable task. Both sessions fed into the brainstorming sessions.

In this section the brainstorming sections are summarized and pertinent quotes provided. In a sense the questions provided each small working group were primer questions to get the conversations going. In the end, most sessions focused on the last 2 questions about the future scenario and development strategy. The summary of the brainstorming sessions in therefore focused on those two questions. For the sake of brevity, this section is concise.

1. Future scenario: The roadmap will unfold a vision on where we want to be in the future, e.g. in ten years' time including the stakeholders' opinions on required/envisaged future systems, processes and technologies, preferred future practices and skills etc. Comments around this theme include:

    - What if we changed our conference abstract instead of being an academic abstract to being a 1 page sheet it might have a figure or whatever on it but it's aimed to be more relevant in industry and it says here is what I studied here is what is important that's it.
    - If an industry member is going to participate they don't write a full paper they write a one page thing that says here is my problem and any other questions I have that need to be answered in order for me to resolve the problem - an excellent little paper that academics can pick up and say let's collaborate on this, it's a great idea.

- Often times I don't present my best work at conference because I had submitted as a journal; I think a lot of people will just publish their B work in conferences instead of their A work and that's not good.
- This morning (at the conference) the ILO guy mentioned action research and action research is a fantastic opportunity for collaboration between academia and research and CIB should be really leading that to.
- With regards to diversity in construction, women tend to go into the planning and design process not out in the actually production phase.

2. Development strategy: What is needed in terms of knowledge, information, tools, concepts and applications to enable the respective systems, processes and technologies to develop from where we are today to where we want to be in the future? Comments around this theme include:

    - Safe design is not just accidents but it is occupational health incidence, ergonomics, and a better work place.
    - Because we look at ethics and morals differently in different countries we can't deal with in exactly the same way all around the world.
    - I would really like to see W099 being more of a one stop shop you know the go to place for whatever health and safety issues you have. The ability to come up with resources that can give currant advice and point to work that is being done.

5. Future Directions

The results and summaries presented here are going to be further analysed and refined through a series of on-line consultative workshops to be conducted April 2015 with the goal of drafting the research roadmap around the four specific aims highlighted in Section 2. A workshop will be held at the 2016 World Building Congress for final validation of the roadmap. Reports on the roadmap will be conducted at every annual W099 meeting beginning in 2017.

6. Conclusions

This paper provides the initial insights to the development of the W099 research roadmap. It is not a complete paper with definitive conclusions as the research is preliminary. The purpose of the research roadmap is to guide the workings of CIB W099. It is not directorial and should never be considered so. The idea is that the collective experiences, expertise and research excellence of the group can be brought to bear on specific goals that will in the long run improve and enhance the safety, health and wellbeing of the communities of which we are all a part. The pre-conference academic debate and the 'Bashing the Heads of Bunny Rabbits' session considered how we as a research community can and should use creative, innovative and fun ‘audience engaging’ approaches to deliver a serious and critical message, how do we make vision zero harm a reality? And where do each of us start on this journey? Just as the medical team (1966 to 1980) took a global and yet focussed approach to the eradication of small pox there are lessons to be learnt on how seemingly unattainable goals can be achieved with a very specific and concerted strategy, using the wide range of skills, cultural diversity and resources available within the group. For example, if we had a goal to ensure that prevention through design was to be a core element of every designers’ education within a set period, then how would we set about achieving it? It is the coming together of researchers’ approaches and specific W099 goals that will successfully deliver the strategy, as we take the research into the classroom and into the field, making it live of the page.

As researchers, individually or in groups we have the capacity to devote time to CIB W099 goals, without compromising individuality or without precluding and non-CIB W099 research projects. Setting in place a 10-year development strategy allows commission members from one conference to the next to review and update the strategy, taking into consideration the evolving world’s needs and the changing worldview. Consequently, a rolling 10-year strategy is created, which with the goodwill and endeavours of W099 will remain relevant and impactful.

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What happened when the elevator came to Norway? A case study of change in Norwegian building regulations over time.

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Abstract

This paper examines how the regulatory description of elevator technology has developed during the course of Norwegian regulation history. It tells the story of how a particular piece of interaction between a society and its built environment is described and re-described several times before it becomes a stable part of the collective horizon.

The main hypothesis underlying this paper is that the development of regulations in time reflects feedback-loops between the regulating society and the environment it builds for itself. By studying the text of the regulations, one can consequently see how the perspective of the society evolves on the subject of its built environment.

This paper establishes the built object as the pragmatic interface where society must interfere if it wants to have an actual effect on the whole of built environment. The content of society`s interference becomes empirically available in imperative descriptions of the built object - found in building codes.

By carrying out a content analysis of the building codes, along two sets of parameters, we present an analysis of a specific topic in the Norwegian Planning and building Act, as well as the corresponding Technical Regulations, as they unfold in time. One parameter is the specific topic — the regulations' internal categories. The other parameter is the modal force of the normative descriptions, from recommendations via advice to explicit, quantified regulations. The reading provided by these parameters together accentuates how regulations shape the content of the built object as a societal imperative.

Visualized as a series of diagrammatic plot distributions, the analysis combines quantitative (number of plots per theme) and qualitative (modality of statement) perspectives. By adding a timeline that allows us to inspect how the regulatory situation evolves over time (from one

regulatory situation to another), we are effectively adding a reflective component to our understanding of the impact of societal values on built environment.

In addition to the exposition of the regulatory history of elevator technology, the findings present us with an analytical toolset that allows us to access and discuss the interaction between society and built environment as their reciprocity evolve over time.

Keywords: Built environment, building regulations, elevator technology, content analysis

1. Introduction

The interaction between a society and its built environment is a two-way dynamic. We embed information corresponding with our collective needs and agreement into the environment by building.

Containing explicit descriptions of the object, building codes are available sources of society´s imperative actions upon the environment. This information can be studied as individual instances in time, however, when put together and regarded as process, they can be interpreted as feedback-loops – going from built environment back to society.

This study selects one specific topic, namely the description of “lifts and escalators” from the Norwegian building code and analyses its’ development all the way back to the first national building law. The genealogy of “lifts and escalators”, as described in building codes, is presented along a timeline exhibiting when the topic first became a regulatory concern, how it was described, and how the description has developed over time up to present day.

The developmental pattern of the elevator description shows how even an uncontroversial building technology undergoes a development in the regulations before it finds its form. The pattern indicates relations that exist between society and elevator technology, specifically. A fundamental conviction of the authors of this paper is, however, that this pattern permits the unwrapping of more general insights into the nature of the process of regulation as an interaction between a society and its built environment.

In this specific study of Norwegian building codes, we pose the following research questions:

- What happened in the building codes when the elevator come to Norway?
- How did the regulatory description of elevators develop up to its present conditions?
- What genus of interaction does the regulatory development of elevators indicate?

In order to address these questions, firstly, the object is identified as the operative interface of interaction between a society and its built environment. The method section specifies the analytical operations done in this special case study of “lifts and escalator”-descriptions in Norwegian building codes. The findings visualise a time series of regulatory elevator descriptions into a continuous image of societal process. Finally, the findings are discussed in light of the research questions, followed by a summary with recommendations pointing towards future, comparative studies to test the hypothetical answers.

2. Theoretical Framework

Building Projects are inherently social activities (Fallan, 2008). The organisation and execution of such projects represents the collaborative effort of a community. Building projects utilise shared resources like infrastructure to enable acts of adaptation that individuals would be incapable by themselves. Regardless of being informally or formally constituted, this makes them strategic acts (de Certeau, 1980); they provide advantages to action by the manipulation of shared environment. Socially, these actions matter, not only because they are interactions, but because they contribute to ground a social reality in(to) the physical reality by their results.

The effects of a building are shared; they are beyond private interest alone. Even if the physical entity is necessary for embodying the result; a building, as shared reference, matters beyond the interest of the individual and the technology that enables its necessary scale. Buildings have (cognitive) agency in the interdependent, inherently social field of action (Gieryn, 2002). The social significance of buildings exceeds their instrumental aspects. They partake in matters of aesthetical, political and epistemological importance (Kara, 2011).

The notion of a building commonly refers to a physical artefact. To avoid the misunderstanding of reducing the basic unit of the built environment to its purely technological aspect, we refer to the base unit of the built environment with the more abstract term *object*.

It is the long-term interest of the collective that makes a society interfere directly into building projects. Settling local conflicts before they take on more large-scale consequence is a practical interest of any society that wants to remain stable over time. Any social action of the magnitude of building holds potential conflicts of interest. The broadness of its social significance and sheer longevity of a built object adds to the severity of the potential conflict scenarios. A project can be mediated by rules and regulations that solves conflict as they arise; In order to ensure its interest in the future consequences of the built object, however, a society must lay down guidelines before conflict arise — it must anticipate.

To have an actual effect on future environments, society`s interest must be expressed in the interface where content is embedded into environment. It must take the form of descriptions that cannot easily be replaced or translated away among the many concerns and interest that surface within the project framework. To make a difference in the built environment, societal interest must, because it is embedded via the project process, at one juncture of translation become explicit object descriptions in order to be actionable.

The most direct imperative descriptions of the object are found in building codes. Many societal documents and institutions describe the built object, either explicitly or by implication; none, however, do it with the same specificity and imperative force as building codes. In building codes society as a collective efficiently acts upon the object; its description effectively decides whether something is built with societal recognition; building codes define what is legal. To be explicit enough to avoid the risk of mistranslation building codes actually must provide imperatives in the object scale.

Society`s imperative descriptions of the built object interface represents a readily available empirical channel of the interaction between society and built environment. Building codes ideally represent a society embedding content into built environment for societal reasons. It does so in the most efficient scale and in a form that is meant to have an actual effect. The codes are well documented – their availability, impact and explicitness makes them a direct access for the analyst into the interaction between a society, as a collective, and its built environment.

Different societies have been shown to exhibit a varietal of different building regulations (Heijden, 2009). Comparative studies of building codes have been done within the EU (Meijer et al., 2002). The Norwegian code is not included in these studies. It should, however, be directly comparable, and correspondingly valuable, as a case. No studies found focus directly on building codes` explicit description of the object. The Norwegian case explicitly states a social purpose (§ 1-1, Norwegian planning and building Act). This makes it a potential reference point for studying the content a society embeds for societal reasons – that presumably are of a social nature.

Studying how a specific topic in the Norwegian building codes develops over time, provides insight into the dynamic of the interaction it represents. The effect of a building code on environment should over time have an effect (through a change in consensus among the users) back upon the regulations, urging change if the effects are not satisfactory. Modification within a particular topic of description should in theory reflect change in consensus due to a shared, collective experience. Regulation`s effect on the object can be studied in a time series of building codes. By focusing on a delimited part of these time series, a material that normally remains opaque because of its density and historicity, can be laid open in the explicit way it actually effects and have effected the built environment.

Elevators exemplify a conventional building technology. They attract little controversy as a thoroughly regulated building technology. That elevators pose a significant safety risk in case of malfunction or lack of maintenance presumably contributes to this fact. A study of their development into the contemporary situation thus can shed light into the process of how a new invention becomes a conventional, regulated building technology. The manner in which the regulatory description changes would lay bare the formalist aspect of implementing technology into the environment. As the material for future comparison, this process perspective would also help us understand how building regulations play a role in making certain technologies conventional.

3. Method

Methodically, this study is conducted according to a three-part structure: Firstly, it is framed as a case study, consisting of a literary review of Norwegian regulation documents (Yin 2009). Secondly, it is internally structured as a content analysis of these documents *(Blumberg et al., 2014, Krippendorff 2013)*. Thirdly, it visualises the analytical toolset that leads to the findings (*Tufte* 1997, 2006).

A content analysis enables a reading of how building regulations reflect the interaction between built environment and a society by being a method of highlighting how it makes its content (description) explicit. The goal of a content analysis, according to Krippendorf (2013), is to "infer features of a non-manifest context from features of a manifest text". In this study, these telling features are made apparent by displaying an inventory, not only of what (about the object) the building code describes, but also how it describes: How it reflects its purpose, and effects as a societal imperative.

A selective reading of a time series of Norwegian building codes generates the input of this study. Regulatory statements with descriptive reference to the built object demarcate the units of analysis. The object of reference corresponds with the output of a normal normal building project as defined in professional standards (Moe; et al., 2010). This is a delimiting choice made to focus on built regularities rather than exceptions.

Regulation documents covering the top level of building code, specifically, building Acts and technical regulation are the source texts of this content analysis. Every regulatory situation in the history of the Norwegian building code, as defined by the valid Act and its technical regulations, provide a series of descriptions. This corresponds with the acts of 1924, 1965, 1985, 2008, and the technical regulations of 1928, 1949, 1969, 1985, 1997 and 2010. In addition, a substantial supplementary document expanding on fire safety in institutions from 1963 is included. Yearly revisions of the regulations texts are not included in this study. The sources are limited to the mentioned documents with their revisions as they where openly available at lovdata.no, the Norwegian data base of legal material, per October 2015.

The Norwegian building code handily categorizes its description of the built object into topics. Applying topic as an analytic parameter creates a selective reading into the "Lifts and escalators" topic (section 29-9, chapter 29, Act 2008), as all other topics effectively fall outside our analytical frame.

The regulatory descriptions designate different degrees of explicitness to different components of its description. This scale emerges from the linguistic modality a statement is expressed in. Within the language of the building code, a relative degree of explicitness forms a hierarchy that remains opaque in normal reading. These structural "how"-components of the regulatory description actually affect the real world pragmatics of what is built.

By assigning each analysed statement with a linguistic modal degree, the analytical construct re-codes the reading of the regulation to show a relative relation between each statement. This enables a reading of the building code that accentuates the modal aspect. The scale of modal degrees is derived from the actual, present Norwegian Planning and Building Act (2008). As a continuity, legal modalities expresses an interval spanning from vague possibility to singular, unambiguous necessity. In the Norwegian case this correspond roughly with four levels: From making *Recommendations*, it increases to *Cohesive recommendations*, before becoming binary (yes, no) as *Absolute regulations*, all the way up to the most forcefully specific: *Quantified regulations*. This most specific tier describes legal necessity by prescribing intervals (within, below or above) of certain pre-established values to which the built object must correspond to be legal.

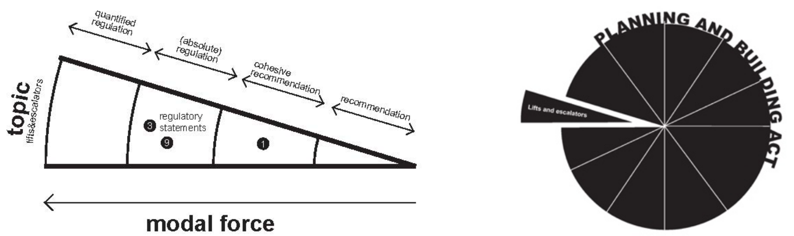
This analytic reading of of a specific topic of description in Norwegian building codes accentuates “how” a topic is expressed. Accentuating the workings of a modal hierarchy within the regulation text reveals the mechanics of (regulatory) expression that corresponds with the pragmatic effect of the building code on built reality. By adding a timeline, the development of descriptive force and explicitness of the topic in question appears.

Because of the imperative signification of the building code, high legal linguistic modality corresponds with forcefulness of the actual effect it prescribes to built reality. Revealing descriptive force unlocks a perspective on the building code`s actual effects. This should correspond with a society`s will to enforce this specific solution out of societal interest in its effect on the built environment. Topic in itself merely designates societal interest, and topic volume only society`s interest`s relevance for settling controversy.

Reference numbers assigned to each unit of analysis ensures replicability to the study. Any individual number can be traced back to a statement in the regulation texts. This makes the procedure replicable and testable. The process relies on human judgment interpreting a grammatical/semantic material. It would not be suitable to an automated procedure. The reliability of the study could be developed in the future, by multiplying the procedure, either to provide Bayesian reliability, or a quantified deviation measurement.

4. Analytic Procedure leading to Findings

Firstly, the body of each regulation text is sorted into topics using the 2008 chapter and sections headlines. The “Lifts and escalators” topic is selected for a specific, in-depth study (Figure 1). Secondly, each individual statement describing the topic is given a number an allotted with a modality according to the scale (also Figure 1).



ic and modality

Thirdly, repeating this to all the 11 unique regulatory situations in Norwegian history since 1924 leaves us with a collection of comparable diagrams showing volume and modality of “lifts and escalators”- descriptions (Figure 2).

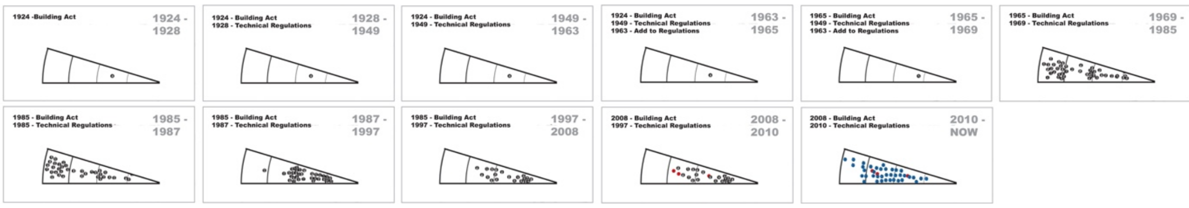


Figure 2: The 11 unique regulatory situations of Norwegian history

Fourthly, the diagrams are distributed chronologically, allowing us to read them as a process. Fifthly, we add a time-line of 100 years and distribute the diagrams on that timeline showing the Norwegian history of elevator regulation. Sixthly, removing the individual diagram, leaving only the plots, the y-axis of the combined diagram now denotes modality, roughly corresponding with descriptive specificity and force (Figure 3). Seventh, and finally, we approximate the plots to a graph by visual analysis; this leaves us with an historical image of the specificity of elevator regulation in Norway (descriptive modality force / time) as our findings.

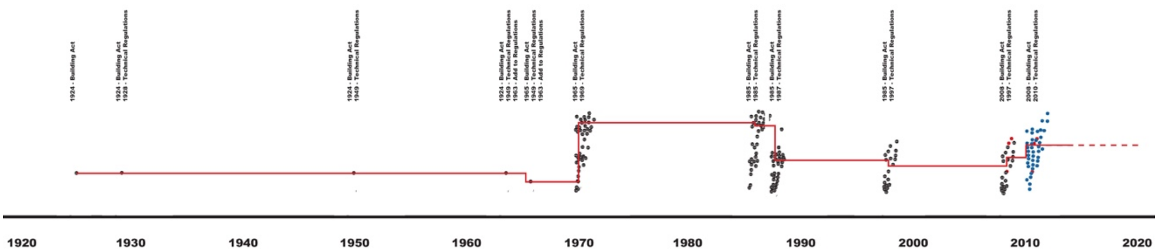


Figure 3: Adapting a graph to the scatter plot

5. Findings

According to the graph in Figure 3, "lifts and escalators" went from barely regulated to very specifically so in 1969. Assuming this occasion corresponds with the period elevators became a proper regulatory concern, that is; a regular building technology and not just a possibility, the introduction of societal interest is characterized by a dramatic increase in modal force (will to specify). At this introduction, the regulation of elevators in built environment appears distinctly specific and forceful.

In 1969, elevator specificity went from barely described to very concerned. The development of regulatory description, however, is characterized by a decline in specificity during the 1980s, that continues in 1997, before a new an uplift in specificity (modal force and volume) appears in the present building code. This new top, however, peaks at a lower level than the peak of specificity characterizing the introduction of the topic into the Regulatory body in the 1960s.

Doing an F´(x) operation on the function (Figure 4), now displaying the finding as degree of modal change/time, displays this tendency even clearer. There appears to be a significant positive change in modality/specificity of description in 1969, followed by negative tendencies in the 80s and 90s, and a new, less dramatic positive tendency leading into the present situation.

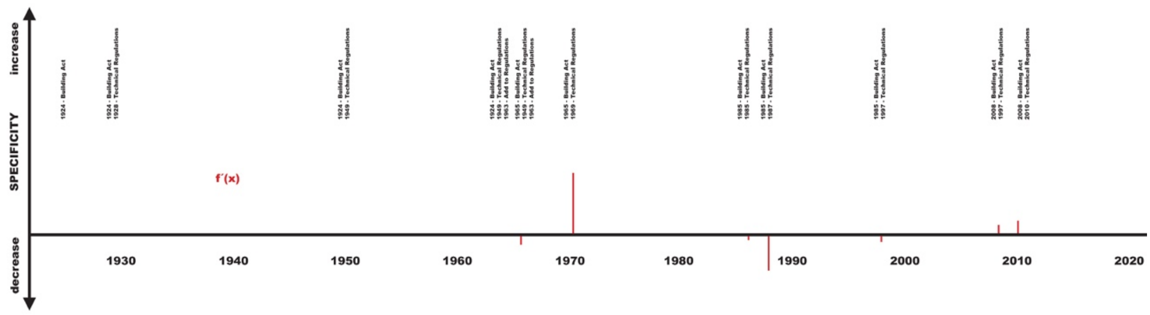


Figure 4: Modal changes in elevator regulations

6. Discussion

The findings clearly indicate that elevators were introduced as a regulatory concern which significant modal force, corresponding with a high degree of specific effects in the built environment. The difference between merely being regulated— a requirement that elevators must be accepted and inspected by officials (the Act of 1924) — to being described in details by the regulation text — down to the diameter of the metal cord used in the mesh in the bottom of the elevator shaft — is quite dramatic.

The modalities of the introductory 1969 technical regulations indicate that strong societal forces took very specific interest in the elevators. Since elevators were relatively new to the general public, whom the building code represent, this force may be the result of either an expert`s perspectives, or that the safety concern (or phobia) connected to the novelty of elevators lead us, as a collective, to limit them to one specific form.

After the initial specificity, our findings show that the regulatory description went through some adjustments, clearly becoming less forceful (and specific), first in 1987 and further in 1997, before they have a resurgence of specificity in 2010. They are yet, however, to reach the same level of force and specificity as the introductory situation of 1969.

The fall in the 80s and 90s, and the new, albeit lower peak in 2010, clearly suggest that the development does not follow a linear pattern. The pattern of the regulatory description of “lifts and escalators” in the Norwegian building code that follows from 1969 is neither a gradual increase in specificity, nor a decrease. According to the findings, elevator regulations rather exhibit a wave-like development. From the present perspective in this historical process, descriptions swing from a high initial state towards a lower overall degree of specificity: From few accepted elevator solutions to several, yet far from laissez-faire.

If this pattern corresponds with an interaction between the regulating society and its built environment, it seems to be characterised by an action-reaction process. A society that embeds content into the build environment by imperative should be expected to adjust these imperatives over time: As a collective, society learns from the consequences of its imperatives through their effects, working back upon its originators from the built environment. The wave-like pattern displayed, if it does represent this interaction of action-reaction, could correspond with a learning process.

Looking at the tendency at display from 1969 and through the present situation, based on the hypothesis that the underlying dynamic driving this development is a learning process, then it seems reasonable to suggest that the descriptions of built environment nested in building regulations, and in this specific case of building technology that is elevators, behave very much like some sort of a collective inquiry. In fact, the Norwegian society poses a very specific hypothesis of the correct (societal) specification of elevators in the build environment in 1969. The collective learns from the consequences of this description, re-state new, less constricting hypothesis in the 80s and 90s, learns from these, and (finally) finds that we need to be more specific in 2010, however not as specific as the first try in 1969 (illustrated by line drawn between peaks in f(x) in Figure 5 below).

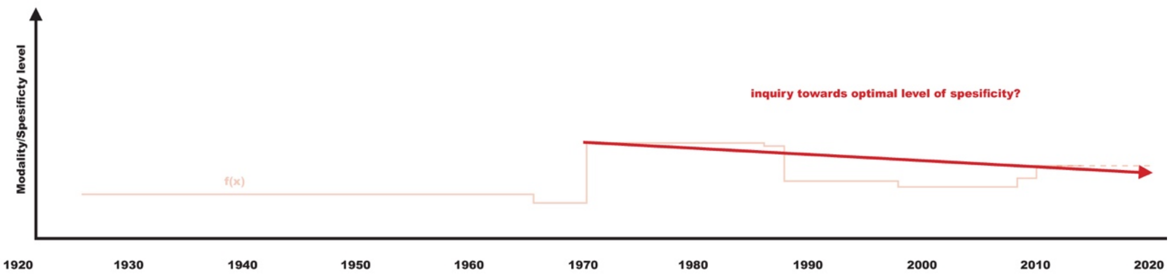


Figure 5: The historical development of Norwegian elevator regulations

If the development of “lifts and escalators” in the Norwegian building code represents a general pattern, the interaction between society and built environment evolves like a big collective experiment. Based in shared interest, Norwegians experiment (try and retry) with the correct level of specification; that is, a beneficiary balance between limits and possibilities of a building technology to meet our collective needs and aspirations; as a society being a temporal continuity. This implies that “the first” description, like the specificity of “lifts and escalator”-regulation in the 1969 is likely to be less than optimal. As a part of a learning process, however, this is just a part of the process. It is adjustment through learning from consequences over time that represents intelligent improvement (and not hitting the spot the first time by share luck).

Learning is not an unlikely explanation of the observed dynamic as it represents a driving force in itself, for intelligent creatures and societies. Learning characterizes the enjoyable process of improvement. Improvement of building codes over time, by collective inquiry is subsequently the collectively enjoyable process towards the most stabilizing, yet dynamic balance of technological augmentation of our environment.

7. Conclusions

This study displays some tendencies in the introduction and development of elevator description in Norwegian building codes over the past 100 years. The main tendency shown resembles a wave-like development from high to lower specificity – a development that as a manifestation of an interaction between a society and its built environment, seems to corresponds with that of a collective learning process.

The scientific contribution of the findings and the toolset developed represents an analytical perspective on the dynamic between society and built environment. This perspective could be of methodical value for regulation professionals, policy makers and technologist alike. It also, however, opens the question of whether these observations of the elevators regulation history are unique to Norway. Few comparative studies cover both the EU and Norway, and for the findings of this study to be generalizable, further studies are in order.

By replicating the analysis to cover building technologies besides elevators, in and outside the Norwegian regulatory situation, the perspective and hypothesis suggested can be tested to see whether "lifts and escalators" regulation represents an oddity or if it embodies a more general pattern in the relationship between society and built environment – that of a reciprocity characterized by continuous inquiry: Of testing, adjusting and improving.

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Spatial Meteorological Information for Built Environment in the Changing Climate of Finland

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Abstract

Climate change will decrease the heating and increase the cooling energy demand of buildings, and poses challenges in urban planning and construction of buildings. On the other hand, buildings also affect the local climatic conditions. The complex interactions between climate and built environment need to be taken into account in urban planning, designing new buildings, as well as, in renovation of existing buildings.

Two types of past and future hourly test reference weather data sets have been produced for selected locations in Finland, one for considerations of energy demand and the other for purposes of building physics. Using the data sets as input for dynamic building energy simulations, the annual energy demand for heating and ventilation in southern Finland was assessed to decrease by 15-18 % by 2050, and the annual cooling energy demand to increase by 28-34%. Spatial distributions of the future changes in heating (HDD) and cooling (CDD) degree days over the whole country were assessed based on gridded (10 km x 10 km) daily temperature data. By the end of the century in a high emission scenario the HDD will reduce by 1000-2000 Kd compared to the present climate. In a low emission scenario the HDD will be reduced by 500-1000 Kd. The biggest changes will take place in northern Finland and during winter months. The heating period will be shortened by several weeks. The cooling energy demand will remain small compared to heating demand also at the end of the century.

However, these assessments based on meteorological measurements at standard weather stations do not give adequate information about climatic conditions in urban areas. An urban heat island study and simulations with an advanced high-resolution weather model demonstrate how built environment can modify the spatial temperature distribution in Helsinki. Besides affecting the building energy demand, the urban heat island effect intensifies adverse impacts of heat waves on human health. Buildings should be thermally comfortable not only in weather conditions typical for the present-day climate, but also in extreme weather situations and the changing future climate. Comprehensive, integrated information is needed to assess well-being in built environment.

Keywords: heating and cooling demand, climate change, urban heat island, health impacts, weather models

1. Introduction

Ongoing climate change, as well as, climate change mitigation and adaptation policies will have remarkable impacts on built environments. In cold climatic conditions like in Finland, the energy efficiency and reduction of greenhouse gas emissions are main climate related concerns. However, warmer, wetter climate and side-effects of improved insulation of buildings may also have adverse impacts on wellbeing of people, besides increasing the cooling energy demand in summer. Moisture control appears to be challenging in newer buildings both during construction and in use, and mechanical ventilation requires also energy. On the other hand, buildings and changes in land use affect local climatic conditions. Therefore the complex interactions between climate and built environment need to be better understood and utilized in urban planning, and assessed together with sociodemographic changes in order to provide healthy and comfortable built environment for people. Urbanization and socio-demographic changes, like an increasing share of elderly in the population, will further emphasize the importance of integrated, detailed spatial assessments.

Here we mainly concentrate on spatial meteorological information for built environment in the changing climate of Finland. Examples are given about estimates of future chances in the heating and cooling energy demand of buildings in Finland due to climate change: Besides temperature, we briefly describe here changes in other meteorological parameters relevant for built environment such as humidity, precipitation, wind and solar radiation. Furthermore, we demonstrate the urban heat island effect and impacts of built environment on weather and climate in a metropolitan area in Finland. Heat related mortality and regional differences in vulnerability of Finnish population during heat waves are discussed in context to demonstrate the need for integrated information from various sources to be used in urban planning, construction of new buildings as well as renovation of old houses.

In chapter 2 we shortly describe both present and future climate in Finland in general, proceed next to the tailored climate scenarios for building in form of test reference weather data sets and spatial calculations for changes in heating and cooling degree days. In chapter 3 we concentrate on impacts of buildings to the local weather and climatic conditions and in Discussion we reflect on use of applications of these information e.g. in planning green areas in urban areas and preparedness during heat waves.

2. Buildings in changing climate

2.1 Climate variability and change in Finland

The climate of Finland is influenced by the northern geographical position of the country and its location in the western coastal zone of the Eurasian continent. Weather types may vary rapidly depending on the direction of the airstream, and the seasonal and inter-annual climate variabilities are large. Due to cold climatic conditions the energy demand for heating dominates over cooling in Finland. However, the energy demand for cooling cannot be ignored in a warming climate.

The annual mean temperature has already increased over 2 °C since pre-industrialized time in Finland, implying a rising trend of 0.14 °C/decade (Mikkonen et al, 2015). The warming has been more rapid since the 1960s. The observed increasing trend has been higher during winter than summer. The temperature increase exceeds the global average in high latitude countries like Finland. The aim of international climate politics to limit the increase of global mean temperature to 2 °C would mean that the annual mean temperature in Finland would increase by almost 4 °C and precipitation by 10-15 %. In case of high greenhouse gas emissions the annual mean temperature would increase about 6 °C by the end of the century and annual precipitation about 20 % by the end of the century.

The increase in summer temperatures is also expected to manifest itself in longer and more intense heat waves in the future. Based on Ruosteenoja et al. (2013a), summer days with a daily mean temperature above 20°C may occur at the end of the century three to four times as often as during the recent decades. Similar increases are expected for the duration of hot periods.

Along with increasing temperatures, Finnish winters are becoming moister, darker and less snowy. Solar radiation in winter is estimated to decrease by 10-15 %, relative humidity to increase by 2-3 percentage units, and in southern Finland the snow water equivalent will probably be reduced by 70-80 % (Ruosteenoja et al. 2013a). In winter the probability of precipitation in form of rain or sleet will increase, and risks related freeze-thaw damages alter. These changes are thoroughly discussed in the works of Ruosteenoja et al. (2013b) and Vinha et al. (2013).

2.2 Test reference weather data sets

Two types of test reference weather datasets have been developed for Finland, one for considerations of building energy demand and the other for building physics. The former data set aims to describe typical meteorological conditions and the latter critical conditions from the viewpoint of damages in buildings due to moisture.

The impacts of climate change on the demand, delivered consumption and costs of building energy have been assessed by Jylhä et al. (2015) for a typical residential house in Finland. The influences of air temperature, solar radiation, wind speed and air humidity on energy demand were simulated by the IDA Indoor Climate and Energy simulation program, utilizing a recently-developed synthetic Test Reference Year (TRY) hourly weather data as its input (Kalamees et al. 2012). The TRY2012 data set, describing typical climatic conditions in 1980-2009, appeared to work well in capturing the average building energy demand of the example house during that 30-year period. Future TRY data sets were constructed by modifying the TRY2012 time series in accordance with climate model simulations.

Using these future climate projections as input for the building energy simulations, it was assessed that the annual energy demand for heating of spaces and ventilation will decrease by 15-18 % by 2050, whereas the annual cooling energy demand will increase by 28-34%, the lower and upper ends corresponding to the multi-model mean climatic responses to low and high greenhouse gas emission scenarios, respectively. The impacts of the changing climate on the delivered energy consumption and energy cost per m^2 were assessed using three alternative heating systems and two different cooling systems. With other influential factors (e.g., building technology and practices, floor area) held constant, climate change is expected to reduce the amount and cost of energy used in buildings in Finland. The findings can be used to identify potential needs to revise building codes and to improve the energy performance of buildings in order to better mitigate climate change and adapt to its impacts. The results also demonstrate the added value of dynamic building energy simulations compared to the use of cooling degree-days.

The Finnish climate is rather demanding for building physics. Weather datasets containing temperature, relative humidity, wind speed and direction, direct and diffuse solar radiation and precipitation at hourly resolution in 1980-2009 have been produced by Ruosteenoja et al. (2013b) for four locations in Finland. On the basis of the 30-year datasets, two building physics test reference years were selected by Vinha et al. (2013) to represent weather conditions that are particularly critical for the emergence of damages due to moisture in buildings. Corresponding future scenario test reference weather datasets for the building physics purposes were then constructed by employing special treatment for the solar radiation and precipitation data. According to Vinha et al. (2013), climate change increases risks related to moisture behaviour and fault tolerance in several present-day envelope structures.

2.3 Heating and cooling degree days as spatial information

In order to provide spatial information about the anticipated impacts of climate change on heating and cooling demand, use was made of recent past and projected future temperature data on a 10 km x 10 km grid over Finland (Pirinen et al, 2014). The baseline values for the heating (HDD) and cooling degree days (CDD) in the present climate were calculated for the 30-year climatic normal period of 1981-2010, and future scenarios for three 30-year periods (2010-2039, 2040-2069, 2070-2099) were produced for three greenhouse gas emission scenarios (SRES A2, A1B, B1). In operational monitoring of heating demand, an indoor temperature of 17 ^{o}C is used in Finland as the base temperature for heating degree day calculations (S17), and was therefore also applied here. For cooling degree calculations, +18 ^{o}C was chosen as base temperature. Currently in Finland the cooling demand is not monitored operationally.

In the present climate the HDD varies from 3800 Kd in southwestern Finland to 5000-6000 Kd in northern Finland, and heating demand is the highest typically in January. The biggest changes due to climate change are projected to take place in Lapland, where the HDD will be more than 1000 Kd smaller already by middle of the century in the high emission scenario. By the end of the century the heating degree days will be reduced by about 2000 Kd in northern Finland and in southern Finland by more than 1000 Kd (Fig 1, left) in high emission scenario, the reduction is about one third of the value in present climate. In the low emission scenario the heating degree days will be reduced by 500 in southern and 1000 Kd in northern Finland.

Thus, Finland will benefit of climate change through reduced heating energy demand. The changes will take place throughout the heating period and are the biggest in the middle of the winter when measured as absolute values. However, changes in May and September will also be large due to the changes in the length of heating period. In the present climate in southern Finland the length of heating period is about 250 days (8.5 months) and about 300 days (10 months) in northern Finland. By middle of the century the heating period will already be a couple of weeks shorter in southern part and about one month shorter in northern part of the country in case of the high emission scenario (A2). By the end of the century in northern Finland the heating period will be about 1.5 months shorter and in southern Finland 3-4 weeks shorter than in present climate (Fig 1, right).

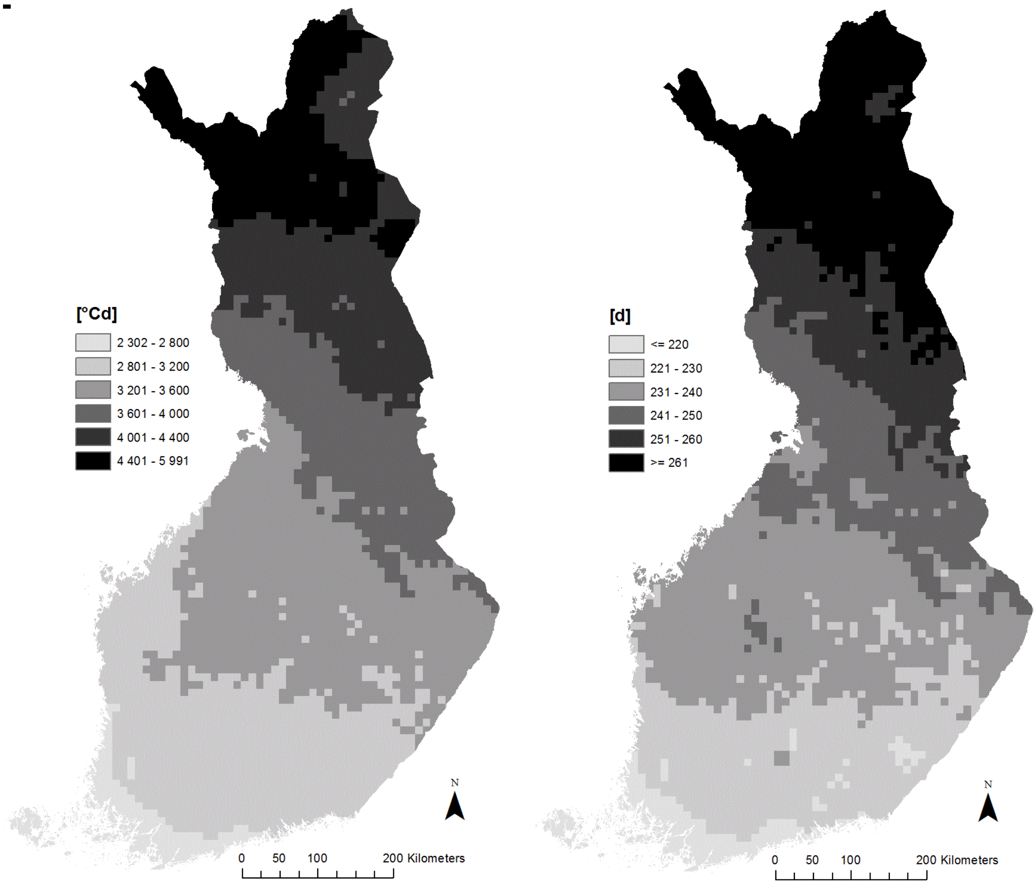

Fig 1. Heating degree days (left) and length of heating period (right) in Finland at the end of the century in high greenhouse gas emission scenario (A2) (Pirinen et al. 2014).

As discussed by Jylhä et al. (2015), the simple CCD method seems to work less adequately for quantitative estimates of future changes in energy demand than HDD does. This is because solar radiation notably affects cooling energy demand in Finland. In qualitative terms, however, CDD can be a useful measure in approximating the spatial distribution of future increases in cooling energy demand, provided that future changes in Finland will be spatially more uniform for solar radiation than for temperature. Obviously, more research is needed for quantitative assessments of future increases in cooling energy demand.

3. Built environment changes climate

3.1 Urban heat island in metropolitan area in Finland

By the end of the decade 2000-2010 the urbanization rate in Finland reached 85%, which means that a little bit more than 4.660.000 Finns live nowadays in cities or city-like settlements. Since the urban heat island effect was recognized in London in the beginning of the 18th century, uncountable numbers of researches (Arnfeld, 2003) have shown that cities and city-like settlements change the climate inside their borders. In general this phenomenon is based on the facts that surface areas absorbing direct solar radiation are greater in cities than in the non-build-up surroundings, while evaporation by trees, bushes and other green areas and sealed surfaces is weaker. Furthermore it is known that every agglomeration of buildings is producing their own heat island effect, at least in some extent. This is also valid for Helsinki where, beside the downtown city centre on the peninsula in the Gulf of Finland, several local centres, like Herttoniemi and Malmi, show their unique urban heat island effect (Fig. 2, Drebs, 2011). Maximum detected air temperature differences between the city centre and surrounding rural area in Helsinki, approximately 9 degree Celsius (Drebs and Vajda, 2006), are in concord with other researches, where the number of city inhabitants has been correlated with the greatest urban heat island intensity (Oke, 1973).

In the changing climate the human well-being in cities will arise as an important concern for inhabitants, city planners and decision-makers. Due to demographic changes, and temperatures differences in urban areas, questions on how to handle the changes in cooling and heating energy demand will become more actual. In order to mitigate adverse impacts of urban heat island, green infrastructure (green roof, green walls, allotment garden, parks, avenues) and natural ventilation corridors need to be considered in city planning.

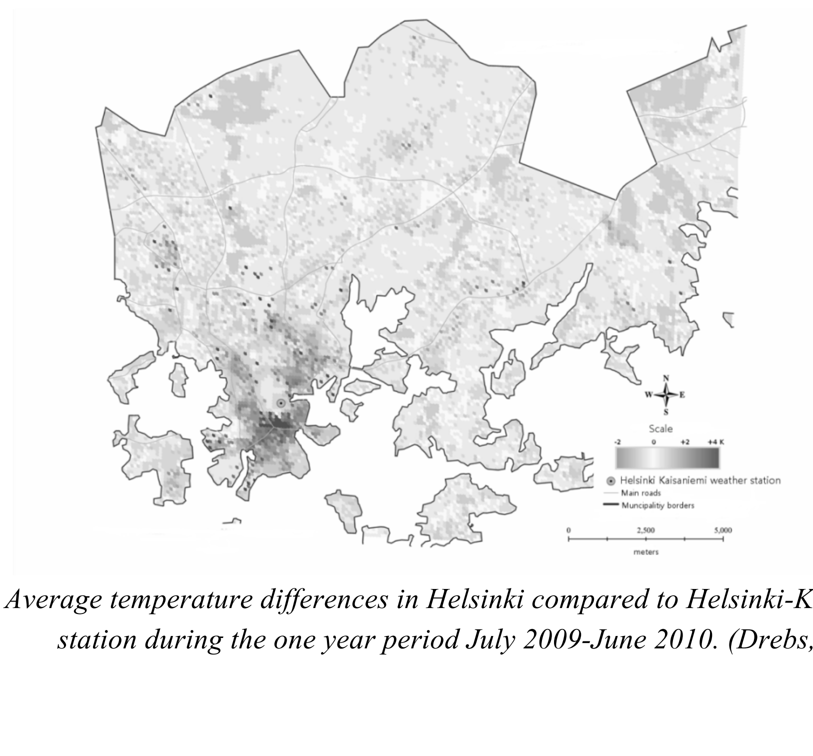

Fig. 2. Average temperature differences in Helsinki compared to Helsinki-Kaisaniemi weather station during the one year period July 2009-June 2010. (Drebs, 2011)

3.2 Physically-based modelling of the urban effects

In assessing the impacts of global climate change in an urban landscape, a challenge is presented by the fact that climate model output data have a coarse temporal and spatial resolution. Besides, observed weather data representing the present climate conditions do not account for differences between the actual climate in cities and at weather stations that are typically located in open vegetated land (rural or natural landscapes). High-resolution physically-based land surface models, by contrast, account for local characteristics when simulating the exchange of heat, water vapour, and momentum between the atmosphere and the underlying surfaces, as well as the meteorological conditions close to the surface. Examples of the detail added by a land surface model are given in Fig. 3, showing simulations carried by coupling the SURFEX land surface model (Masson et al, 2013) to operational forecasts of the Finnish Meteorological Institute. Surface characteristics including land use, vegetation types, and urban morphology were given on a grid of 500 m by 500 m.

The upper two panels of Fig. 3 show the temperature in the afternoon on a warm and sunny summer's day. The temperature above the roof-top level, shown to the left, is a 36-hour forecast by the operational HARMONIE system, based on the AROME atmosphere model (Seity, 2011), here applied on a 2.5 by 2.5 km grid. The spatial pattern is in this case entirely dominated by the land-sea contrast. This contrast is prominent also closer to the ground and in the street canyons (SURFEX: upper left), but there is additional spatial variability, which can be related to the surface characteristics (not shown): the warm (dark) spots are found over densely built areas where the cooling effect of evaporating moisture is small, while fields, forests, and water bodies are relatively cool.

The lower two panels of Fig. 3 show corresponding data for a cold winter's day. Above the roof tops (left), the pattern is again dominated by the land-sea contrast, but with opposite sign compared to the summer case: the ice-free sea is now warmer than the land. As in summer, the land sea contrast is prominent also near the ground (right), and, as in summer, the land use and surface characteristics again give rise to additional spatial variability. Dense urban areas are again relatively warm, owing now mainly to the heat released from buildings and traffic (urban heat island, see Sec. 3.1) while forests and field remain colder.

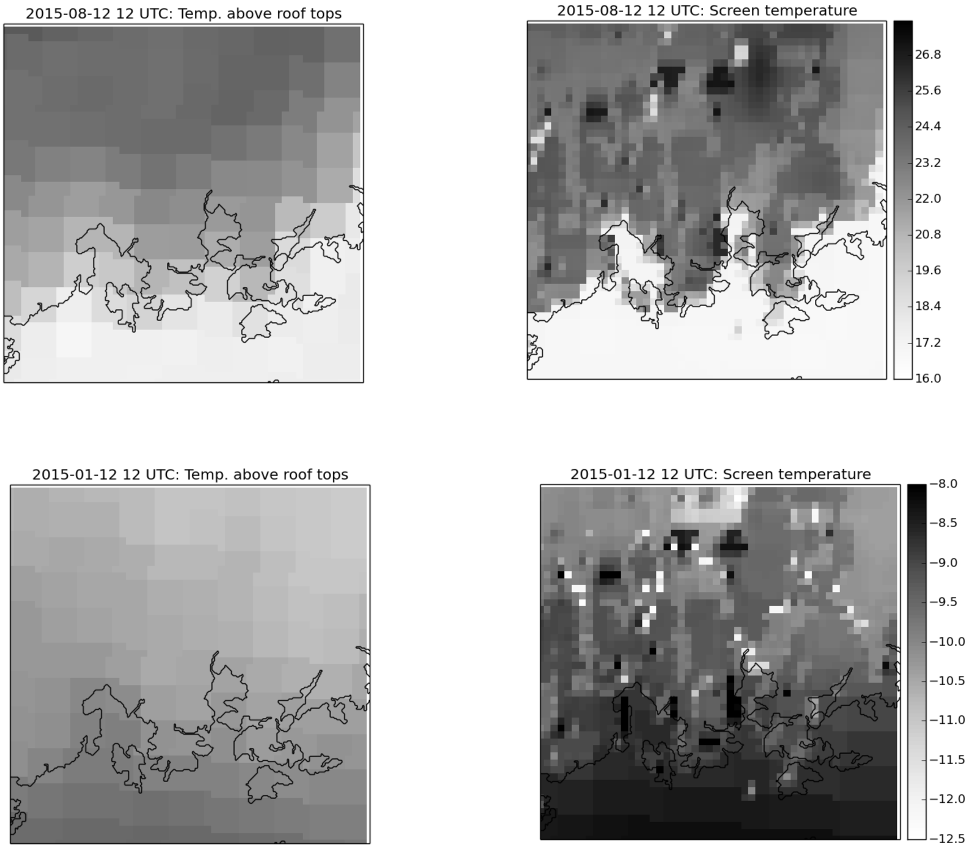

Fig. 3. Examples of the influence of a built-up environment on temperature in summer and in winter. The upper panes show the temperature (degrees Celsius) around the Helsinki region at 12 UTC on the 12th of August 2015. Left hand side: operational 36-hour forecast above the roof top level, right hand side: SURFEX model at screen level. Lower panels: as the upper ones, for 12 JTC on the 12th of January 2015.

4. Discussion

The energy efficiency of the buildings and the climate policy have been the main motivation for the heating and cooling energy projections and their spatial assessments presented here. However, use of the climate information could be further extended for the benefit of sustainable development and quality of life of habitants in urban areas. Climate data, socio-demographic and building stock data can be compiled and studied in more comprehensive way than often currently done. Such comprehensive considerations should be taken into account both in renovation of old building stock and in planning and construction of new urban areas and buildings.

Most of Finland is sparsely populated and, thus, most of both heating and cooling energy is actually needed in southern Finland. For monitoring the development of energy efficiency in Finland, and reporting heating demand of buildings to EU-level with one figure only, we also calculate annual average HDD which is weighted according to the population distribution over Finland. More accurate energy demand assessments might be obtained by combining spatial weather and climate information with the detailed building stock information and population distribution and their future scenarios.

In spatial planning it is important to recognize areas with vulnerable population groups and functions like nursing facilities during extreme weather conditions. Vulnerability to temperature extremes varies depending on socio-economic and demographic distribution and changes in them, e.g. on the proportion of elderly in the population. During the heat waves 2010 and 2014 in Finland about 300 extra deaths took place. According to Kollanus and Lanki (2014) the impact of hot weather can be seen in causes of deaths due to cardiovascular and respiratory diseases, mental disorders and nervous system diseases among elderly. In that study nursing facilities especially were found to have increased mortality during heat waves.

We demonstrated the urban heat island effect in the present climate of Helsinki. As a following step, it would be important to make multi-disciplinary studies to provide information on spatial distribution of population vulnerability (age distribution, housing) to temperature extremes in urban areas. Good examples of such studies are made e.g. in London and Hamburg (Wolf and McGregor, 2013; Schoetter et al., 2013). Recognition of vulnerable areas within the biggest cities in Finland could be utilized not only by urban planners but also by other authorities such as health and rescue authorities, and security of supply.

Furthermore we demonstrated using weather models how buildings can impact the local climate. These kinds of assessments could be utilized in planning of new areas. The efficiency of green infrastructure in minimizing the negative impacts of urban heat island can be studied with the help of such a model. The intensity and extent of the heat island vary according the weather patterns. The weather prediction models are continuously improving both in spatial and time scales and future weather service may be able to provide more detailed forecasts for daily technical building services.

Due to the Finnish long heating period, the security of energy supply is important in all weather conditions, especially in rural areas. We have good experiences on the use of weather forecasts in early warning systems in many sectors of society related to power cuts due to wind storms. The utilization of weather forecasts could be improved in preparedness and early warning systems also in cases of heat and cold waves, especially in health sector.

5. Conclusions

Impacts of climate change and complex interactions between climate and built environment need to be taken into account in decision making in urban planning, designing new buildings and in renovation of existing buildings.

Nowadays, climate information is mainly used in assessments of energy demand in buildings, and energy efficiency is a driving force in design of new buildings and renovation of old ones. Besides energy considerations, however, it would be important to assess combined impacts of climate and built environment on the health and well-being of people, as well, and thus improve the quality of life.

In the future the present work can hopefully be extended into systematic inclusion of weather and climate information in urban planning e.g. in multicriteria analysis for decision making in order to compare various alternative plans (Martinelli et al., 2015). Microclimatic simulations in residential area would help in providing healthy and thermally comfortable environment for inhabitants with best possible use of green infrastructure, and distribution of open spaces and buildings both in present and future climate.

Higher resolution spatial weather and climate information together with vulnerability assessments of population in built environment could also be used in preparedness during heat and cold waves. The preparedness would realize as prevention of extra health problems and burden in health care systems. Daily technical building services would benefit from new, improved weather forecasts concepts that are tailored especially for their area of the interest.

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Application of Transient Hygrothermal Modelling to Assess Thermal Transmittance: A Case Study in Dublin, Ireland

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Abstract

Building performance simulation has an important role to play in accurate energy efficient design, yet it is widely recognized that over-simplification in the modelling of physical phenomena leads to substantial sources of error. The evaluation of building envelope thermal performance is fundamental to the correct design of energy efficient retrofit solutions. Thermal transmittance (*U*-value) is a widely used and standard calculation method to assess thermal performance of the building envelope. However, simple calculations such as these do not incorporate climatic conditions applicable to the locality of the building. Simple simulations can be composed to account for moisture loading, moisture retention and the direct result of local climate conditions on transient thermal flux and thermal transmittance. This paper presents selected results of a recently completed research project to demonstrate that it is possible to assess moisture content to simulate corrected transient thermal transmittance of external walls using a hygrothermal modelling tool. The hygrothermal responses of cavity walls in a 1970's elderly nursing home in Dublin, Ireland and its components were assessed with a water content chart, linked to the moisture dependent conductivity of materials. The results and discussion presented in this paper highlight a need for the application of hygrothermal simulation tool to design optimum thermal retrofit/upgrade of exterior wall systems in various geographic locations.

Keywords: Existing building, Retrofit; Transient thermal transmittance; hygrothermal modelling; Performance gap

1. Introduction

In the last decade the obligation to ‘retrofit’ existing buildings in response to the long-term challenges of climate change and resource constraints has gained increasing significance (Dawson, 2007, Kelly, 2009, Centre for Low Carbon Futures, 2011, May and Rye, 2012). In the last couple of years the EU Directive on the Energy Performance of Buildings (EPBD) was superseded by the Recast EPBD placing a further emphasis on even higher thermal performance and efficiency levels of existing buildings in Ireland. This emphasis has been reinforced by the publication of the new Technical Guidance Document (TGD) Part L 2011 enforcing higher fabric efficiency values on existing buildings. Despite this, Ireland’s greenhouse gas (GHG) emissions including CO_2 are above the European (EU27) average and still rising to levels that will exceed allowances and commitments made for the Kyoto Protocol (Agency, 2015a, Agency, 2015b). Delivering a sustainable retrofitted building project remains a challenge in the industry due to lack of managing knowledge in sustainable construction projects. It has been argued that there is a possibility for substantial carbon emission reduction through appropriate approaches to sustainable retrofit, however, achieving it presents a multifaceted and difficult problem to the industry due to lack of knowledge management (Shelbourn et al., 2006). As 70% of current residential housing being built pre-dating building regulations including extremely poor insulation and energy efficiency levels, energy consumption optimisation and CO_2 emission reduction can be applied through the thermal upgrade of existing buildings to target the highest savings (Kema, 2008, Shelbourn et al., 2006).

Current research recommends further research on the thermal properties of traditional building materials and construction components; improvements to the thermal transmittance calculations; and a standardised methodology for in-situ measurement of thermal transmittance (Baker, 2011, Künzel, 1998, Little, 2011). Correspondingly, Alliance, (2012) noted that there is little work which describes or quantifies the performance of buildings in relation to energy efficiency while the evidence available is often flawed as it is not based on direct measurement or observation of buildings prior to retrofit work and frequently relies on modelled assessments to prove assertions of improvement.’ It is hoped that this research will inform the on-going deliberation and impact thinking with reference to the measures undertaken to reduce carbon emissions in relation to existing buildings.

The following paper details research into the thermal and hygrothermal performance of an existing residential nursing home in Dublin, Ireland. The nursing home is a 1970’s cavity wall with brick veneer façade, due to be retrofitted in both layout and thermally. A number of solutions were presented for thermal upgrade, with hygrothermal simulation applied to each. The existing building was then analysed using thermography in accordance with ISO 6781:1983.

The research set out to evaluate some of the key issues inherent in the standard calculations using climate and material data to simulate thermal response of cavity walls exposed to the reality of varying climate conditions and locations. Hygrothermal analysis has not previously been tested to aid the simulation of thermal transmission due, most likely to a recent focus on hygrothermal assessment for mould prediction and safe construction. However, this paper presents hygrothermal modelling as an ideal solution to the thermal assessment of thermal upgrade design as a result of pre-established model verification.

2. Moisture & Heat Control by Hygrothermal Simulation

The analysis of the coupling of heat and moisture is known as "hygrothermics" (IBP, 2015b). Building performance modelling began in the 1950's in an effort to calculate net energy demand, analysing the ways in which energy loads could be reduced by building related measures and getting information on the temperature without heating and cooling as this enabled the evaluation of overheating risks (Hens, 2009). Just a handful of models, were able to quantify the air and humidity balances in the building. Instead rough estimates on infiltration and ventilation were used and humidity remained untouched (ASHRAE, 2001).

Building regulations in Ireland recommend that the risks of interstitial condensation should be addressed by following the guidance within TGD Part L leading to British Standard BS 5250:2011. It is recommended here that the risk is assessed with a calculation using the Glaser method, specified in EN ISO 13788:2012. However, this 'conventional' assessment method completely ignores liquid moisture transport, for example as a result of wind-driven rain (WDR). More sophisticated one and two-dimensional full heat and moisture models are available that allow modelling vapour and liquid flow, that are transient in nature, that consider moisture sources such as wind-driven rain, rising damp, initial moisture, sorption and de-sorption, interstitial condensation and surface condensation. They are based on procedures set out in EN 15026:2007, and software packages for such assessment are available, for example MOIST, Match, Wufi, Latenite, Delphin and HygIRC (Sanders et al., 2014).

The first guideline on moisture control analysis by hygrothermal simulation was issued in 2002 by the International Association for Science and Technology of Building Maintenance and Monument Preservation (WTA), an association dealing with preservation and renovation of heritage constructions and rehabilitation of the building stock (WTA, 2002). Five years later the European Standard EN 15026 (2007) which is largely based on the WTA guideline was published (Kunzel, 2014). However, both documents do not contain any information on how to deal with small defects in the building envelope. Parallel to the standard work in Europe a slightly more comprehensive standard on moisture control design has been developed in North-America (BSR/ASHRAE, 2008). As a result of numerous damage cases linked to rainwater penetration into constructions with rendered facades, this standard has been the first that proposed the consideration of the effects of small leaks in the exterior finishes of exposed walls (Cheple et al., 2000).

2.1 Review of Simulation Tools

A report by Hens (1996) showed that 37 programs had been developed for Heat, Air and Moisture (HAM) analysis. A review of hygrothermal models suitable for building envelope retrofit analysis was conducted by Corporation (2003). This review identified 45 hygrothermal simulation tools. Delgado et al. (2010) expanded this figure to 57 hygrothermal modelling tools. This list was reduced to 14 hygrothermal models based on their availability to the general public. A critical review of these simulation tools and their level of complexity can be read in their book: (Delgado et al., 2012). WUFI was used in this research however as it has been validated in the field and laboratory more than other hygrothermal simulation tools.

2.2 WUFI (Wärme Und Feuchte Instateonär - Transient Heat and Moisture Transiency)

WUFI is a family of software products that allows realistic calculation of the transient coupled one- and two dimensional heat and moisture transport in walls and other multi-layer building components exposed to natural weather (IBP, 2015a). The software has been validated by detailed comparison with measurements obtained in the laboratory and on IBP's outdoor testing field (IBP, 2015a). Both one and two dimensional simulation tools have been validated numerous times using data derived from field and laboratory tests (Künzel, 1995). In terms of heat transfer, WUFI takes into account: thermal conduction, enthalpy flow (including phase change), short-wave solar radiation and long-wave radiation cooling (at night).

Vapour-phase transfer is by vapour and solution diffusion while liquid-phase water transport occurs through capillary conduction and surface diffusion. Convective heat and mass transfer is disregarded in WUFI models. In this case a simplified method of calculation of μ has been used for materials:

$$\textit{Vapour resistivity (Vr) x 0.2} = \mu$$

The thermal and moisture conditions and transport in buildings and building components are coupled. It is well known that high moisture levels result in higher heat losses, and the temperature conditions in building components influence the moisture transport. The traditional method for assessing the moisture balance of a building component has been the Glaser method (described in TGD Part L and ISO 13788) which analyses the vapour diffusion transport in the component. However, this method does not account for the capillary transport of moisture and for the sorption capacity of the component, both of which reduce the risk of damage in case of condensation. Furthermore, since the Glaser method only considers steady-state transport under simplified steady-state boundary conditions, it cannot reproduce individual short-term events or allow for rain and solar radiation. It was meant to provide a general assessment of the hygrothermal suitability of a component, not to produce a simulation of realistic heat and moisture conditions in a component exposed to the weather prevailing at its individual location (IBP, 2015b). WUFI software requires standard material properties and moisture storage and liquid transport functions. For boundary conditions, measured outdoor climates – including driving rain and solar radiation – are used.

3. Methodology

The methodology used in this phase of the research is modelled around multi-methodological design, incorporating some qualitative research to allow a fuller piece of research as suggested by Creswell (2009). Data collection and analysis through past and present research by others, along with policy design standards, recorded climate data, housing figures, common external wall constructions, standard design calculation methodologies and non-standard yet required design calculation methodologies corresponds well with and suits the theory of a quantitative methodological approach (Corbetta, 2003, Maxwell, 1998, Maxwell, 2012), the research is structured, performing a series of calculations and recording performance data to produce results which clarify the question. A qualitative approach was used to develop an understanding of the problem and improve methods for the quantitative element of research.

Searches were undertaken of recognised relevant academic and specialist building conservation literature databases through a number of journals and websites of the statutory bodies responsible for the protection of the Irish, UK and European environment. Using the technical indices, namely Technical Guidance Document Part L, the standard calculation methodology for external wall performance was identified as the *U*-value (W/m²K). This document then referenced extended documents explaining *U*-values and materials. Through analysing these documents the *U*-value calculation was evaluated, gaps in the process established, and solutions identified. *U*-value calculations are isolated from climate conditions, and thermal transmittance should be representative of in-situ performance. This problem was identified to be resolved using hygrothermal simulations through WUFI 5.3. The existing wall assembly with varying retrofit solutions applied in a Dublin based maritime climate was assessed using hygrothermal simulations in conjunction with examples set out by (IBP, 2013, Künzel, 1995, Künzel, 1998, Little, 2009, Little, 2011). The existing wall structure was verified through visual inspection through a bore scope along with measurements using metric system as an internationally agreed decimal system of measurement. Thus, the following thermal retrofit/upgrade assemblies were chosen for this study (see , , &).

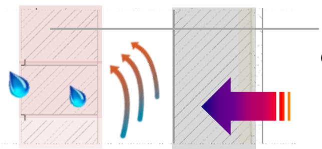

***Fig. 1** - Uninsulated Cavity Wall*

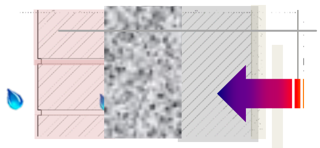

***Fig. 2** – Cavity Fill Cavity Wall*

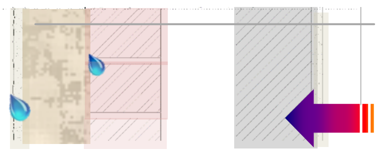

***Fig. 3** – Externally Insulated Cavity Wall*

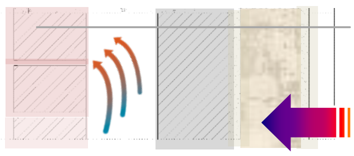

***Fig. 4** – Internally Insulated Cavity Wall*

4. Retrofit / thermally upgraded fabric performance

The fundamental implication of this research was to determine the effect of moisture content in the existing construction. With moisture, conductivity is affected, altering the assumed dry conductivity of materials. In this paper, the overall construction was simulated over 3 years to establish the expected water content in the wall after a significant period of time (as shown in **Fig. 7**). The existing wall thermal transmittance was calculated as 1.688W/m²K following calculation procedures within EN ISO 13788:2012. This was then used as the benchmark to compare against.

4.1 Orientation

Hygrothermal simulation was performed to establish the water content expected in each layer of the basic wall assembly, which then facilitated accurate thermal transmission calculations based on the corrected conductivity of the layers. Firstly, hygrothermal simulation was performed on the existing wall assembly for all 4 geographical orientations using a Dublin maritime climate file acquired from Meteotest (providers of weather, climate and environmental data in Europe). This study highlights the effect of combined wind and rain (wind-driven rain or WDR) on the thermal transmission of the existing wall build-up. For the purpose of this paper, the potential worst case scenario for the case study was analysed. As is demonstrated in ***Fig. 5*** & Table 1, the West façade is presented as the least thermally efficient façade orientation. This is due to a prevailing westerly wind in Ireland, thus driving rain exposure.

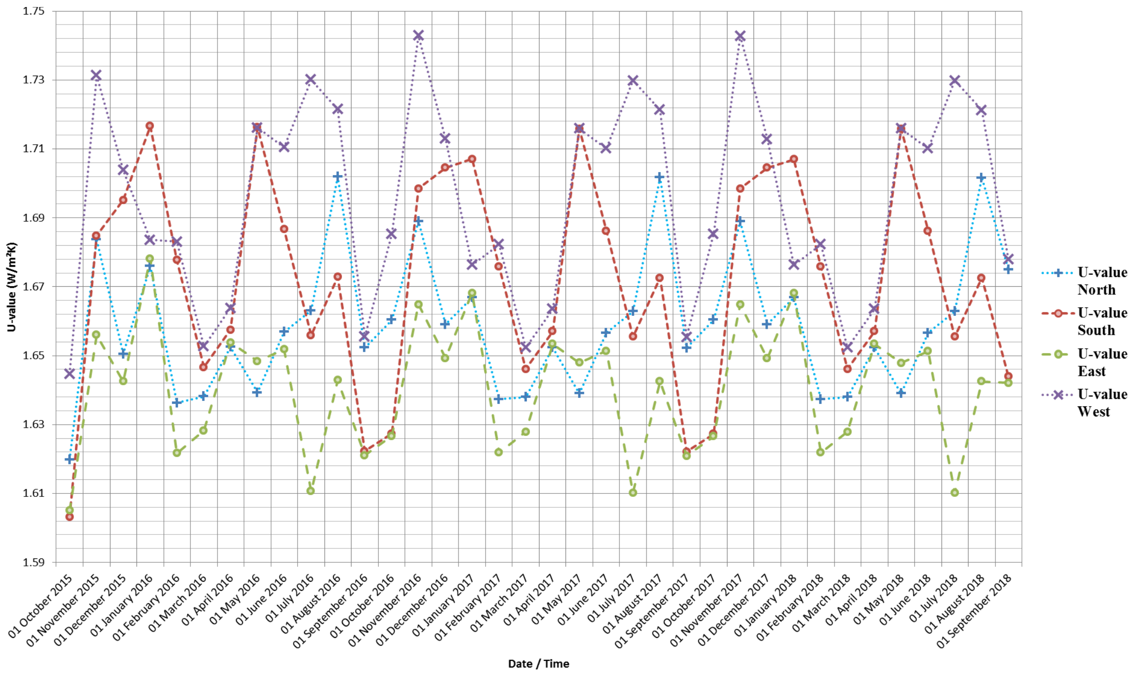

Fig. 5 – Thermal transmittance trend based on orientation. Source: WUFI Simulation.

Table 1. Transient thermal transmission values for all wall types. Source: WUFI Pro 5.3

	Benchmark(W/m²K)	*North (W/m²K)*	*South (W/m²K)*	*East (W/m²K)*	*West (W/m²K)*
Avg	1.688	1.859	1.877	1.824	1.913
Min	N/A	1.801	1.777	1.780	1.835
Max	N/A	1.927	1.953	1.875	1.980

Following the analysis of the influence of orientation on thermal transmission, Table 1 illustrates the benchmark thermal transmittance compared against the average transient thermal transmittance based on expected moisture content. Startlingly, the contrast is quite significant, up to 17.2% higher (poorer) than the traditional thermal transmittance and 13.3% higher on average. According to BS 6946, a significant correction shall be applied when over 3% variation from the original thermal transmittance is encountered. Thus, correction shall be applied to the thermal transmittance in this case.

As mentioned, the existing uninsulated wall assembly must be simulated to assess the water content of each layer to formulate the transient moisture dependant thermal transmission. The simulation was performed on a westerly orientated façade over 3 years to derive a pattern of increased, decreased or steady predictable moisture content (see **Fig. 6**).

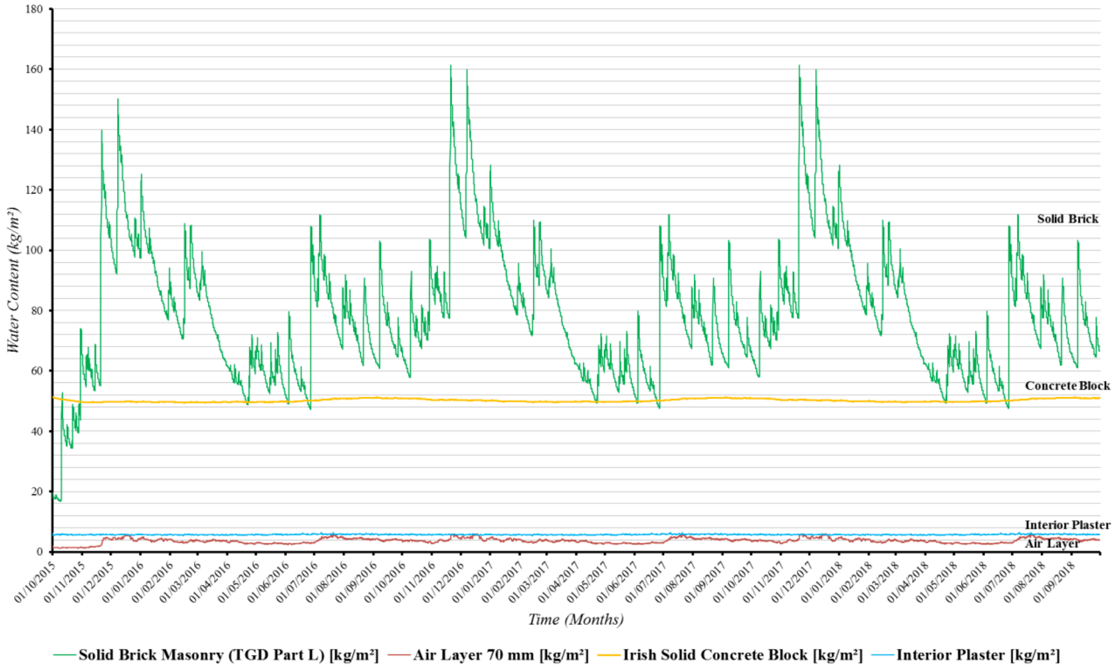

***Fig. 6** – Water content of individual component layers*

Fig. 6 reveals that the wall did not dry slowly or fully. The WUFI postprocessor analyses hourly temperatures and heat flows resulting from the full transient simulation, taking into account hygrothermic conditions in the assembly which result from exposure to climate and occupant behaviour. This includes the effects of variable material properties (in particular, the effect of the variable moisture content on the thermal conductivity), additional thermal transport processes (such as latent heat transport by vapor flows), additional heat sources (such as solar radiation), and parameters depending on environmental conditions (such as wind-dependent surface transfer coefficients). The postprocessor also computes a monthly transient thermal transmittance, using the formula

$U = (-Q) / \Delta Ta$ where, *ΔTa [K]: Monthly mean value of temperature difference between indoor and outdoor air temperature*

5. Retrofit Assembly Simulation

According to TGD Part L 2011, only material alterations require a backstop or target thermal transmittance for existing buildings of 0.60W/m²K. As a target emanating from the overall research, the backstop thermal transmittance as set out in the Sustainable Energy Ireland (SEAI) Better Energy

Homes Scheme for thermal upgrade funding were selected as design targets of 0.27W/m²K for all forms of thermal upgrade treatment to external walls.

Thermal transmittance targets were achieved through the application of insulation on the existing wall assembly. To accurately predict the moisture content and thermal transmittance, accurate material properties were compiled in *Table 2* from (Department of the Environment, 2011), WUFI Pro 5.3, and material manufacturers directly.

Table 2 Table of material data for simulations

Wall Types	***Insulation Material Applied***	***Conductivity (W/mK)***	***Specific Heat Capacity (J/kgK)***	***Bulk Density (kg/m³)***	***Porosity (m³/ m³)***	***Water Vapour Diffusion Resistance Factor***	***Insulation Location***
WT1	Kingspan EPS White	0.038	1130	14.8	0.95	60	***Internal Insulation***
WT2	Gutex Wood Fibre Board (thermoroom)	0.038	2100	131	0.91	2	
WT3	Calsitherm Calcium Silicate	0.057	1303	222	0.92	5.4	
WT4	Sto Perlite	0.042	850	100	0.96	8	
WT6	Isover Mineral Wool	0.035	840	115	0.95	1	
WT7	EcoCell Cellulose	0.040	2500	70	0.95	1.5	
WT8	Kingspan PIR	0.022	1400	32	0.99	50	
WT9	Kingspan Phenolic	0.020	1880	43	0.95	200	***External Insulation***
WT10	Kingspan EPS White	0.038	1130	14.8	0.95	60	
WT11	Kingspan EPS Platinum	0.031	1130	17	0.95	30	
WT12	Rockwool Façade Mineral Wool	0.038	1030	135	0.953	1.1	
WT13	Gutex Wood Fibre Board (thermowall)	0.039	2100	160	0.90	2.1	
WT14	Kingspan EPS EcoBead	0.033	1200	11.5	0.95	60	***Cavity Fill Insulation***
WT15	Rockwool Mineral Wool EcoWarm	0.039	850	40	0.95	1.1	

These insulation materials were then incorporated into hygrothermal models and simulated over a 3 year time frame in a Dublin based maritime climate.

The water content of the wall assemblies did not drop below 15kg/m³ beyond the first month. So, 80% of wall assemblies exhibited a rising water content which stabilized after 3 years, while the remaining 20% of wall assemblies still displayed increasing water contents. These results indicate a trend which may provide a predictable performance applicable to these wall assemblies. Furthermore, water content may be predicted for each wall assembly as analysed in **Fig. 7**.

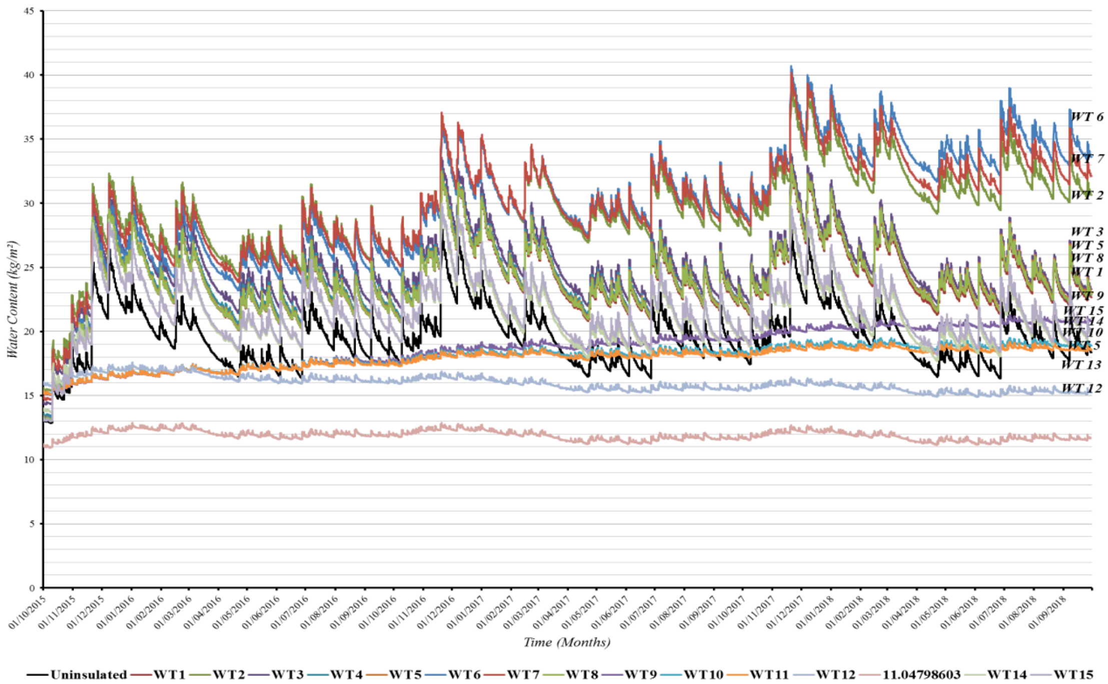

***Fig.** 7 – Water content in each wall build-up. Source: WUFI simulation*

This water content was applied and incorporated to thermal transmission simulations over the same 3 year period in **Fig. 8**.

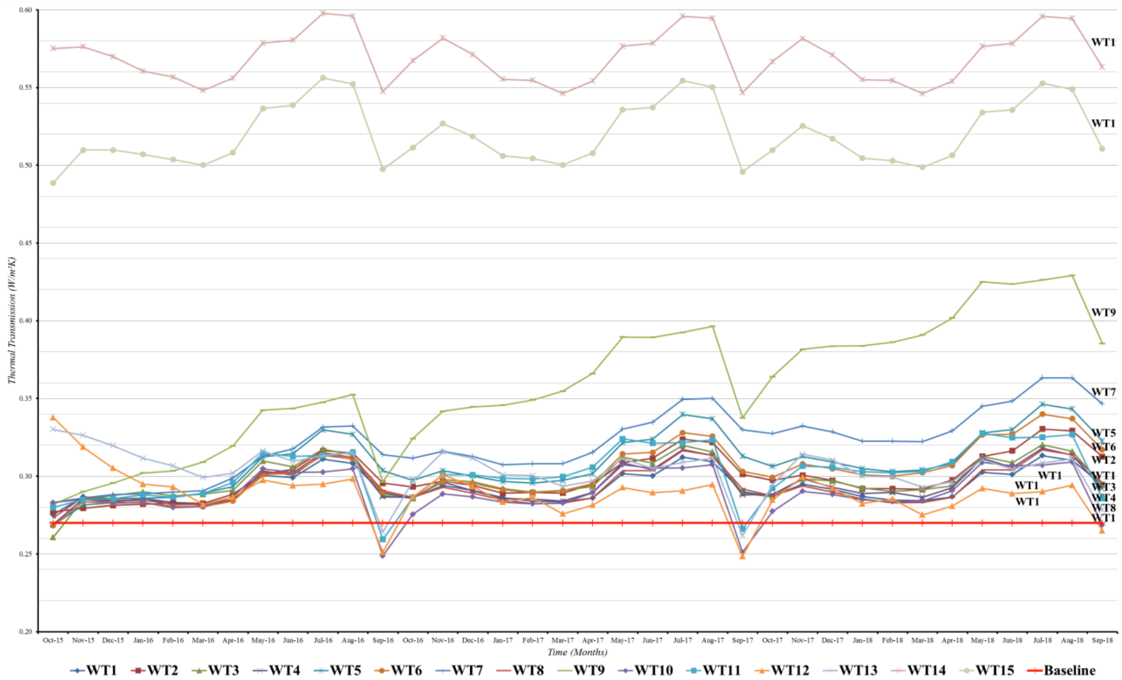

***Fig. 8** – Trend of cavity wall retrofit thermal transmittance. Source: WUFI simulation*

The fundamental here is that the thermal transmittance for each wall assembly varies dramatically as demonstrated through the hygrothermal simulations in ***Fig. 8***. **Table 3** clarifies the findings of ***Fig. 8*** through a chart highlighting the highest thermal transmission.

Table 3 Transient thermal transmission values for all wall types. Source: WUFI Pro 5.3

	WT 1	WT 2	WT 3	WT 4	WT 5	WT 6	WT 7	WT 8	WT 9	WT 10	WT 11	WT 12	WT 13	WT 14	WT 15
Avg	0.300	0.300	0.298	0.295	0.309	0.302	0.321	0.294	0.358	0.289	0.302	0.289	0.304	0.570	0.520
Min	0.277	0.277	0.261	0.269	0.269	0.268	0.283	0.273	0.282	0.249	0.259	0.249	0.262	0.546	0.489
Max	0.330	0.330	0.320	0.318	0.346	0.340	0.363	0.317	0.429	0.309	0.328	0.338	0.330	0.598	0.556

Table 3 confirms the inconsistency between the standard thermal transmission calculation and these simulations. The benchmark thermal transmission of 0.27W/m²K was exceeded by as much as 158% in the case of phenolic insulation at maximum peaks. On average, this translates to 33% greater than the benchmark.

6. Discussion

The finding of this stage of the research suggests that orientation has a significant impact on the hygrothermal performance of an external cavity wall. Correspondingly, the orientation will have a significant impact on the thermal transmittance of the same wall assembly. This means that when designing an external wall, designers should focus the design parameters around the West façade for hygrothermal performance and thermal transmittance in Ireland. Furthermore, the findings from the research identify and highlight the disparity between thermal transmittance from standard calculations and the gap between those and the simulations presented here. It is clear that the existing thermal transmittance calculation methodology is imbalanced with a number of flaws in its composition. This could be addressed using the knowledge derived from this research. To further add to this research, verification through in-situ analysis will be carried out on this case study property. Different techniques can be employed to measure in-situ thermal transmittance such as, for instance, thermographic surveys (Albatici and Tonelli, 2010, Fokaides and Kalogirou, 2011), however, the common in-situ measurement methodology uses thermal flux sensors (Peng and Wu, 2008, Desogus et al., 2011).

7. Conclusions

This paper has reviewed hygrothermal simulations along with standard *U*-value calculations as a method to increase credibility and validity of conclusions resulting from further experimental research. This paper is intended to serve as an introduction to issues emanating from a larger research project in order to encourage researchers to more fully study the topic.

The realm of heat transfer and building physics is a question throughout the AEC (Architectural, engineering and construction) sector, particularly within retrofit and refurbishment. This has been confirmed through an examination of previous research in the field, accompanied by personal experience. The understanding gained regarding the influence of external and internal climactic conditions has already, and continues to enhance the product of this research. Adopting hygrothermal simulations, along with accurate material data analysis has allowed a more concise and defined format of information to be assessed. Through the trawling through previous literature available on AEC research, comparable precedent has been established to set a benchmark for results generated from this research

The findings of this paper identify discrepancies between hygrothermally simulated and standard method *U*-value calculations. The effect of moisture, wind and solar radiation may cause the thermal performance gap illustrated in the simulated assemblies versus the standard method *U*-value. Thus, this paper offers a source of information for researchers and designers exploring the performance of external walls to anticipate best practice detailing and in-situ thermal performance values.

Modelling the wall assemblies, with different porosities, moisture storage capacities and liquid water transport coefficients along with accurate climate data gave very different calculated moisture contents and correspondingly, a corrected thermal transmittance. It is clear that, if advanced hygrothermal models in accordance with EN 15026:2007, such as WUFI, are to be used to carry out routine assessments of moisture conditions and *U*-values in building structures, considerably more construction material data must be made available by manufacturers to achieve realistic simulation results.

Effective research on detailed heat transfer in construction is difficult and necessitates skill and knowledge that is rarely provided in AEC research programs. To understand the full range of challenges faced when doing research, graduate AEC students should take at least one course on building physics, preferably one that covers both heat and moisture control incorporating material and climactic influence.

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Building a Prosperous Urban Future with Reflective Roofing

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Abstract

The great challenge of the next 100 years is to remake our rapidly growing cities into structures that can stand up to environmental changes with residents that are healthier, happier, and more prosperous than previous generations. We often do not think about the roofs above our heads, but making thoughtful materials choices on urban rooftops is a critical, readily-implementable strategy to help meet our new urban challenges. Roofs comprise over 25% of urban space and are readily accessible and easy to upgrade relative to other urban sustainability interventions. With roofing technologies that are currently available, cities can improve their biodiversity, reduce rising urban temperatures, improve health and quality of life, and defend against high energy costs and power blackouts.

One of the key sustainable roof technologies in the market today are reflective, "cool" roofs. Reflective roofing is an ancient concept achieved with modern technologies that have been growing in the market over the last 20 years. Reflective roofing is a cost-effective and easily deployable strategy to cut cooling energy demand by up to 20%, reduce temperatures in and around buildings, improve air quality and health, and cancel the warming effect of atmospheric greenhouse gases. This paper will provide building owners, government officials, and corporate decision-makers with:

1. the tools to quantify the benefits and costs of reflective roofing for buildings, communities, cities, and the planet;
2. an understanding of the available reflective technology options and a look forward at cutting-edge technologies that will be on the market in the next few years;
3. a roadmap for implementing reflective roofing in a variety of contexts via a detailed review of the most successful policies and programs worldwide that have helped spur local adoption of cool roofs including building and energy code requirements, construction specification requirements, green workforce development, and innovative public information campaigns.

Keywords: cool roofs, reflective roofs, urban heat islands, energy savings

1. Introduction

The parallel challenges of warming global temperatures and a mass migration from rural to urban spaces highlight the importance of improving the sustainability of cities. The benefits of sustainability to urban quality of life, economies, energy use and health are well understood, but even leading cities face difficulties in effecting real change quickly in their complicated and interconnected urban ecosystems. An effort to making smarter choices about roofs, such as using more solar reflective materials, can significantly and immediately benefit efforts to enhance the sustainability of the world's urban spaces. This paper will review the benefits, costs, and technologies available to implement cool roofs and describe a few examples of cities that have used reflective roofing to save energy, cut energy bills, improve grid reliability, cool urban heat islands, and improve the health and social welfare of its citizens.

2. Roofs are a platform for urban sustainability

2.1 Good roofs make sustainable cities

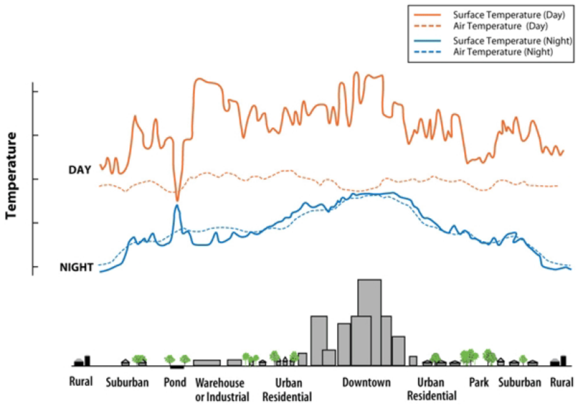
While the average person doesn't give it much thought on a regular basis, roof space is an important platform for urban sustainability efforts. Akbari (2008) found that roofs made up between 25% and 35% of the overall urban fabric in the studied cities. This is a significant amount of urban space that, if upgraded with reflective roofing, vegetation, solar power, or some combination, could drive benefits worth between $0.40 per square meter and $4.33 per square meter in the form of energy savings, reduced health care and storm water management costs, per Kats (2015).

Implementing sustainable roofs can rapidly change cities. Policy makers and building owners have more opportunities to upgrade the sustainability of roofs than other building components or pavements. Roofs are replaced every 15-20 years on average – a replacement rate of 5-7% per year. The benefits to energy use, air quality, health, urban economies, and global climate change mitigation of better roofing start the minute they are installed.

2.2 Urban heat is the defining sustainability challenge for the 21st century city

As Figure 1 from Zhang (2010) shows, cities tend to be an average of 4 to 6 degrees Celsius hotter than rural areas. This phenomenon, known as the urban heat island or UHI, is the result of several factors. Cities are less vegetated relative to rural areas. Buildings block or slow natural wind patterns that would help move heat. Cities are hubs of human activity that generate heat. The biggest contributor to urban heat islands, however, is the predominance of dark, impermeable roofs and pavements that absorb solar energy and radiate heat. UHI is both a day-time and night time phenomenon. Indeed, Climate Central (2014) found that night-time UHI can exceed 20 degrees.

The world is in the midst of a rapid urbanization. The United Nations reports that the percentage of the world's population living in cities will grow from 50% today to 80% in 2050 – all moving into urbanized space that makes up less than 2% of the earth's surface. Oke (1973) and Georgescu (2013) found that the increase in urban density and city size exacerbates all of the factors that cause UHI. Currently, excess urban heat is rising at twice the rate of global average climate change.



Overheated cities experience a number of negative impacts that affect almost every aspect of urban life.

Figure 1: Temperature differences between different levels of urbanization. Source: NASAUrban heat leads to increased energy consumption

Solar energy absorbed by buildings converts into heat energy that is either transferred inside the building or blown off the roof to heat the surrounding air. For buildings with environmental controls, excess heat leads to an increase in cooling energy demand. In general, the relationship between temperature and city demand for electricity resembles a hockey stick. Below a threshold air temperature, typically between 24 to 27 degrees Celsius, daily energy demand is relatively constant. Demand for electricity spikes dramatically as temperatures rise above that threshold. Akbari (2001) indicated that peak electricity demand increases by 2 to 4 percent for every 0.5 degrees Celsius increase in temperature above a threshold of about 15 to 20 degrees Celsius. In New York City, for example, electricity consumption is 29 percent higher on a 32 degree Celsius day compared to a 26 degree Celsius day. The demand for cooling is generally highest during peak electricity consumption hours, the late afternoon and early evening. Akbari (2005) found that the UHI-related increase in air temperature is responsible for 5 to 10 percent of U.S. peak electric demand.

2.2.1 Urban heat reduces air quality

Decreased air quality is one of the most far-reaching effects of UHIs. Poor air quality, in which the ozone levels and levels of small, inhalable airborne particles (PM-2.5) from nearby coal plants are high, is detrimental to public health and the environment. The World Health Organization (WHO) estimated 21,000 premature deaths per year occur across 25 European countries because of high levels of ozone (Amann et al. 2008). WHO further estimates that 14,000 respiratory-related hospital admissions in Europe are directly due to high ozone levels.

Urban air quality influences and is influenced by a city's temperature. An increase in temperature corresponds to the rate at which ozone feed stocks cook into ozone. Akbari (2005) found that for every 1 degree Celsius the temperature in Los Angeles rises above 22 degrees Celsius, smog increases by 5%. Figure 2 from Piety (2007) showed how smog forms in a nonlinear fashion in accordance with the maximum surface temperature at Baltimore-Washington International Airport. Each point represents an 8-hour period. At 27 degrees Celsius, most of the points are below the minimum EPA compliance level of 60 parts per billion (noted with a red line in Figure 2). At and beyond 32 degrees Celsius, the majority of points lie above minimum compliance, meaning the amount of ozone is at dangerous levels.

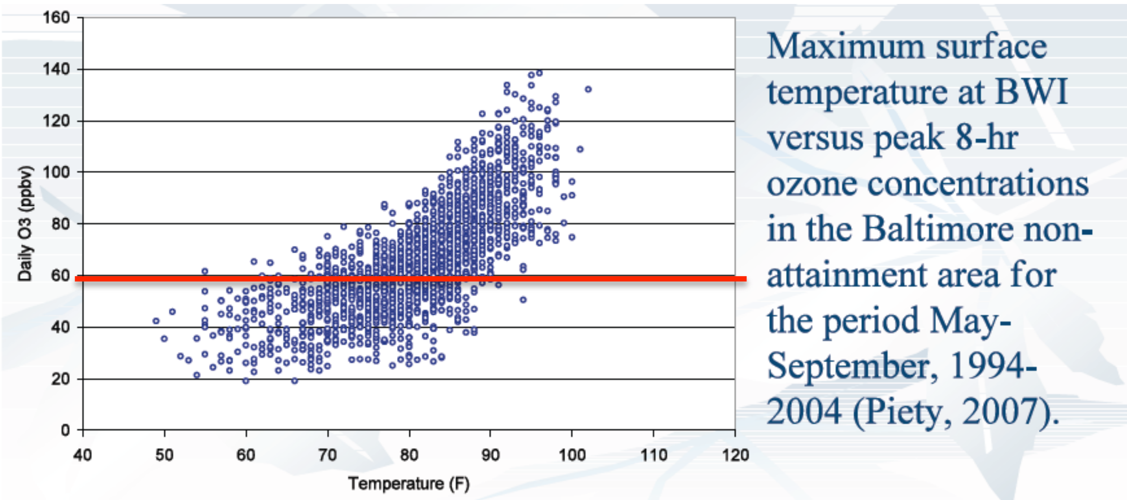


Figure 2: Ozone concentrations by maximum surface temperature. Piety (2007)

2.2.2 Urban heat compromises health

Increased daytime temperature, reduced nighttime cooling, and high air-pollution levels increase health problems and mortality, especially among low-income and elderly populations. In fact, Wong (2012) found that between 1989 and 2000, studies of 50 U.S. cities recorded a rise of 5.7% in mortality during heat waves. The Centers for Disease Control and Prevention (2012) reported that over a 12-year period (1999-2010), excessive heat caused 7,415 premature deaths in the United States. Heat waves in Europe claimed over 52,000 lives in 2003 alone – one of the greatest natural disasters in history.

In addition to causing higher daytime temperatures, urban heat islands keep cities and their residents from cooling off at night. Hotter nighttime temperatures are especially dangerous during extreme heat events. Urban populations are often unable to recover from the daytime heat and become more vulnerable to heat-related health problems in subsequent days.

2.3 Reflective roofing mitigates urban heat

Replacing dark urban surfaces with more reflective and lighter-colored surfaces on roadways, walkways, and roofs is a primary UHI mitigation strategy. The darker a surface, the more potential it has to store heat. A light-colored or reflective surface has a very small potential to store heat because of its high albedo, or reflective ability. Surfaces that reflect solar energy stay cooler, release less heat into the surrounding air, and allow for nighttime cooling in a city.

Cool surfaces are measured by how much light they reflect and how efficiently they radiate heat (thermal emittance or TE). Solar reflectance is the most important factor in determining whether a surface is cool. A cool roofing surface is both highly reflective and highly emissive to minimize the amount of light converted into heat and to maximize the amount of heat that is radiated away.

Most roofs are dark and reflect no more than 20 percent of incoming sunlight (i.e., these surfaces have a reflectance of 0.2 or less); while a new white roof reflects about 70 to 80 percent of sunlight (i.e., these surfaces have a reflectance of 0.7 to 0.8). New white roofs are typically 28 to 36 degrees Celsius cooler than dark roofs in afternoon sunshine while aged white roofs are typically 20 to 28 degrees Celsius cooler.

2.3.1 Benefits of cool roofs to individual buildings

Energy savings potential: Increasing the reflectance of a roof from 0.1-0.2 to 0.6 can cut net annual cooling energy use by 10 to 20 percent on the floor of the building immediately beneath the roof by reducing the need for air conditioning. Levinson 2010 presented an analysis of energy savings in new and old office and retail buildings by U.S. zip code. The analysis found that there are net energy savings in every part of the U.S. (warm and cold climates) except in northern Alaska. Target Corporation, one of the largest American retailers, has experienced net overall energy savings (based on all energy consumed for heating, cooling, lighting and equipment) between 0.5% and 1.0%, depending on location, in their facilities across the USA by specifying white reflective thermoplastic membranes. These energy savings collectively result in several millions of dollars in energy cost savings annually for the company.

Cost savings potential: Levinson 2010 found the average annual net energy cost saving (cooling energy saving minus heating energy penalty) for a white roof on a commercial building in the U.S. is $0.36 per square meter ($0.40 in 2015 dollars). Retrofitting 80 percent of the 2.6 billion square meters of commercial building roof area in the U.S. would yield net annual energy cost savings of $735 million. Globally, cool roofs could save billions of dollars. Kats 2015 evaluated the economic benefits from the installation of cool roofs on municipal buildings in Washington DC and found that cool roofs installed on 2.6 million square meters of municipal roof space would generate net savings to the city of $46.5 million ($17.88 per square meter) in energy cost reductions and avoided health costs.

Improved thermal comfort: In a building that is not air conditioned, replacing a dark roof with a white roof can cool the top floor of the building by 1 to 2 degrees Celsius. Programs to install cool roofs and train proper fan use in Philadelphia led to 3 degree Celsius reductions in indoor air temperature during hot days. These temperature reductions are enough to save lives in extreme heat waves and make non-conditioned work environments like barns and warehouses more usable and comfortable for employees.

2.3.2 Benefits of cool roofs to cities

Reduced summer heat island effect Simulations run for several cities in the U.S. in Akbari (2001) have shown that city-wide installations of highly reflective roofs and pavements, along with planting shade trees will, on average, reduce a city's ambient air temperature by 2 to 4 degrees Celsius in summer months. Reducing urban temperatures makes cities more comfortable and enjoyable to live in and promotes healthier populations.

More resistance to heat related deaths Cool roofs can cool the areas in a building where the risk of death during heat waves is high. For example, there were 739 deaths in the Chicago heat wave of 1995. Virtually all of the deaths occurred in the top floors of buildings with dark roofs. Subsequent heat waves have claimed thousands of lives in the U.S., France, Russia, and elsewhere. Kalkstein 2014 found that 10 percent increases in urban vegetation and reflectivity can reduce mortality during heat waves by 6-10 percent.

Reduced peak electricity demand Cool roofs can improve utility capacity utilization and therefore profitability, reduce transmission line congestion, avoid congestion pricing, and forego the need for additional investments in peaking generation capacity. Rosenfeld et al. (1996) estimated that eliminating the urban heat island effect in Los Angeles a reduction of 3 degrees Celsius could reduce peak power demand by 1.6 gigawatts and save about $175 million per year ($268 million in 2015). Approximately $15 million of that amount was due to more reflective pavements. A 2004 analysis of New York City by the Mayor's Office of Long Term Planning and Sustainability, when electricity averaged $0.165 per kWh, found that a one degree reduction in temperature would cut energy costs by $82 million per year. Electricity prices have subsequently increased by over 20 percent. Hoff (2014) found that peak energy cost savings can be double the base energy savings in many cooler climate zones. Most cost benefit analyses have not quantified this important aspect of energy savings until recently.

Air quality benefits City-wide temperature reduction not only makes cities more comfortable, but also improves air quality because smog (ozone) forms more readily on hot days. Simulations of Los Angeles in Akbari (2001) indicate that lighter surfaces and shade trees could cool temperatures and thus reduce exposure to unhealthy levels of smog by 10 percent to 20 percent. Across the U.S., the potential energy and air quality savings resulting from increasing the solar reflectance of urban surfaces is estimated to be as high as $10 billion per year.

2.3.3 Benefits of cool roofs to the planet

Global cooling potential Akbari 2008 found that replacing the world's roofs and pavements with highly reflective materials could have a one-time cooling effect equivalent to removing 44 billion tonnes of CO_2 from the atmosphere, an amount roughly equal to one year of global man-made emissions. Every 10 square meters of white roofing will offset the climate warming effect of one tonne of CO_2. Assuming the average car emits 4 tonnes of CO_2 per year, the combined "offset" potential of replacing the world's roofs and pavements with highly reflective materials is equivalent to taking all of the world's approximately 600 million cars off the road for 20 years. Put another way, the cooling offset of global reflectivity from cool roofs would cancel the warming effect atmospheric GHG generated by 500 medium-sized coal power plants over the life of the roof.

3. Reflective technology options

3.1 Reflective Roof Technology Options

3.1.1 Roof Types and Cool Roof Options

Cool roofing materials can be divided in to two categories, based on their intended use. Although some technologies are suitable for both applications, generally they are intended for use in either low (≤9.5°, 2/12) or steep (>9.5°) slope installations. The requirements for being considered a cool roofing material vary by category and program. Table 1 summarizes the requirements of the two most prominent programs in the USA, California's Title 24 Energy Code and the Environmental Protection Agency's Energy Star Program.

Table 1. Cool Roof requirements

	Reflectivity		Thermal Emissivity		SRI
	Initial	Aged	Initial	Aged	
California Title 24					
Low Slope	n/a	0.63	n/a	0.75	75
Steep Slope	n/a	0.20	n/a	0.75	16
Energy Star					
Low Slope	0.65	0.5	n/a	n/a	n/a
Steep Slope	0.2	0.15	n/a	n/a	n/a

In the United States, the reflectivity and emissivity (together, their surface properties) of roofing materials are tested according to protocols defined by the Cool Roof Rating Council (CRRC).

The CRRC includes representatives from roofing manufacturers and other experts. The CRRC's standards are recognized in major building energy codes and list both initial/ as received and 3 year aged values.

Cool roofing materials are available in a wide variety of technologies. The most common low slope roofing materials include coatings, single ply membranes and mutli-ply bituminous systems. Coatings are applied over waterproof membrane systems such as dark colored elastomeric single ply sheets or bituminous systems, to provide the desired reflective properties and/or to extend the underlying membrane's service life. Acrylic coatings are most commonly used in these applications. A significant advantage of coatings is that they can be applied to in-place membranes, thereby salvaging the existing materials and negating the need to remove, dispose and replace them, most significantly, the existing thermal insulation. Acrylic coatings have some of the highest initial reflectivity values, with a few products in the low 90 percent range.

Liquid membranes are also available which typically consist of multiple layers of field applied acrylic, polyurethane or other fluid chemistries, incorporating reinforcements. These types of products are particularly beneficial for roofs with difficult access and extensive amounts of roof top equipment and other penetrations concentrated in small, congested areas where roll goods are impractical, such as on high rise buildings.

Combined, thermoplastic single ply membranes, which include both polyvinyl chloride (PVC) and thermoplastic olefin (TPO) materials, represent more than 40% of the low slope roofing market in the United States. The ever increasing demand for energy saving cool roofing materials has been a key driver in their growth over the past years. These materials have initial reflectivity values within the low to the high 0.80 range. They can be applied in a variety of configurations including mechanically attached, induction welded, and adhered. The use of hot air welding to seal the seams of the sheets in roll widths of 8' or 10' allows for high application productivity and low installed costs. Although much less common, some suppliers also offer elastomeric membranes with a white, reflective weathering surface.

Modified bituminous membranes have benefited from the development of reflective granules, and products are now available that achieve reflectivity levels above 0.70. Some metallic surfaced materials achieve values in the same range as thermoplastic membranes and acrylic coatings. Modified bitumen sheets which are typically installed in two or more layers, provide redundancy and a high level of resistance to mechanical damage. A variety of sheets are available depending on the application technique to be used: torched on, adhered with hot asphalt or cold adhesives, or mechanically attached. They are often selected in re-roof situations where their compatibility with existing bituminous materials is advantageous.

Table 2 provides a summary of the initial and three year aged solar reflective properties of the various types of materials available (NOTE: All of these materials have high thermal emittance values, therefore for clarity, only the reflectance values are included)

There are a myriad of cool roofing material options available to choose from. Ryan (2015) noted that there are more than 4,600 products listed in the Energy Star database, and about 2,600 products listed in the Cool Roof Rating Council's database (2015). With products available across the entire spectrum of technologies, performance levels and price there is a cool roof solution for every need and situation.

Table 2: Reflectivity performance ranges for common roofing products.

Type	Number of CRRC Rated Products	Initial Reflectance			Aged (3-year) Reflectance		
		Average	Max	Min	Average	Max	Min
Asphalt Shingles	58	0.26	0.41	0.13	0.26	0.37	0.16
Build-Up and Modified Bitumen Sheet Roofing	84	0.49	0.88	0.25	0.45	0.8	0.23
Concrete/Clay Tile and Slates	429	0.31	0.82	0.08	0.30	0.74	0.1
Field-Applied Coatings	484	0.80	0.94	0.04	0.68	0.87	0.03
Metal Products	1008	0.36	0.77	0.25	0.36	0.74	0.24
Metal Shakes/Shingles (including Granular Coated Metal)	17	0.31	0.46	0.22	0.30	0.44	0.23
Other Roof Products: Fluid Applied Membrane Roofing	10	0.80	0.9	0.42	0.68	0.78	0.43
Single Ply Thermoplastic and Thermoset Roofing	123	0.71	0.91	0.06	0.60	0.81	0.07

There are alternative approaches to achieve similar effects to high surface reflectivity. Some jurisdictions recognize ballasted roofs as alternatives to reflective membranes or coatings in their regulations. Large stone ballast acts as a heat sink, moderating heat transfer into the building. Vegetated or "green" roofs consist of waterproofing membranes covered with growing medium and vegetation. These roofs provide cooling energy savings and help mitigate the urban heat island effect through a combination of shading by the plant media and evapotranspiration. Some major metropolitan areas are incentivizing the use of green roofs as a means to provide some relief to aged, deteriorated storm water sewage systems which often are tasked with handling water volumes far greater than anticipated when they were installed. Although costs continue to decrease over time, they generally have installed costs that are upwards of 50% more expensive than conventional roofing systems.

3.1.2 Design Considerations for Low Slope Cool Roofs

As with all roofing materials and other outdoor surfaces, cool roofs are subjected to various forms of soiling. Research has shown that the degree of soiling tends to level off or plateau after approximately three years of exposure, which is the basis for reporting aged reflectance and emittance values in the most prominent cool roof rating programs. When accounting for the effects of cool roofs in HVAC and other building physics calculations and assessments, only aged values should be considered.

Akbari (2005) has shown that cleaning of some types of cool roof materials such as thermoplastic membranes can restore practically all of a product's initial reflectivity it is rarely practical or cost effective to do so. The benefits of cool roofs are clearly reduced by surface soiling. However, an analysis of all products in the CRRC database with an initial reflectivity of 0.70 or greater (average: 0.82), and an initial emissivity of 0.75 or greater, showed the average 3 year aged reflectivity of these products to be 0.70, with over 90% of the products having an aged reflectivity greater than 0.60. Most modeling on the energy and UHI mitigation impacts of cool roofs is based on an assumed value of 0.55 for aged reflectivity.

Some have postulated that in cold climates cool roof surfaces do not heat up as much as darker materials in the winter months, thereby making them more prone to condensation, and less capable of drying out any condensate that may form. Fenner (2014) reported on a survey of twenty four retail stores in northern US states. All the roofs had mechanically fastened reflective thermoplastic membranes and had been in place more than 10 years. None of the roofs had a vapor retarder. No evidence of condensation was found in any of the roofs. As the Department of Energy (2010) has noted with regards to the potential for condensation in cold climates, "…while this issue has been observed in both cool and dark roofs in cold climates, the authors are not aware of any data that clearly demonstrates a higher occurrence in cool roofs.."

Energy codes are calling for ever greater amounts of thermal insulation in buildings, which some believe negate the energy savings benefits of cool roofs Desjarlais (2012) ran simulations using the "Simplified Thermal Analysis of Roofs" (STAR) model to attempt to answer this question. They modeled a cool white roof, incorporating code mandated insulation levels, for a representative city in each of the USA climate zones to establish the base lines. They then repeated the analysis with a black roof, and found that additional insulation was required in all cases for the black roof to achieve the equivalent energy performance as the white roof (Table 3). Ramamurthy (2015) conducted a field study of 5 roofs with various combinations of albedo and insulation values (up to R48). They found that the most energy efficient roof construction consists of a high albedo membrane over high amounts of insulation at their location in the North Eastern USA, where the number of heating degree days is approximately five times greater than the number of cooling degree days.

Table 3: Additional insulation required for a black roof to achieve the equivalent energy performance as a cool roof

Climate Zone	Representative City	Default R-Value, White Roof,	Additional R Value required for Black roof
1	Miami, FL	20	17
2	Austin, TX	25	16
3	Atlanta, GA	25	11
4	Baltimore, MD	30	10
5	Chicago, IL	30	6
6	Minneapolis, MN	30	5
7	Fargo, ND	35	5
8	Fairbanks, AK	35	3

3.1.3 Cool options for steep-slope roofs

The most commonly used steep slope materials in the USA include asphalt shingles, various types of tiles, wood shakes and metals (which can also be used in some low slope applications). Traditionally, with the exception of white colored products, these materials had modest levels of reflectivity, typically 20 percent or less. There has been, particularly in the residential sector, resistance to the use of white products for aesthetic reasons. However, there have been significant developments in most technologies such as reflective granules in shingles, and advances in cool pigments for use on metal, concrete and clay tiles, to name but a few. A variety of "cool colors" is now available in most technologies, which removes a significant obstacle to broad implementation of the concept in sloped, particularly residential, market segments. Some steep sloped materials are approaching reflectivity levels of some of the more common low slope products.

3.1.4 Advances in Cool Roofing Technology

Developmental work is being carried out in most roofing material technologies to further improve upon the reflective properties of materials. Although still in the early stages, the use of fluorescent cool dark pigments is expected to provide metal roof coatings with unprecedented levels of reflectivity. Similarly, the use of synthetic granules will improve the reflective properties of shingles and modified bitumen membranes. One area of great interest is reducing the degree of soiling so as to maintain higher levels of reflectivity over time. Some suppliers are adopting photocatalytic technologies which trap and remove ground level ozone precursors from the air. In the longer term, shingle type products incorporating "directional reflectivity", will have a dark, traditional appearance from the ground, while the portion of the product's surface facing the sky will be reflective. Promising research is also being carried on thermochromic and electrochromic materials, that will shift color as temperatures change, potentially eliminating any winter heating penalty.

4. Reflective Surfaces in Policy

Cities and other jurisdictions have enacted a variety of programs and policies to encourage the deployment of cool roofs. Voluntary programs include awareness programs, volunteer cool coating initiatives, and incentive programs to reduce first costs. The most effective measures to drive a transition to reflective roofing have been cool roof requirements. In nearly all cases, the requirements apply to new roofs and when a roof is undergoing a substantial repair or replacement and include alternative compliance options such as solar PV installations or vegetated roofing. Chicago was the first U.S. city to require cool or vegetated roofs, in 2001. Since then, about half of the 30 largest cities in the U.S. have some sort of reflectivity requirement for roofs. Figure 3 details the evolution of cool roof requirements in the U.S.

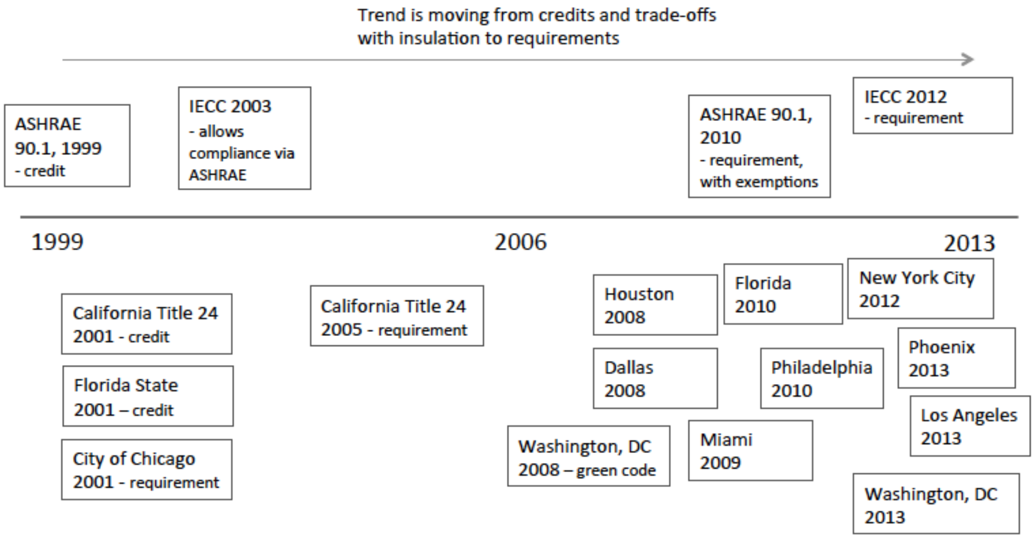


Figure 3: Evolution of cool roof requirements in the U.S.

5. Conclusions

The high concentration of dark heat absorbing roofs and paved surfaces covering significant portions of cities creates Urban Heat Islands (UHI), where localized ambient temperatures are significantly higher than in adjacent rural areas. These elevated temperatures contribute to reductions in air quality and decreased cooling energy demand in conditioned facilities. The additional GHG emissions resulting from the additional power generation compound the air quality issues. The confluence of climate change and the rapid urbanization projected over the coming decades will only exacerbate the problem globally. Broad adoption of cool roofing can play a significant role in mitigating these effects. By reflecting incident solar energy away from roof surfaces, they can moderate the UHI effect and decrease cooling energy consumption, resulting in a significant reduction in GHGs. Cool roofing can also reduce the impact of extreme heat events on occupants of non-conditioned spaces. Cool roofs provide the greatest benefit during peak power demand periods, which can delay or even negate the need to construct the additional power plants in many locations. All of these benefits can be achieved without appreciably changing the way we construct our buildings, and generally without a cost premium over traditional darker materials in all types of low and steep slope roofing technologies. Although a rapid transition to broad implementation of cool roofing strategies would be preferable, requirements mandating the use of cool roof materials in all new construction and during the re-roofing of existing structures will achieve the desired effect over time without additional cost to any stakeholder.

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Green Roof Thermal Performance in Colombia

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Abstract

In some European countries, green roofs have been a research topic stimulating a wide use of these applications. In Colombia, there has been a growing interest in the topic during the last years. The draft Agreement 386 of 2009 made by Bogota's City Council *"By which they are implemented, promoted and encouraged the development of green roof technologies in Bogota"* presented how green roofs and walls can contribute to improve the current environmental problems. Like other cities around the world, Bogota has flooding problems, loss of biodiversity, pollution, inefficient energy use and heat island effect, among others.

This study seeks to examine temperature regulation on a building's rooftop in the city of Bogota, Colombia; due to the influence of a green roof. Locally, there has been no research involving temperature measurements to quantify these effects. Thus, this investigation evaluate the effect generated by the green roof over the surface rooftop under exterior high and low temperatures. Additionally, the study sought to identify possible impacts of green roofing on the waterproofing membrane longevity, due to temperature fluctuations. This document discusses methodology used for temperature measuring along with analyzed scenarios during a four months measurement period. Results suggest that heat flux and thermal performance differences between the green roof and gravel ballasted roofs seem to be influenced mainly by solar radiation, ambient air temperature and volumetric moisture from the substrate. A deeper growing medium or increase on irrigation supply, may allowed the use of larger plants with potentially larger LAI which could reduce canopy air temperatures. This could lead to higher rates of evapotranspiration, and thus a better temperature regulation and further reduce heat flux into the building. Finally, conclusions are proposed about green roof thermal performance in a subtropical highland climate, and its isolation effect on decks or terraces.

Keywords: Thermal performance, green roof, insulation, sustainability.

1. Introduction

Natural cooling techniques in structures or buildings have been used through centuries. In recent decades however its use has been scarce due to the inclusion of air conditioning. The introduction of mechanical systems of air conditioning in buildings with its great energy consumption, has become the standard alternative for refrigeration and air conditioning of interior spaces in buildings today. According to Del Barrio (1998), green roofs do not act as a cooling mechanism, but rather as an isolation one by reducing heat flow through a building roof. It has been found that a well-designed and managed green roof can behave as a device of high quality insulation during summer in temperate zones.

Based on the study carried out by Ascione, Bianco, Rossi, Turni and Vanoli (2013) the following three aspects resume the physical phenomenon occurring during the operation of a green roof:

- Use of the inertial mass of the substrate such as a heat storage.
- Vital processes of vegetation such as photosynthesis absorb heat energy.
- The layers of soil and vegetation may induce ceiling cooling by evapotranspiration.

In addition, these physical and thermal behaviors of green roofs contribute to reduce the heat island effect, as the increase of the temperature in urban areas in relation to surrounding area. Akbari and Konopacki (2005) state that in large cities, this difference can exceed 5°C, since urban areas have extensive hard surface areas that absorb solar radiation and reflect the heat back into the atmosphere. On the other hand, in Teemsuk and Mander (2009) investigation, green roofs help protect roofs from extreme fluctuations of temperature, increasing the structural durability.

During the last decades, due to climate change and especially to the urban heat island effect; generated by continuous removal of green areas, green roofs have proved to be a cost effective alternative due to their ecological characteristics and its contribution to energy conservation in the construction sector. Besides, the application of bioclimatic concepts in the urban sector is limited by the fact that the densely built environment does not allow the use of vertical surfaces for passive solar strategies. Even natural ventilation, the simplest technique, is not always applicable since air and noise pollution in the urban environment lead to the need for airtight buildings. Theodosiou (2003) claims that horizontal surfaces of buildings, such as the ceilings or roofs, receive a high thermal stress during the summer and require strong measures to prevent excessive heat loss during the winter. Green roofs can be a solution to these problems.

1.1 Basic concepts

Çengel (2007) defines heat as the form of energy that can be transferred from a system to another as a result of a temperature difference. Heat transfer always occurs from the medium that has the higher temperature to the lower temperature, and stops when both reach the same temperature or equilibrium. Heat can be transferred in three different ways: conduction, convection and radiation. All modes require a temperature difference. The two principal ways of heat transfer in green roofs are explained next.

1.1.1 Conduction

Conduction is energy transfer obtained by the interactions between adjacent particles of a substance. It is a heat transfer process based on direct contact between bodies, where no exchange of matter occurs. The process can take place in solids liquids or gases. Experiments have shown that the ratio of heat transfer through a layer flat ($\dot{Q}$) is proportional to the temperature difference through this and the heat transfer area, but inversely proportional to the thickness of the layer, i.e.: $\dot{Q} = kA * \frac{T_1 - T_2}{\Delta x} = -kA * \frac{\Delta T}{\Delta x}\ [W]$

Doing the limit, where $\Delta x \rightarrow 0$, the above equation transforms to the differential form, which is called the Fourier law of heat conduction: $\dot{Q} = -kA * \frac{dT}{dx}\ [W]$

Where the constant of proportionality k is the thermal conductivity of the material, which is a measure of the ability of a material to conduct heat. A high value indicates that the material is a good conductor and a low value indicates that it is an insulating material or poor heat conductor.

1.1.2 Convection

Convection is the energy transfer mode between a solid surface and adjacent liquid or gas that are moving and includes the combined effects of conduction and fluid movement. Despite the complexity of this phenomenon, the transfer speed by this mode is proportional to the temperature difference and is expressed in convenient form by Newton's Cooling Law as:

$$Q_{convection} = hA_S(T_S - T_\infty)\ [W]$$

Where h is the convection heat transfer coefficient, in [W/m2*°C], A_S is the surface area through which heat transfer takes place by convection, T_S is the surface temperature and T_∞ is sufficiently away from the surface temperature.

2. Methodology

This study has been developed to fulfill three objectives: (1) Designing a controlled field experiment to compare thermal performance of green roofs on buildings; (2) Evaluate thermal-insulation effect of green roofs along a vertical temperature profile extending from outdoor air to green roof layers and to the ceiling surface and air; (3) Compare thermal performance of two plant species with different growing mediums. Prior to experiment design, literature review was made of journal published studies investigating green roof thermal performance by experimental measurements. This study is mainly based on the articles by Ascione, Bianco, Rossi, Turni, and Vanoli (2013); Parizotto and Lamberts (2011); D'Orazio, Di Perna, and Di Giuseppe (2012); Hien Wong, Chen, Leng Ong, and Sia (2003); and Getter, Rowe, Andresen, and Wichman

(2011), where parameters such as temperature, airflow, heat, and humidity were measure, in order to calibrate a mathematical model and perform simulations of different scenarios.

2.1 Site and green roof description

The site where the instrumentation was carried out to measure the temperature continuously in different layers of the green roof, was the central cafeteria inside the main campus of the Universidad de Los Andes. The roof is located in the South-East of the city of Bogotá on the lower part of the Hill of Monserrate, at latitude 4°36'02. 5"N, and longitude 74°03'54.8"W. The area has a climate with 11.5°C average temperature (maximum temperature of 23°C and minimum of 8°C) and 698 mm annual average rainfall, with a bi-modal distribution defined, from April to July and from October to December (IDEAM, 2014). This point was selected, due to the logistical advantages offered, and allowed to install an 110V electrical outlet for the data acquisition equipment. As well as having two different species of plants (Sedum and ferns) the green roof has an area of gravel large enough to have a control as shown in Figure 1.

Figure 1. Universidad de los Andes Green-roof

2.2 Equipment description

Temperature measurements were performed using 8 thermocouples type J, made with an iron and constantan wire. Thermocouples are the most common industrially used temperature sensor. A thermocouple is made with two wires of different materials together in one end, which when applying temperature at the junction of metals generates a very small voltage (Seebeck effect) of the order of millivolts which increases with temperature.

The equipment responsible for carrying out the conversion of millivolt thermocouple temperature measuring is a datalogger, which also allows to store the measured data. The dependency between the voltage delivered by the thermocouple and the temperature is not linear, therefore it is the duty of the electronic instrument designed to show the reading (datalogger), perform the linearization; i.e., take the voltage and knowing the type of thermocouple, see internal tables and match the temperature with the corresponding voltage, as shown in Figure 2.

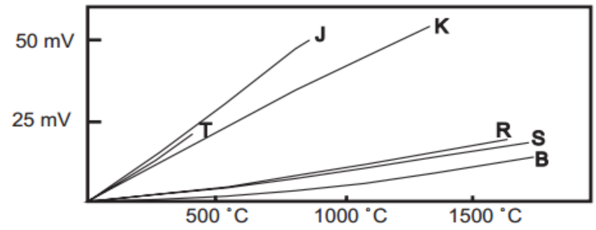


Figure 2. Temperature curve calibration for different types of thermocouples

The datalogger chosen for this research is the OMEGA model OM-USB-5201, which provide eight differential thermocouple input channels and have two integrated cold junction compensation (CJC) sensors for thermocouple measurements. Thermocouples inputs are software programmable for types J, K, T, E, R, S, B and N. An open thermocouple detection feature lets you detect a broken thermocouple. Also an on-board microprocessor automatically linearizes thermocouple measurement data. Finally the OM-USB-5201 has data logging capability, so measurements can be logged to a standard CompactFlash memory card (512 MB). These features allow all parameters to be measured and recorded at 5 min interval.

2.3 Measurement period

Temperature measurements began from late August until the first days of December of the year 2014. During this period of time three experimental stages took place. The first consisted in carrying out preliminary tests on experimental green roof trays arranged in the building of the Department of Physics and Geosciences of the Universidad de los Andes, where various green roof modules were implemented and instrumented in a previous research by Pérez and Groncol S.A. (2013). In these modules in different trays and at different media depths, temperature was measured during a period of time approximately 1 month, starting on 26 August and ending September 23. This first stage main purpose was to familiarize with the equipment and perform preliminary analysis of the thermal performance of green roofs. The second stage consisted of measurements in the ferns on the green roof of the central cafeteria at 4 different depths (Fig. 3); both on the part of the plant cover as well as in gravel cover. At this stage measurements took place for more than 1 month, beginning on September 29 and ending on November 7. Finally, the third stage as well as the second, consisted of measurements both in the part of the vegetation and gravel surface. However at this stage we measured on a Sedum portion of the green roof for approximately 1 month, beginning November 7 and ending on 2 December of the year 2014. Figure 3, shows the sectional drawing of Ferns and Sedum plants in the green roof. The gravel portion has the same distribution of thermocouples, the only difference is that there is no vegetation cover and instead of substrate or media there is gravel ballast.

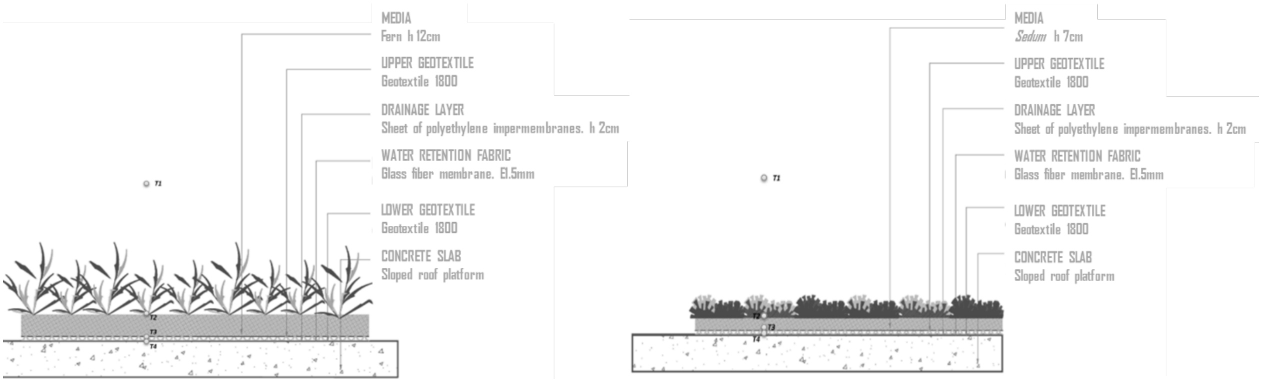


Figure 3. Location of thermocouples on green roof (Ferns and Sedum)

3. Results

Table 1, shows the conventions and location of the thermocouples placed on the plant species Sedum and ferns in the green roof and gravel ballasted roof.

Table 1. Conventions and location of the thermocouples in the green roof and gravel ballast

	Thermocouple	Datalogger Channel	Location
Green Roof (Ferns and *Sedum*)	1 *(T1)*	CH0	Temp. 1m height
	2 *(T2)*	CH1	Plant surface (Ferns and Sedum)
	3 *(T3)*	CH2	Beneath media or substrate
	4 *(T4)*	CH3	Water retention roof membrane surface
Gravel Ballasted Roof	5	CH4	Water retention roof membrane surface
	6	CH5	Beneath gravel
	7	CH6	Gravel surface
	8	CH7	Temp. 1m height

3.1 Ferns

Figure 4 shows temperature measurements results in the Ferns of the green roof at 4 different depths, always comparing with the control temperature of the gravel ballast. It can be observed that the day where the maximum recorded temperature arose was on 12 October, whilst the day where the minimum recorded temperature appeared was on September 30. Below are the results at the 4 different depths, where the first graph shows that the ambient air temperature is the same measure from 1m height of the ferns and the gravel, this fact confirms the validity of the measurements, and allows to analyze the rest of the data collected and draw conclusions on the thermal performance of a green roof.

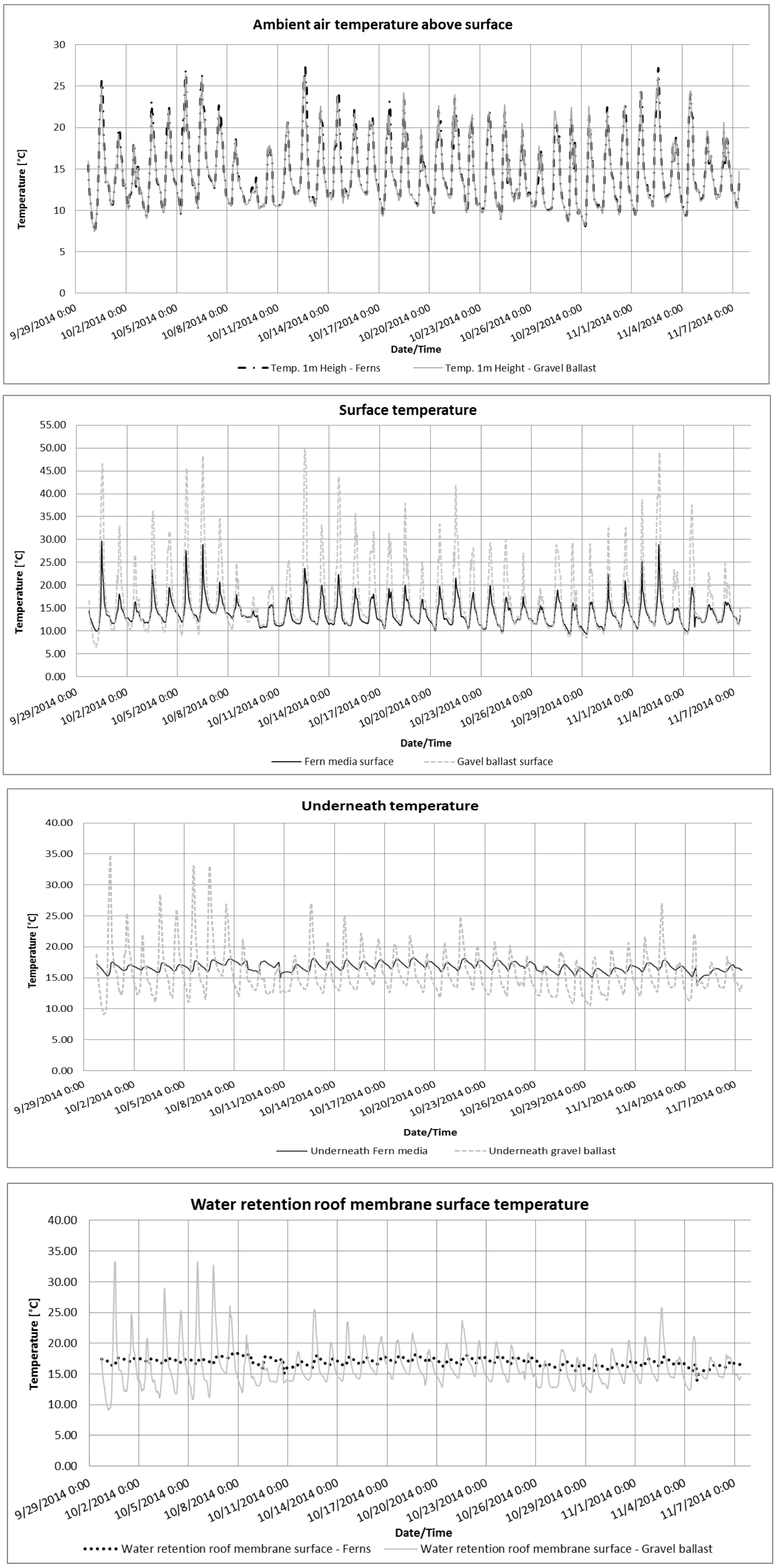
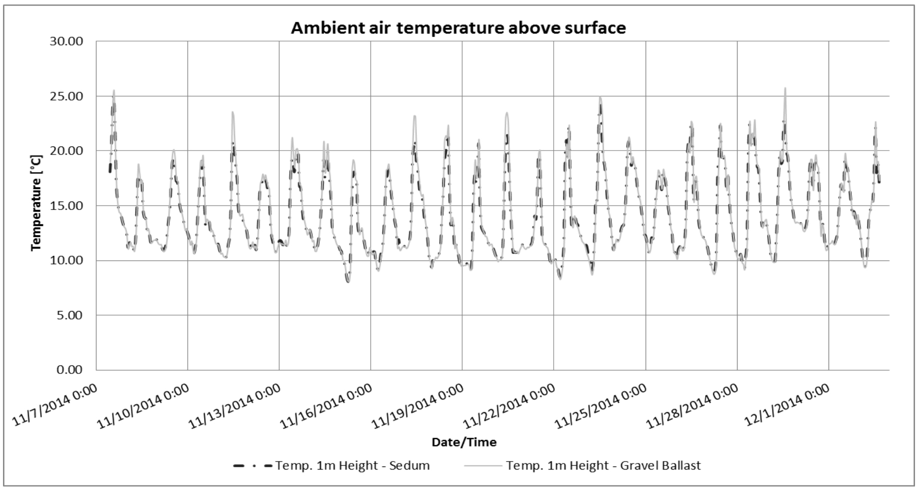


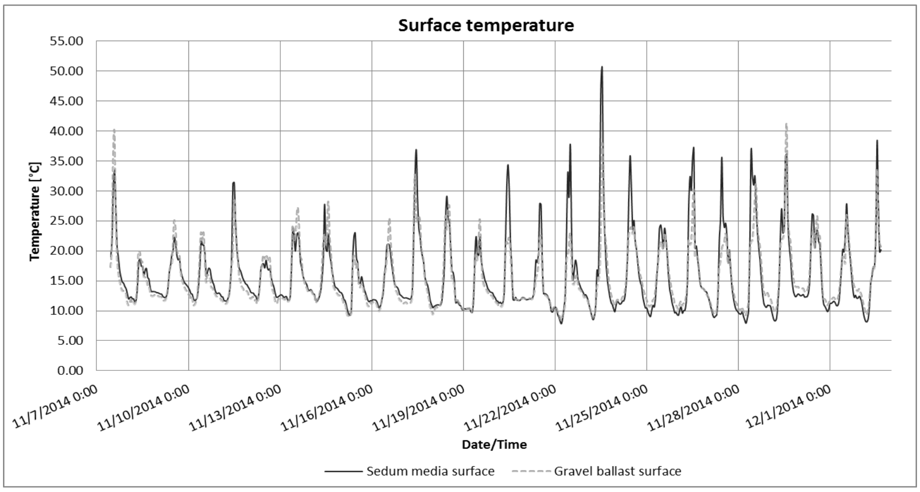
Figure 4. Ferns temperature measurements at 4 different depths

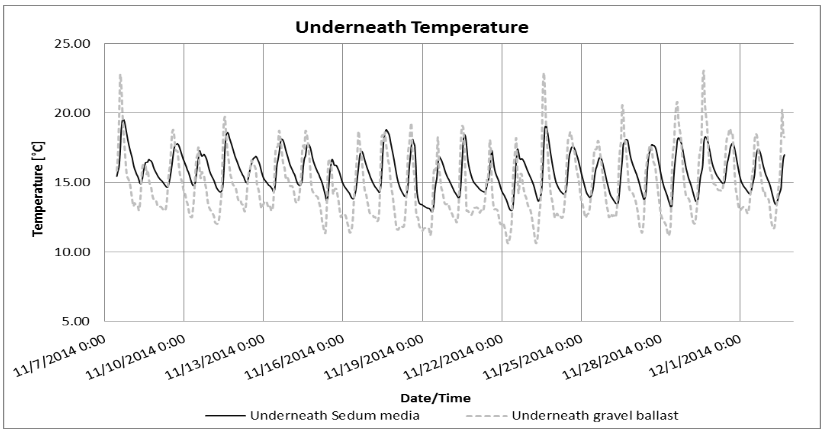
As expected, this maximum temperature was recorded on the surface of the gravel (Ch6), which in theory should gain much more heat than the surface of the substrate or growing medium due to shading from plant canopy and transpiration cooling provided by the plants. This phenomenon leaves a transcendental factor in evidence, and is the important potential function that complies the foliage of the plants against temperature regulation and therefor heat transfer to a roof ceiling.

3.2 Sedum

Figure 5 shows temperature measurements results of the Sedum at the same 4 different depths as the ferns. In this case, the day where the maximum recorded temperature arose was November 23, whilst the day where arose the minimum recorded temperature was 28 November. Following are the results at the 4 different depths mentioned above.







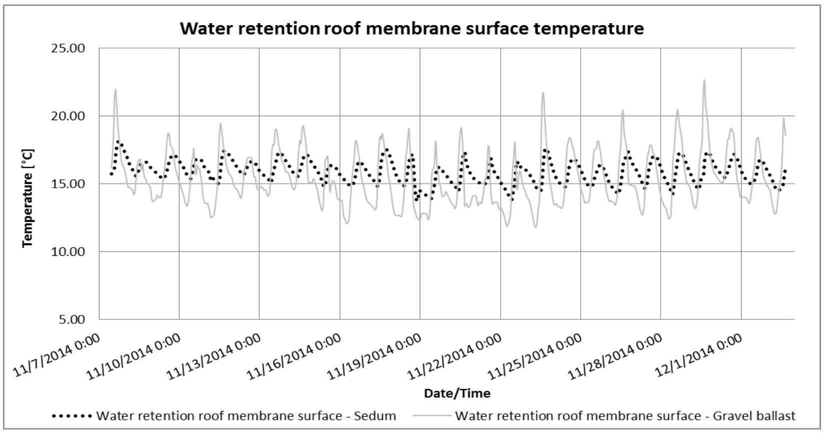


Figure 5. Sedum temperature measurements at 4 different depths

Unlike measurements in the ferns and contrary to what was expected, the maximum temperature was registered on the surface of the growing medium beneath the plants (Ch1) rather than in the surface of the gravel (Ch6). In this case the Sedum has less plant canopy (LAI) compared to ferns. This generates less shade and therefore heats up much more the substrate surface than the gravel ballast.

3.3 Heat transfer

In addition to the results of the measurements of temperature shown above, it was estimated the flow of heat that is transferred to the concrete slab both by gravel and green roof with ferns and Sedum. For this calculation we used the Fourier law of heat conduction explained above in the theoretical framework. Although heat transfer occurs by the combined effect of convection and conduction, in the next analysis we only took into account the conduction effect.

To calculate heat transferred from the surface of the gravel and green roof to the concrete slab, it was necessary to consult the literature for theoretical values of thermal conductivity (k) of gravel and a typical green roof substrate. For the green roof the study of Sailor, Hutchinson, and Bokovoy (2008), establishes that thermal conductivity of a substrate varies depending on its humidity, where k is between 0.25-0.34 W/(m*K) for dry samples, and between 0.31-0.62 W/(m*K) for wet samples. The adopted value of k for the substrate was 0.41 W/(m*K), based in the research by Becker and Wang (2011) where they used this value and also turns out to be a critical value, since corresponds to a humidity of 82% of the substrate. On the other hand, the thermal conductivity value adopted for the gravel ballast was 0.27 W/(m*K), since this corresponds to the value of k for dry sand according to the ASHRAE (1967), and was also used on Becker and Wang (2011) research. The depth of the fern substrate is 12cm and the Sedum growing medium is 7cm, whilst the gravel ballast is 5cm thick.

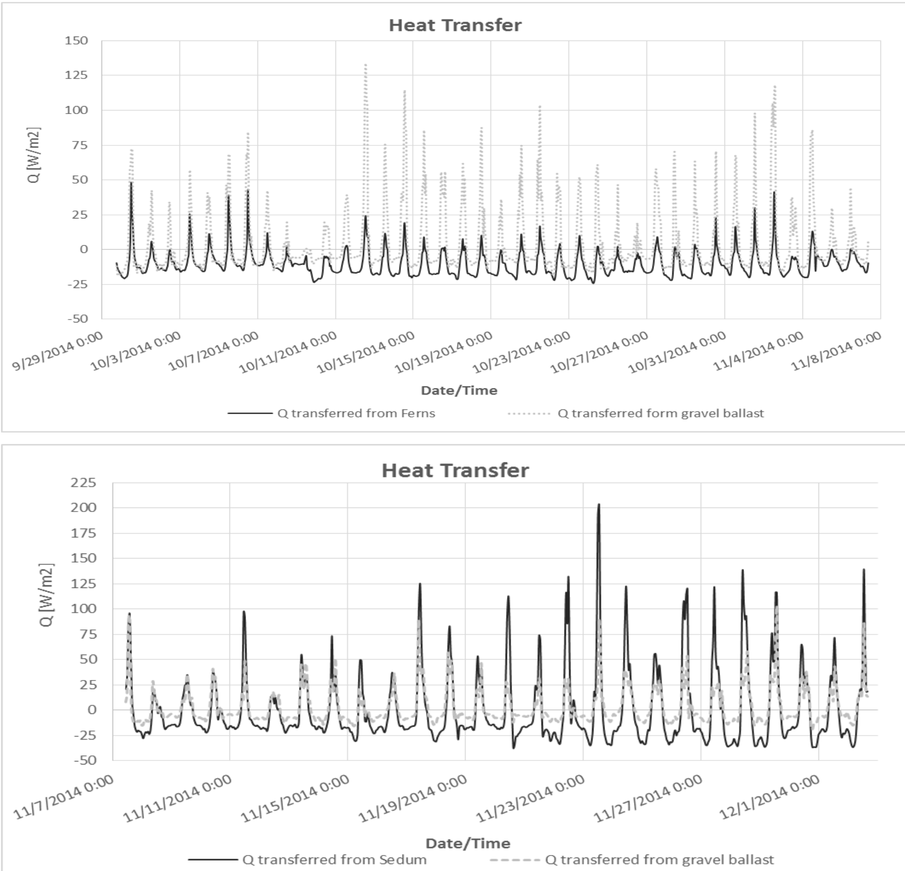


Figure 6. Heat transfer by conduction in Ferns and Sedum

Figure 6 shows heat transfer in ferns is much lower than in the Sedum. Heat negative values indicate that the flow is leaving the building, i.e., the building is losing heat. While positive values of Q indicate that the flow is entering the building, i.e. the building is gaining heat. Calculating heat flow allows to see the way in which heat travels through the green roof and gravel ballasted roof over time. This is useful to understand if green roofs have a better thermal performance than a control ceiling (gravel). However, values of heat alone do not express the overall thermal performance of green roof in comparison to gravel. To quantify the amount of heat that the green roof prevents or avoids the building loses in cold weather and win in warm weather, heat flow values were converted into gained or lost energy per square meter of roof. Heat flows are in W/m^2, therefore to convert them to an amount of energy transferred, heat flow must be multiplied by the period of measurement in seconds.

$$\frac{Energy\ Gain\ or\ Lost}{m^2}[MJ/m^2] = Q_m * t_m$$

Where, Q_m is the average heat flux in the period of measurement, and t_m is the number of seconds in the period of measurement.

4. Discussion

During the second experimental stage, Ferns portion of the green roof lost in average 34.09 MJ per square meter. This means that on average the effect of the green roof implementation with ferns prevents the structure to gain heat or produce an upward heat flux from the concrete slab toward the surface of the substrate. On the other hand, throughout the third experimental stage, both Sedum and gravel gain heat. Sedum gain in average 0.35 MJ of energy per square meter. Hence on average the effect of the implementation of the green roof with Sedum prevents the building gaining 6.04 MJ/m^2, due to the roof portion with gravel gain in average 6.39 MJ/m^2. In both experimental stages, the portion of control roof (gravel) gain more energy than the one with green roof (Ferns and Sedum). This let us conclude that on average the effect of having no vegetation cover in the portion of gravel produces the building roof to win heat or gets hotter through a downward heat flux from the gravel surface onto the concrete slab. A deeper growing medium like in the Ferns substrate, allowed larger plants with potentially larger LAI to grow, which could reduce canopy air temperatures and further reduce the heat flux into the building.

5. Conclusions

Results demonstrate how roof temperatures and heat flux are influenced by a green roof in Bogotá, Colombia during a period of time of almost 6 months. The investigation is worthy because most research focus on green roof thermal performance in seasonal places or with temperate climate, but Bogotá has a very steady weather over all the year without no seasons. In the case of this study heat flow was calculated only by conduction for each stage of measurement which must be very close to the total transferred energy flow in a conventional roof. A more complex model that also considers the transfer of heat by convection and radiation would be needed to quantify and understand the total flow that moves through the substrate and vegetation cover to the concrete slab. For this reason, convection and radiation heat flows were not considered, and also the equipment used only allowed to measure the transfer of heat by conduction.

In terms of obtained results, it can be concluded that with the shade generated by plant canopy, the temperatures measured on the surface of the substrate, for the two types of vegetation were lower than measurements on the surface of the gravel ballast. The maximum decrease in temperature caused by the plants was around 25°C. The temperature measured under the vegetation varied according to the LAI of the plants. Heat transfer through the control roof (gravel) was greater than through the green roof. Thermal benefits generated by the green roof were the combined effects of the depth of the layer of substrate and vegetation. The damp medium can provide an effect of additional insulation on the roof during all day, whilst vegetation mainly provides protection against solar radiation.

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Measurement Of Residential Building Airtightness Using The "Blower Door Test" And Its Relation With Indoor Air Quality

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Abstract

Airtightness and control of the internal ventilation are among the main factors to be considered in order to evaluate the energy efficiency of a building; moreover, they both strongly influence indoor air quality. Building airtightness has several advantages, such as the reduction of uncontrolled passage of cold draughts and of interstitial condensation. Non-adequate building envelope airtightness can cause mould formation. Some moulds are not infectious, while others produce toxic substances called "mycotoxins" that cause serious infections in more vulnerable people. Other types, such as Cryptococcus, may instead endanger everyone's health. The sick building syndrome is one of the unpleasant consequences of uncontrolled air draughts, which contribute to the distribution of spores within the environment. Therefore, in order to verify the energy and environmental performance of the building related to airtightness, the "Blower Door Test" is used to measure the hourly rate of air exchange caused by the inaccurate installation of doors and windows, to the presence of passing pipelines or to common construction defects. The test is carried on closing all the openings and placing a fan as temporary replacement of a door. The test, carried on with the aid of a thermal imaging camera to identify the critical points and optimize the airtightness, gives general information about the construction quality. The paper presents the testing method and the results of air permeability "Blower Door Test – Method A", carried out on March 6th, 2015 at a private residence located in Fiume Veneto, PN, Italy. The test verified that the value fell within the limits for the building certification according to the CasaClima A Protocol. The paper wants to highlight how an appropriate level of building airtightness, together with a mechanical ventilation system, allows reducing heat losses but also contributes to improve the quality of indoor air with the reduction of pathologies for users.

Keywords: Blower Door Test, airtightness, Indoor Air Quality, mechanical ventilation, Sick Building Syndrome

1. Introduction

Airtightness is one of the most relevant features to optimize the technical performance of the building envelope. Proper design and construction of air-tightness of the envelope ensures:

- The reduction of energy losses for ventilation;
- The reduction of energy requirements;
- The thermal protection of the envelope, in order to avoid sudden changes in temperature;
- The absence of passage of sound in an uncontrolled way;
- The reduction of any external or internal pollutants, due to the masonry (formaldehyde, radon, pentane, etc.);
- The absence of uncontrolled air currents;
- The correct functionality of the ventilation system;
- The absence of interstitial condensation and the consequent deterioration of the structures or the growth of hidden mould or brown rot.

PassiveHaus Institute indicates that in the presence of a slot of 1 mm and 1 meter in length, the formation of a mould amounts to 360 g of average water per day in presence of an internal temperature of 20° C and 50% of Relative Humidity (RH) with 0° C outside and 80% of RH. The mould mechanism is well explained in an article of WBDG – National Institute of Building Sciences USA (Morse, Acker 2014) and correlated with the absence of air tightness (*exfiltration)*. Condensation triggers the formation of fungi in wood buildings: one of the most important brown rot fungi is Basidiomycota (Palanti) that, according to the National Institute of Health (Mondello 2008), can cause cryptococcosis, pulmonary mycosis that may occur in patients already immunocompromised. During summer, as also indicated in Morse, Acker, the same mechanism in the opposite direction causes the entrance into the room of the spores (*infiltration)*. As the pollutants from the inside of the wall can enter in the internal environment, in the same way the interior pollutants can stop in uncontrolled cracks proliferating in the presence of mould and determining the possibility of concentration of further biological mass. In buildings where the tightness is improved, certified with blower door test, and in presence of a mechanical ventilation system, users are positively affected by better environmental conditions (Voci 2014).

The "blower door test" evaluates the airtightness of a building. The method determines the hourly rate of air exchange caused by gaps in the building envelope, due to the inaccurate installation of doors and windows or to the presence of cables and pipelines passing gas, or general construction defects. The test is performed closing all the openings to the outside, including air inlets on the walls of the kitchen, and powering a fan placed in temporary replacement of a window or of a door which lowers and raises the pressure within the interior volume; instruments that measure the pressure difference between inside and outside and the intensity of the air flow are connected to the fan. The measurement is corrected considering the atmospheric pressure, the temperature outside and inside of the building and the wind speed. The test is performed with the aid of a thermal imaging camera to better identify the critical points and optimize the airtightness. The test gives a global measure of the building quality construction, allowing to avoid problems such as: interstitial condensation with consequent degradation of building components, unbalance of mechanical ventilation, increase in energy consumption, uncontrolled passage of noise, uncontrolled passage of pollutants from the outside, etc.

The “blower door test” can be carried out according to two methods defined in UNI EN 13829:2002 – “Thermal performance of buildings – Determination of air permeability of buildings – fan pressurization method”, (the current EN at the time of the test, now substituted by ISO 9972:2015): Method “A”, which can be made only when all finishes are complete, including the installation of sanitary, and Method “B”, which can also be carried out in unfinished buildings, with the doors and windows already installed, for early detection of possible losses of the airtightness. It is suggested to use the method “B” at the time of installation of windows and systems already installed, in order to control the structure-frame nodes, the plants passages and more generally any node of connection between different parts of envelope. Since the case study building of this paper was already finished, the Method “A” was used.

2. Description of the building and of the refurbishment

A compact volume characterizes the building, with the main front almost exactly facing south. It is part of a complex of terraced houses in Fiume Veneto, in the province of Pordenone, in a district built in the seventies.

Figure 1: South elevation of the building

The property already made some changes to the building, with the installation of photovoltaic panels and the replacement of the old gas boiler with a condensing one. However, these interventions, despite having brought a reduction in expenses for electricity and a slight reduction of costs for heating and domestic hot water, had not yet solved the constant and repeated mould growth on interior surfaces. The target of the project were therefore:

- make rooms permanently healthy, both through the control of thermal bridges to prevent the formation of mould, both by the application of new painting in low VOC emissions;
- a great reduction in energy demand, achieved through interventions on the entire building envelope (insulation, replacement of windows and mechanical ventilation with heat recovery on time) and on the plant.

Due to the constraints of the building (PV system already installed, the presence of thermal bridges, permanence of users during works and presence of adjacent buildings), it was decided to combine exterior insulation with a limited internal insulation. Particular attention also has been taken to the proper execution of tightness, both on the perimeter of windows, both closing with sponges to tightness the existing corrugated pipes. The application of the thermal insulation on the outside of the building has brought benefits both in winter and summer; Furthermore, the presence of a staircase for access to the roof allowed to take advantage, during the summer months, of the chimney effect, optimizing the intervention for the typical hot and humid climate of this geographical context.

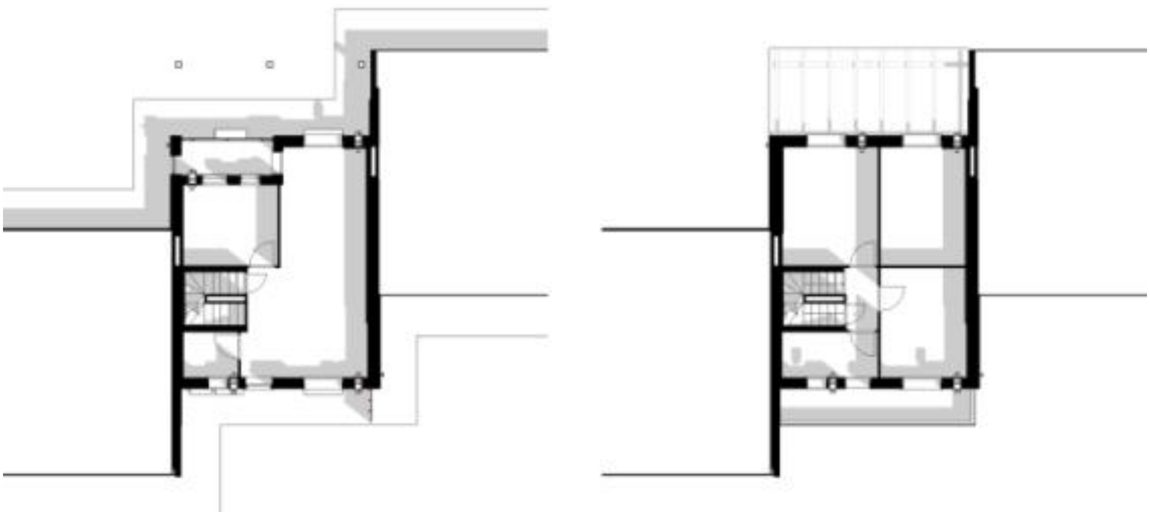

Figure 2: Plans of the ground floor and first floor

North and south façades, being free parts, were isolated with exterior insulation; east and west fronts were, where necessary, insulated inside. Roof was isolated with outside panels coupled with bitumen; over them, washed gravel plates, retrieved before the beginning of works, were then installed. Concerning the internal partition over the cellar, a layer of insulation coupled with plasterboard panels was positioned at the intrados. The thermal bridges caused by different solutions of thermal insulation (internal and external), were solved by extending the outer insulation beyond the limit of the heated volume. This is why the degraded existing external platforms were demolished, thus being able to continue the outer insulation of the walls to the ground and consequently solving the thermal bridge perimeter. Finally, doors windows provided with abutment to the ground were installed; this guarantees the correct installation of the perimeter and of new triple glazing window with PVC frame, coupled to new rolling shutters box designed to accommodate the thickness of thermal insulation. The works carried out have significantly improved the technical characteristics of the housing that reached the transmittance values given in Table 1.

Table 1: Data of the building elements transmittance after the intervention

Element	*Trasmittance value*
Wall	*0.15 W/m^2K*
Roof	*0.15 W/m^2K*
Floor	*0.49 W/m^2K*
Window frame (Uf)	*1.20 W/m^2K*
Window glass (Ug)	*0.70 W/m^2K*
Window total (Uw)	*1.02 W/m^2K*
S/V ratio	*0.82 m^{-1}*
Average trasmittance (Um)	*0.23 W/m^2K*

3. Description of the test

The test was carried out on March 6th, 2015. The instruments used, in accordance with UNI EN 13829:2002 – "Thermal performance of buildings – Determination of air permeability of buildings – fan pressurization method", were:

- The blower door test system, including air tightness sheet, adjustable fake aluminium frame to be fixed temporary to the door and the fan;
- The control gauge for the measurement of air changes inclusive of data cable, to be connected to the fan, USB cable for PC connection, coloured red pipe to be installed over the sheet outside the building for the control of external pressure, yellow pipe to be connected to the fan for the control of the pressure generated by the fan itself;
- A o-hygrometer to check the temperature and humidity of the air, inside and outside;
- A PC equipped with control software Retrotec FanTestic Pro;
- A camera;
- A thermal anemometer.

Table 2: Test equipment

Type	*Model*	*Technical data*
Blower Door Test System	*Retrotec*	*Fan 1000 S.N. 1fn002258* *Meter DM32 S.N. 401881* *Software Retrotec FanTesticPro*

Thermal imaging camera	*Trotec IC 80 LV* *S.N. 36030527*	*Resolution 384 x 288 pxl* *Geometric resolution 1,1 mrad* *Field of view (FOV) 24° x 21°* *Standard lens20° x 15°* *Software IC-Report DuoVision*
Thermohygrometer	*Mini MX-RH*	*Temperature accuracy ± 0.3°C* *Humidity accuracy ± 3% RH*
Portable gauge	*HD 2134 with Pitot tube*	
Digital camera	*Casio Exilim*	*Resolution 20.1 MPix* *Optical zoom 6x*

To perform the blower door test according to Method "A" all finishes including toilet services must be installed; the building must then be ready to be inhabited. The preparation of the test were as follows: once calculated the net volume of the heated volume, the sheet was installed on a appropriate opening, usually an entrance door; in this case, the used blower door test system was suitable for openings from 74-112 cm to 134-247 cm. The frame jamb must be not less than 30 mm; in this case the test frame must be installed over the frame. The chosen opening should not be exposed to the sun to avoid system overheating and changes of pressure difference between inside and outside in a way not in accordance with the real climate data. For safety reasons, during the installing activities the site was adequately illuminated and provided with supply power, particularly few meters close to the opening used for the test. It is useful having a temperature difference between interiors and exterior so, when the depressurization starts, the incoming air from the slots is recognizable since it has different temperature compared to the surfaces and the indoor air. At the same time, to avoid uncontrolled convective motions and not dependent on the test is useful to not heat any heater or fireplace before the test and eliminate combustion ashes. In order to carry out the test, all openings to the outside (or to cellar, attic, garage, etc.) were closed and the interior doors were opened. In addition, concerning the corrugated tubes, both the interior space between the pipe and electric cable and the space between the tube and the building structure must be sealed. Sanitary discharges were filled with water during the test to prevent from depressurization pumping in smelly gases; furthermore, air hoses have been sealed to prevent the passage of air. During the test, it is strictly forbidden to open the doors between inside and outside, to prevent an uncontrolled speed growth of the fan, resulting in possible failure of the electric motor. Once installed the sheet and prepared the building for the test, the fan, the gauge and its connections to the PC were installed. The following data related to the envelope, essential for the calculation of the air exchange times, were then input into the software:

Table 3: Test data

Fan position	
External opening	*Entrance door*
Orientation	*South*
Altitude above sea level	*20m*
Altitude from the building ground	*0m*
Building data	
Net volume	*343m*^{3}
Envelope surface	*383m*^{2}
Net floor surface	*124m*^{2}
Wind speed	*1 – wind breath - 0.45÷1.34 m/s*
Temperatures and atmospheric pressure	
Inside	*21.5°C*
Outside	*14°C*
$\Delta\theta$	*7.5 K*
Atmospheric pressure verification	*OK - (UNI EN 13829)*

The test was carried out with the following conditions:

- the kitchen hood was sealed during the test;
- heat pumps were not sealed;
- all equipment for ventilation were sealed.

At the beginning of the test the fan was filled on the inner side with a sheet to verify the pressure difference with initial flow equal to zero, with the software set to a predetermined time interval. Once acquired pressure data with flow equal to zero, the membrane temporarily placed on the inner side of the fan was removed and the test according to the Method “A”, that plans to carry out the test first in depressurization and then in pressurization. At the end of the test, the fan on the inside was stopped to check again the pressure with flow equal to zero. The software was set to obtain 10 static pressures at flow equal to zero for 10 seconds each, both before each test (first to depressurization and subsequently for pressurization), both at the end.

11 pressure measurements of the building, first in depressurization and then in pressurization, were acquired, from 15 Pascal up to reach 65 Pascal, with increasing not greater than 10 Pascal. The software was set up to analyse each point of analysis for 20 seconds, for a total of about 4 minutes for each test, during which between 100 and 200 detections were carried out.

During the pressurization phase, in the ranges between -20 and -30 and between -50 and -65 Pascal pressure was not completely stable. This change is the result of the turbulence of the fan due to the conditions of the machine: in the specific case the corridor where the door opened was narrow compared to the needs of the fan. The values measured during the test in depressurization were mediated according to the pressure and, through the points thus identified, a regression line was identified. The points refer to the test in depressurization are well aligned to the regression line, with a correlation index of 99.59%.

The same test was also carried out in pressurization, identifying a number of sealing points useful to define the regression line for the pressurization phase. Placing in the same graph both the straight line representing the depressurization both the one referred to the pressurization, it can be noted that pressurization give values of exchange air time lower than the depressurization; moreover, there is a shorter distance with the high pressures than low ones.

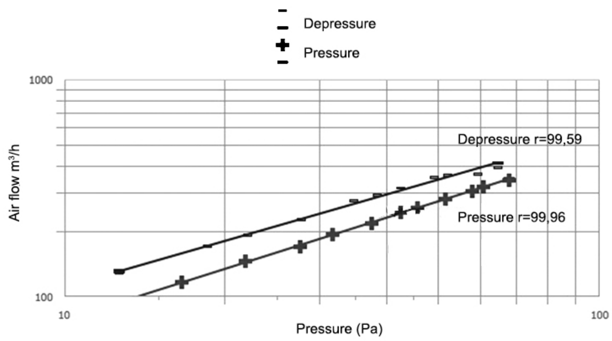

Figure 3: Comparison between pressurization and depressurization lines

In the overall results, during the depressurization air changes times 50 Pa, n50 [/ h] amounted to 1.007, while during the pressurization air changes times 50 Pa, n50 [/ h] amounted to 0.7997.

It is conceivable that air exchange values lower concerning the pressurization compared to the depressurization are dependent from the taping for the sealing air during pressurization, which is "pushed" toward their place, determining a greater efficiency in air tightness. On the contrary, during the depressurization the strips are pulled, facilitating the entry of air from outside. Once the test was finished, results have been obtained by mediating the values of pressurization and depressurization:

Table 4: Results

Air flow at 50Pa	*310.0 V50 [m³/h]*
Hourly air exchange at 50 Pa	*0.9035 n50[/h]*
Air permeability at 50 Pa	*0.809 q50[m³/h/m²]*
Specific flow infiltration at 50 Pa	*2.499 w50 [m³/h/m²]*

The value of tightness obtained was within the range of acceptability to obtain "CasaClima" label. This Protocol requires that buildings that consume less than 30 kWh/m^2 per year must present an air exchange lower than 1.0 h (-1) ± 0.1. The value obtained from the test was n50 = 0.9035 ± 10% h-1 and therefore results were within the limits.

The checking carried out during depressurization CRUISE mode also allowed to highlight some critical issues that, in part, have been corrected and that influenced the final result. Such criticalities have been identified using the thermal imaging camera evidencing the cold spots due to entry of air from outside. Among the most critical issues some electrical outlets were highlighted, affected by air leaks and where the sealing can be improved; the shutters of the windows, where not significant leakage occurs compared to the other but, anyway, present; and the vents, that, despite having been taped as required, presented air losses that affected the performance of air tightness.

4. Discussion

The works carried out in the building produced a significant improvement in performance sealing and envelope insulation. The blower door test has allowed us to identify any additional areas that need work, certifying also good airtightness of the refurbished envelope. The thermal imaging camera has highlighted as points of discontinuity in the envelope, such as window frames, electrical outlets or ventilation ducts, can be a weak point for air tightness. They therefore require an adequate design and checking, which can be carried out precisely by using the methodology presented in this paper. In particular, in addition to Method “A”, useful for buildings already finished, the blower door test Method “B” can be used to evaluate the correct installation and sealing of doors and plants.

The benefits from the refurbishment are not limited to the reduction of energy consumption. Actually, the absence of an adequate air tightness causes a uncontrolled passage of air that, in winter, contains a considerable amount of water vapour. This steam, during the migration towards the outside, touches the cold portion of the stratigraphy on which condensation may form. In wooden buildings and in buildings with traditional wooden roof this constant water storage determines an ideal environment for mould growth, including the brown rot. Among the main fungus brown rot is the Basidiomycota (Palanti) that, according to the National Institute of Health (Mondello, 2008), may cause Cryptococcus, a fungal lung infection that can occur in patients already immunocompromised. These same air currents that caused the formation of mould spores can carry spores inside, increasing the number of indoor pollutants (Horn, 2014), up to the limit beyond which could appear the presence of SBS (Sick Building Syndrome). In not historical masonry buildings, with the exception of the situations in which seismic phenomena have caused cracks in the walls, the most critical elements are the ventilation channels not adequately maintained where – like the ventilation systems of hospitals, although in a lower amount – may form over the years a layer of wet dirt that encourages the growth of bacteria. Similar phenomena may also occur in electrical corrugated channels that can serve as conduits for the passage of humid air (toward the outside in the winter and towards the inside in summer). However, while a cleaning operation with the steam ejected by a probe in ventilation ducts can be done, this is not possible in the electrical channels, which remain therefore a potential critical element. Finally, in “traditional” historical buildings (in masonry), where cracks of the masonry are evident, it is not possible to exclude the deposition of the powder through openings and the formation of interstitial condensation, with the consequent proliferation of moulds and bacteria.

In general, every interstice present in the building envelope may allow the formation of a microbial ecosystem (moulds or bacteria), similar to the one present in domestic dust (Barberan et al., 2015); this phenomenon increases when the airtightness of the building elements is not guaranteed, thus allowing an uncontrolled air flows which favour the transfer of the biological charges and the formation of condensation in the interstices. Also window frames must be included among building elements subject to these issues, since if they are not properly completed or installed, can facilitate the passage of air and the resulting accumulation of dust and dirt at the jamb and seals. These points are likely to the formation of condensation, given the position between inside and outside, becoming a privileged point for the formation of pathogens. Adequate airtightness of buildings is, therefore, an essential technical feature for the protection of healthy indoor air. In this way, it is possible to add a mechanical ventilation system, which allows also to control the exchange of air in indoor environments, allowing the elimination of volatile pollutants.

5. Conclusions

The refurbishment of the building shows how important is not only install renewable energies systems, but also provide the building itself with an adequate thermal insulation, and at the same time ensuring the airtightness of the possible passage points of air between inside and outside. A non-optimum airtightness, in fact, may lead to a worsening of the quality of indoor air, with the consequent diseases for the users. The use of the Blower Door Test allows the control of the airtightness of the housing and at the same time the use of the thermal imaging camera allows to check the presence of air passages through the building, thus allowing to intervene to improve the performance of the building.

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Appropriate Ventilation Solutions for the Iconographic Buildings from the Fifties – A Cross Disciplinary Investigation

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Abstract

In Denmark we currently have an increased focus on preserving the most valuable domestic building examples from the period 1945 - 60. New literature deals with these architectural heritage matters. The authors of this paper argue, that due to question of preservation the buildings physiology is not enrolled in the discussion, and argue that especially this issue can cause a huge damage on the aesthetics of the architectural expression, the facades and the use of the buildings in terms of comfort demands for people living here.

The starting point for the research is preservation, comfort and aesthetics. The primary topic of the survey is the building envelope as a transmitter of external climate to internal climate and vice versa. Three case studies and one reference building as principal renovations are used as information for new innovative and integrative solutions. Analyses and discussions will show a development to the introduction of mechanical ventilation in the building stock with a particular focus on decentralized ventilation systems. To evaluate the retrofitting initiatives a cross-disciplinary corporation between the professions of architecture and engineering are required: this integrated working methodology develops new renovation processes.

Based on both quantitative measurements and on qualitative judgements the cases are analysed comparatively. Parameters such as ventilation solutions in facades are discussed as architectural consequence and value. User interviews will also inform the evaluation. Cases are chosen from earlier research projects and brought into the analysis in order to either see a development or to see more clearly how integrated evaluations of the ventilation and the preserving strategies can lead to a better understanding of an optimized intervention. The paper concludes that interdisciplinary ways of working will improve both architecture and preservation and comfort, and that higher value hereby is created. Furthermore the new initiatives from the industry are shown, which indicates a movement towards innovation of decentralized ventilation solutions.

Keywords: cross-disciplinary cooperation, indoor climate, decentralized ventilation, energy renovation solutions

1. Introduction

The Modern Movement in the 1920s was a reaction to the former stylistic architecture and to the urgent need for low income housing: several architects took the initiatives towards the Modern Movement (CIAM 1933).The modern architectural ideas were among many other ideas defined according to new construction possibilities and industrialized methods: new forms and proportions, flat roofs and no decoration, new materials such as reinforced concrete and steel. New rational building methodology was the new mantra for the movement. The housing areas were laid out in open parks and designed with better flats, where the functionality was the basic fundament for space, distribution and orientation, sun, light and air for people from the working class.

Danish progressive architects were inspired by these ideas and they designed new ways of living at the outskirts of the cities. After WWII there was scarcity of materials, and the modern ideas were moderated to the actual possibilities of solving a huge demand for dwellings. This situation created the modest functionalistic architecture (Nygaard1984), where architectural ideas were designed and built by Danish local craftsmanship, constructions and materials. The result was a special local translation (Lund1993) of these modern thoughts into a large number of very fine suburban areas characterized by masonry and very fine architectural design.

This paper will focus on the functionalistic housing built in the period after WWII 1945 – 1960 (Vestergaard 2011), which represents a most valuable treasure in the diverse Danish urban fabric, especially regarding functionality and aesthetical qualities. The period is known for its embedded qualities both in respect to architecture, space and daylight, but also paying respect to traditional materials and modernistic form and detailing.

Figure 1: Typical housing block, entrance, balconies

The buildings are of different value, but a considerable majority belongs to the architectural heritage of the period (Bech-Danielsen 2015). The buildings are characterised by red or yellow masonry and of high aesthetic quality. The facades are aesthetically well designed and the geometry includes important functional detailing such as very efficient ways of dealing with materials and proportions, balconies and details see figure 1. Basically the architecturally expression of these treasures must be kept through the future retrofitting. The building law is reflected by the designs which address demands to staircases, balconies, indoor design/organisation and size, but also address demands to fresh air and ventilation.

The airflow through the dwellings reflects the building practice of the time and the Copenhagen Construction Law (Københavns byggelov 1939) and was originally operated by separate natural air channels related to the bath and kitchen, see figure 2.

Figure 2: Natural ventilation distributed through facade related to kitchen and bath

Today's urgent demand for retrofitting is caused by the massive backlog in the housing sector, rising energy prices and fulfilling the European targets of CO2-reduction within 2020 and recently 2030 (EU 2010), which generates a growing demand for new renovation solutions for insulation and air-tightness of the existing climate screen.
By upgrading the climate screen and introducing balanced mechanical ventilation in a number of cases this paper will show, how the comfort in the dwellings is improved through the controlled indoor climate and how the air change has become a parameter to estimate indoor air quality. Balanced mechanical ventilation has been introduced to the existing brick buildings from the 1950s social housing, and development of innovative ventilation solutions have moved from centralized to more decentralize over the last decade (Klint 2009b).
This paper argues that there is a development in new ventilation solutions, towards more sensible solutions, while introducing the balanced mechanical ventilation to the buildings from before 1960. Considerations of where and how to place the ventilation unit will be carried out. Economical perspectives and development towards higher energy efficiency of units will be predicted. The challenge of securing a good indoor climate and a high user satisfaction will be argued. It is realized that very little Danish statistic references in terms of technical ventilation systems in existing multi-story housing, have been carried out. Whereas the statistical investigations have been done in Central Europe regarding office buildings (Mahler and Himmler 2008). However; it is here estimated, that mechanical extraction is the most commonly used ventilation system of today in the multi-story housing in Denmark.
When discussing renovation and architectural heritage, it is very important to establish a holistic understanding and framing. The aim of this paper is to review the complex problem in which the research focus is imbedded. To challenge the discussion it has been chosen to focus specifically on the climate screen as an instrument for better comfort in respect to light, sound, temperature, humidity, energy and air and not to forget preservation of the aesthetics of the architecture. In order to point out broader perspectives the complex challenge is done interdisciplinary.

The research question to explore: How to perform a cross-disciplinary cooperation in renovation of social housing to preserve the architectural expression and the facades and the use of the buildings in terms of indoor comfort?

2. Methodologies

The investigation is based on measurements and simulation from four cases, in which selected parameters within energy renovation has been documented, analyzed and evaluated through a triangular survey of quantity, quality and user experiences from questionnaires.
General and newly developed knowledge from the study of literature are brought into the discussion and compared to the case studies.
In order to open the research and discussion, we have used comparative analysis methodology. The reference and the three cases represents a development in Denmark from 1915 up to 1960, both as architectural and construction wise relatively broad change, but especially the demands to indoor climate and energy efficiency compared with the preservation question.
An integrated research process can be understood as a concept in which the determination and development of a product or a process integrates all relevant parameters, ranging from the aesthetical and the psychological aspects to the technical, the logistical and economical aspects. The authors of this paper have as a team developed the research as an integrated research process, which methodologically builds on tools such as 'Clean Process' (Blyt 2013).
Regarding the content of the research we have focused on architecture and engineering, on architectural heritage, on indoor comfort and on user demands: from this foundation the idea of the abstract has appeared. From the very beginning of this survey the broad discussion has played a driving role for defining the content, the analysis and the discussions of both the problem and the working methodology of the integrated research process.

In order to establish the current state of ventilation principles in existing multistory housing, the conditions are shown, see figure 3 for three different balanced mechanical ventilation approaches for renovated housing and for a reference case characterized by natural ventilation as a normal situation for housing built before 1939.

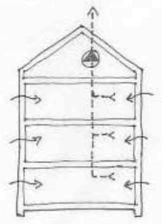
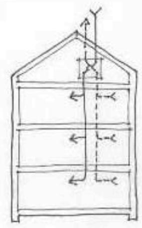
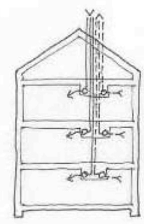
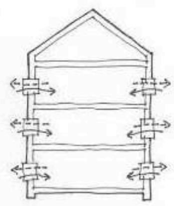
	Reference	Case 1	Case 2	Case 3
Location:	Horsens	Copenhagen	Copenhagen	Copenhagen
Built/optimized:	1945/-	1927/2000	1950/2001	1915/2015
Ventilation system:				
Extraction	X			
Centralized		X		
Decentralized, ceiling			X	
Decentralized, facade				X
Graphical illustration of ventilation solution				

Figure 3: Overview reference case and case 1, 2 and 3

3. Criteria and Findings

The defined parameters for the survey are listed below. Data and sources are quantified and qualified, and user satisfaction is brought into the evaluation. Through the survey the value based importance of the parameters are found.

3.1 Architecture and preservation

It is evident that many of the housing schemes from the 50s are facing modernization, but coordinated knowledge is lacking of how to bring the buildings into the future without compromising the principal preservation values (Dansk Bygningsarv 2015). This brings the headline ´architecture and preservation´ as a highly rated parameter into this paper´s evaluation of both aesthetic and historic values.

The buildings from the period are obviously challenged as both materials, details, cold bridges, joints and the overall aesthetics and a huge amount of buildings must be kept untouched besides from the installations. At the recently published Danish literature of the period the ventilation question is hardly mentioned, but from several case studies from the 50s it is obvious that the question of air exchange can bring these building´s indoor and outdoor expression in danger if not taking properly consideration to the huge damage centralized systems can force. That is basically why we in this paper have focused only on ventilation renewal. Under these circumstances the ventilation devices must be implemented and expressed through a very gentle design. If talking about the façade, the existing façade construction is born with functional perforations such as fresh air canals and filtered masonry to the food store/room. These can be brought in activity in the renovation design.

Through studying this parameter several innovative products have appeared, such as the ventilation window and the integrated parapet solution from Ecovent, see figure 4. Also some products like ventilation windows are very promising constructions for solving the design of the façade (Klint 2009b).

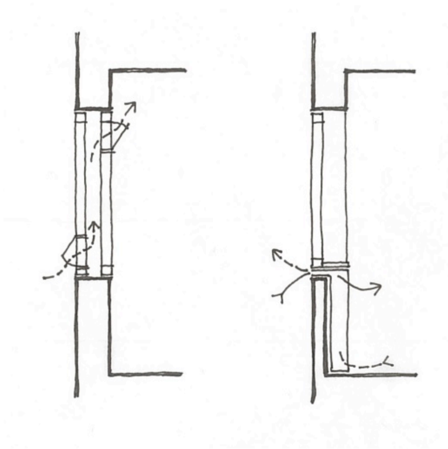


Figure 4: Innovation: Ventilation window and facade solution from Ecovent. To reduce the necessary space required for facade integrated solutions the companies continuingly works with new decentral solutions.

3.2 Space and daylight

Common value based set of norms are existing amongst professional architects regarding a successful experience of architecture: the space should be well defined and proportioned, space should be well lit and the choice of materials should be in harmony and allow the tenants to influence the space with their own selection of arrangement. In addition to this the space should also be designed as extremely functional with good possibilities for furnishing and easy to clean. This means that every disturbing visual installation should be avoided. Both the building regulation in the 50s and a good design ability of the architect shaped the daylight quality. For the future it is important to pay attention to efficient space and to respect the daylight distribution.

The design of the ventilation points in many aspects to the façade ventilation solution. The decentral solution distributing canals to all rooms in the flat, hidden above a hanging ceiling; occupy space primarily in the corridors. Also canals in the rooms can occur. The decentral solutions concentrated under the window inside the heating niche looks very discrete and can be developed to a high aesthetic standard. The decentral solution, described as devices hanging on the wall perpendicular to the façade, will disturb the room feeling. But if integrated under the roof above the window, there will be more discrete possibilities for an acceptable solution. Example of innovation: Change of filters is a huge issue for organizations maintaining the buildings, because this has to be done inside the flat. Also related to this issue it is observed that new innovative filter components are developed. A better insulation value of the window, either 3 layer energy glass or similar will reduce the amount of incoming daylight.

3.3 Energy Efficiency

Energy efficiency in buildings can initiate a mayor renovation, because of the potential annual savings in energy from optimization of the constructions and installations. More than 40% of all surveyed multi-storey housings in Denmark from before 1960 has an energy label D, which is comparable to a maximum annual heat consumption of 150 kWh/m^2/year (Kragh 2015). The heat consumption based on the ventilation of multi-storey housings in the period from 1931 to 1950 is estimated to approx. 25% of the total heat consumption (Wittchen 2004). By using new high efficient counter flow heat exchangers with an efficiency of 80 – 90% such as in the decentralized ventilation systems in case 2 and 3, energy savings as high as 30 - 40 kWh/m^2 per year of the annual heat consumption can be reduced in multi-storey housings from before 1960 (Tommerup 2004).

3.3.1 Energy consumption - Heat

The case studies and the reference building investigated are supplied with district heating. Figure 5 shows the annual heat consumption related to the net floor area for the 3 cases before and after installing the balanced mechanical ventilation system, and for the reference building the consumption before the proposed energy renovation.

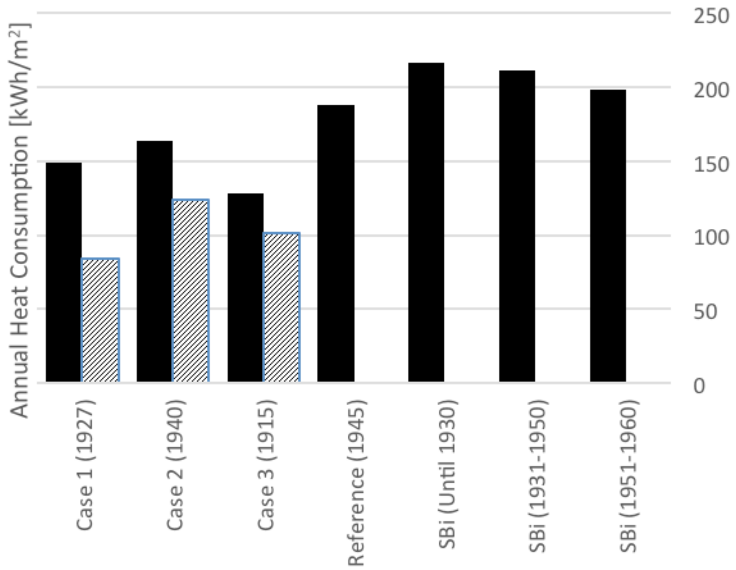


Figure 5: Annual heat consumption before and after renovation

<u>Case 1:</u> This energy renovation is based on balanced mechanical ventilation used with joint intake and exhaust, however there were both central and decentral heat recovery units for the winter combined with natural ventilation in the summer. The energy savings are obtained by preheating the ventilation air in solar low energy ventilation tower to hide ventilation ducts and produce solar energy at the same time.

<u>Case 2:</u> In this case the energy renovation was based on decentralized balanced mechanical ventilation with heat recovery in each dwelling and joint extraction ventilator in the roof space. Solar cells were used to match the electrical consumption of the ventilation units.

<u>Case 3:</u> The energy savings in this case are based on high efficient and low consuming decentralized balanced mechanical ventilation solution in the facade, replacement of the old

windows with new triple layer energy glass and re-insulation of the cavity in the external wall and the story partition.
The average annual heat consumption for multi-story housings in Denmark is based on the SBi-report (Wittchen 2009) on the basis of registration made by the authorized energy labelling consultants in the period from 2005 and 2008. The annual heat consumption in the reference building is based on the registrations from 2013 to 2014 and corrected by the Danish Design Reference Year 2010.

3.3.2 Energy consumption - Electricity

Measurements of the electricity consumption shows that the energy consumption from a decentralized balanced mechanical ventilation unit type V300 from the company Ecovent, which generates a ventilation flow of 45 m^3/h, uses less than 8 Wh electricity comparable with 0,2 EUR per day and an annual electricity consumption of 70 kWh. With an electricity cost of 0,2 EUR per kWh (incl. vat) in Denmark the annual cost for a dwelling with two units is approx. 30 EUR (Klint 2009b).

3.4 Comfort measurements

Measurement of the comfort in existing buildings with newly installed balanced mechanical ventilation shows that the indoor climate generally is improved. However, the comfort parameter of draft caused by leakiness in the climate screen or directly from the ventilation system (both the central and decentralized ventilation solutions) haven't been investigated thoroughly in any of the cases even if the user surveys reveals problems within this area.
Some results show an improvement of the draft problems after re-insulation or replacement of the climate screen; however the draft caused by the ventilation system itself hasn't been covered sufficiently. A research paper aiming at investigating air renewal effectiveness of decentralized ventilation devices with heat recovery (Coydon and Pfafferott 2014) concludes, that even if the ventilation system removes pollutions like CO^2 from the room, the distribution of air and the experience of the air supply is depending on the temperature, speed and direction of the airflow.

3.5 Ventilation rate (carbon dioxid measuring)

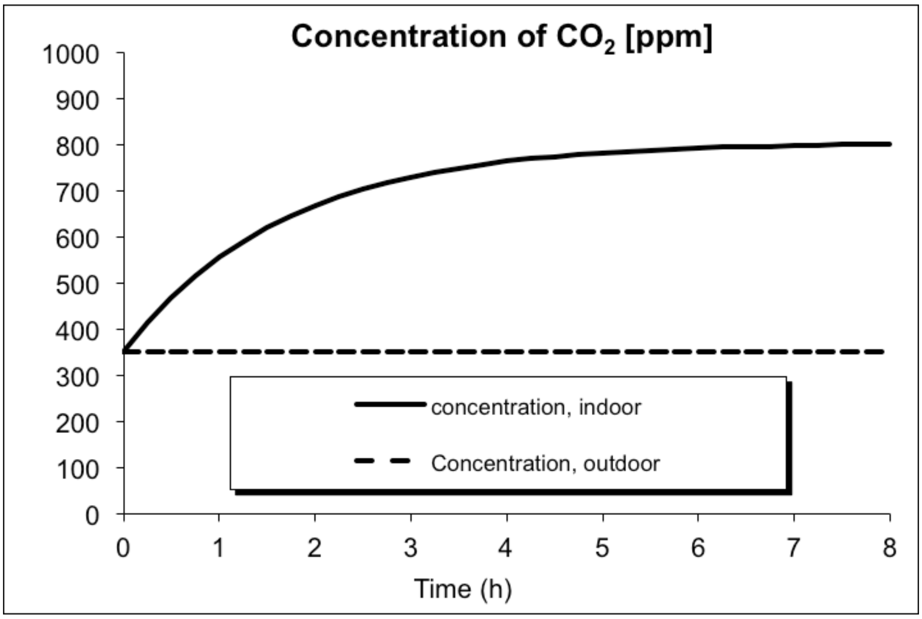


Figure 6: CO_2 concentration progress in case 3.

Figure 6 shows a calculation of the CO2 concentration in case 3 after the dilution principle with an air change of 0,6 h^{-1} corresponding to the measured ventilation amount in the dwelling from the decentralized units. The ventilation efficiency of the decentralized units shows very promising results to comply with the demands, which applies for new buildings in Denmark. However; this has to be documented in a larger scale to have been significance.

3.6 Noise emission from ventilation system

There are no qualified measurements of the noise from the decentralized ventilation solutions, however the units are undergoing a progressive development to reduce the risk of noise, such as optimizing and moving the fans to the primary side of the heat exchanger. The user survey showed no discomfort caused by noise, however a German study in 10 office buildings with decentral ventilation solutions the measured sound emissions in some buildings were above the limits of workspace environments (Mahler and Himmler 2008).

3.7 Users´ survey

In this investigation a user survey was carried out in the reference building with the purpose of comparing a building with mechanical extraction and high potential to saving energy by installing balanced mechanical ventilation with heat recovery.

User experienced dissatisfaction in %	Very often	Often	sometimes	Seldom	Not at all	No opinion
Room temperature	3	14	41	27	12	3
Vertical temperature	13	26	22	27	12	
Draft by the window	13	19	20	32	16	
Draft generally	8	23	17	25	27	
Air quality, smell	7	25	35	19	14	
Air quality, fresh air	1	4	21	31	43	
Air quality, generally	4	39	43	6	1	7
Sound level from int.	12	40	21	13	4	10
Sound level from ext.	3	30	25	23	5	14
Daylight	3	6	17	43	28	3

Figure 7: User survey in reference building

A similar user survey was conducted in a building after the installation of balanced mechanical ventilation with a decentralized solution integrated over the ceiling in the dwelling (Klint 2009b) see figure 7. In the reference building the tenants were generally satisfied with the indoor climate such as the room temperature, draft and daylight quality. However; they experience dissatisfaction concerning the air quality in general and specific when it comes to unwanted smell and noise from the external environment such as neighboring dwellings.

In the survey conducted in the multi-story housing with newly installed balanced mechanical ventilation the tenants generally experienced an improvement with the indoor climate; especially feeling of draft has decreased after the renovation.

In the decentralized ventilation solution integrated in the facade the tenant experienced a much higher comfort concerning the mix of fresh air and had no discomfort with draft, such as before the renovation.

4. Discussion

A movement in the innovation and development of ventilation systems for renovation of multi-storey housing towards more decentralized solutions such as integrated in the facade has been investigated. The parameters from the findings have been discussed in the triangular study and listed according to the starting point of this paper: aesthetic and preservation as well as indoor comfort forms the two paths of our investigation.

4.1 Aesthetic and preservation

- Ventilation doesn't necessary spoil the facade. Possibilities to reuse the existing perforations of the masonry must be taken into account when optimizing the solution. Innovative measures such as the facade integrated ventilation unit under the window (figure 4) can as an example provide acceptable solutions.
- Users must be involved in the renovation to get a higher acceptance of the installations.

- Decentralized ventilation solutions absorb less space for pathways inside the dwelling, which is an advantage to the users.
- When changing the existing windows to triple layer glass the daylight factor most likely will be reduced, however improvement of indoor comfort generally can compensate for this.
- Potential for saving heat, in this case approx. 25 % can accelerate the renovation rate.
- There is a potential for saving electricity compared to central solutions, which can be compensated for with a limited number of solar cells on the roof.

4.2 Indoor comfort

- The indoor climate generally improves with introduction of balanced mechanical ventilation; however, absence of draft must be identified and solved first.
- Possibility to reach a ventilation rate as for new buildings.
- Noise from the devices must be kept under the requirements.
- Users want individual control of the ventilation, which can be made by decentralized solutions.
- Noise from local noise sources, such as traffic, train etc. can be reduced through insulation of the climate screen.

5. Conclusions and perspectives

In the conclusion of the parameter study and the discussions the authors have identified three essential statements:

1. New interdisciplinary working methodologies will improve both quality, quantity and users satisfaction, and the new results will create value.

2. It is obvious that the movement towards development of decentral ventilation stimulates the industry to develop new and innovative products.

3. From the studies a high level of innovative initiatives has been identified, which indicates a movement towards development of more decentralized ventilation solutions in the introduction of balanced mechanical ventilation in the multi-storey housing in Denmark.

Perspectives

- New facade solutions must be developed in a gentle design to solve the perforation of the façade for decentralized ventilation solutions such as new window designs.
- Incoming daylight should not be compromised when changing the façade

- Draft caused by leakiness in the climate screen or directly from the ventilation system should be investigated more thoroughly with focus on temperature, velocity, turbulence and direction of the airflow.
- The ventilation efficiency of the decentralized units should be documented in a larger scale.
- Measurements of the noise from the decentralized ventilation solutions should be carried out.

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How Did We Get Opaque Windows? – Mutual Constitution of Technology and the Built Environment

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Abstract

Construction professionals are continually faced with the challenge of incorporating new technology into their buildings. Much of the current research treats innovations as a discrete entity, thereby overlooking the system properties of many innovations. Implementation often involves extensive accommodation of both the technology and the building. Failure to appreciate this poses significant challenges to the project team, with unintended consequences for the project as a whole. A social construction of technology (SCOT) approach is used to explore the integration of Building Integrated Photovoltaic technology (BIPV) on a commercial project. By exploring the succession of problems and solutions shaping the uptake of BIPV, the analysis also identifies a number of distinct decision modes, including: discrete, conventional and integrated decision making. The first two often contribute to unintended consequences, knock on effects and lock-in, whilst the third is essential for sustainable design. Whereas much of the literature linking sustainability and integration focus on integration across disciplines, this paper links emphasises the need for a holistic understanding of the overlay of different systems constituting a building, including renewable technologies.

Keywords: BIPV, Projects, Innovation, Social Construction of Technology, Co-development

1. Introduction

Construction professionals are continually faced with the challenge of incorporating new technology into their buildings. While much of the research into innovation treats technologies as self-contained entities which can be inserted directly into a building, experience suggests that the process is often much messier. This is especially the case with many of the recent renewable technologies which are systems with multiple components rather than single units. It can also be ascribed to the lack of fit between the requirements of the technology and standard building designs and practice. Far from a simple process, implementation often involves extensive accommodation of both the technology and the building. Failure to appreciate this often poses significant challenges to the project team; decisions concerning a particular design feature in either the technology or the building often throw up new problems, with unintended consequences for the project goals and for the building as a whole. This paper explores these issues by focusing on the micro-level dynamics accompanying the incorporation of Building Integrated Photovoltaics (BIPV). In doing so, it documents the mutual constitution of the technology and the building.

The challenge of green building is often treated as a problem of project team integration, with the focus being on professionals and their procedures and competencies. While this view captures important issues, the focus on professional roles and formal procedures obscures the complex decision making processes which explain how and why challenges are met. In addition, it masks adjustments to both the innovation and the building which accommodation produces. Little attention is paid to how innovative technologies involving cross-disciplinary issues affect the building in which they sit and the processes by which they are installed. What is missing is an understanding of how these interdependencies and the ways they are accommodated come together to shape both the technology and the building.

BIPV offers an example of a technology which is integrated into a building during construction rather than being bolted on during construction. As such, the incorporation of the technology necessarily involves extensive accommodation at many levels and in many different ways as it interfaces with different aspects of the project and its components. These accommodations can be in the form of technical adjustments or through changes to standard designs or ways of working. These technical, design and process-management issues are often treated as distinct and separate but in practice are interrelated.

This paper uses the Social Construction of Technology to explore the ongoing accommodation of both the BIPV technical system and the building. The advantage of this approach is that it draws attention to the succession of problems and solutions which constitute the construction process. By focusing on the actors and objects involved in successive accommodations, it highlights three distinct modes of decision making which inform the uptake of a system innovation at the level of construction projects.

2. Literature Review

Much construction research looks at sector level and macro level innovation; in contrast, this paper focusses on the challenges at the project team level by exploring accommodations to both the innovation and its context as the innovation is implemented. In doing so the paper rejects the notion of linear models of innovation and uptake (Rothwell 1994) and the distinctions between invention, innovation and uptake (Rogers et al. 2001).

A number of papers developed the idea that the effect of innovations varies with the local context. In a well-known typology, Henderson and Clark (1990) distinguished between four types of innovation, based on the relation of the innovation to the firm and its processes; These include: architectural, modular, incremental and radical innovation. Whereas Henderson and Clark focused on the effect of discrete innovations, Slaughter (1998)explored the impact of innovations which are more systemic in nature. Her research classified innovations by their distance from current practice, and their links to other components and systems. She distinguished between the discrete types of innovation outlined by Henderson and those which have system characteristics and which therefore require coordination among the project team, special resources and greater levels of supervisory activity. In a parallel study, DuBois and Gadde (2002) contrasted different types of construction contexts. Their largely conceptual paper distinguished between tight and loosely coupled systems to explain differences in the accommodation of innovations at both project and the firm level. The discussion which follows builds on these arguments concerning variations in the effect of innovations on the local context, be it the building design or the processes through which it is developed and argues for the need to explore empirically the process of accommodation within the project.

The relatively more recent advent of micro level socio-technical studies has contributed significantly to our understanding of innovation implementation in construction. Both Kjellberg (2010) and Harty (2008) used ANT to explore the introduction of innovations at the project level. In a study of the introduction of 3D-CAD software, Harty introduced the concept of relative boundedness to highlight the way in which innovations often have spill-over effects which go far beyond those intended or even anticipated. Harty's study also pointed to variations in actors understanding and thus use of a similar technology. This paper draws on both points, as it explores differences in key actors' motivation for adopting BIPV, their effect on design decisions and their unintended consequences.

An aspect of this problematic can be found in Kjellberg's (2010) study of the impact of a process innovation on the transformation of a warehouse. In his paper, Kjellberg documented the effect of a new warehousing system on both innovation and building design decisions. While, Kjellberg's study focuses on the transformation through implementation of a management system, his argument can be applied to the study of technical, systemic innovations. The research presented below explores the effect of BIPV on the ongoing design of the commercial building into which it was incorporated.

The analysis which follows contributes to these micro-level explorations of the accommodation of building project teams and building designs to the demands of new innovations. In contrast to these studies, the study of BIPV pushes the general argument one step further by problematizing both the design of the technology and the building. It also provides a basis to reflect on different modes of decision making, thus contributing to current understandings of both barriers to uptake and the processes supporting green construction. More specifically, it draws attention to the challenge of integration at the level of decisions.

3. Background

BIPV is a form of photovoltaic technology which is integrated into the fabric of a building. The technology is not fixed in format and in the UK is typically bespoke in design. It consists of several components: the photovoltaic cells which are laminated into the façade/louvre glass, connectors and wiring which take the DC generated electricity from the cell to the invertors, invertors which convert the electricity to AC and an export system which exports surplus generated electricity to the grid. Each of these components have implications for the design of the BIPV and similarly the design of the building will dictate the number of cells used, their configuration, length and location of wiring, position of invertors etc. By considering BIPV as a set of components, it can be considered as a technological assemblage which interfaces with the rest of the building design. Conflicts and resolutions occur as the technology is accommodated within the design and construction of a building. For example, the PV panels are accommodated within the frames of the façade, the wiring has to be concealed within the building and the inverters and metering systems have to fit within both the building and the electrical arrangements of the building.

4. Research approach and method

4.1 Analysis

Social Construction of Technology (SCOT) adopts a socio-technical approach to technological development. Analysis focuses on the networks of actors and objects which form around the specification of problems and solutions in the development of a new technology or, in this case, in the implementation of BIPV into a building (Bijker 2009; Schweber & Harty 2010).

For the purposes of this paper, the approach allows for consideration of the way in which construction professionals deal with problems and their resolution without privileging or distinguishing between types of issues (technical, design or management). It also draws attention to different motivations or criteria for discrete decisions. Although SCOT usually focuses on the development of a single technology, this paper extends the approach to explore the co-development of BIPV and the building in which it is introduced.

The case study, Future Green, is a commercial science centre which incorporates BIPV into the windows to meet its carbon reduction goals. It is one of three case studies in a larger research project; it was selected for this paper because of the very visible and unintended consequences which the introduction of BIPV had for the appearance of the building. Data collection combined semi structured interviews and document analysis. The project was identified by the supplier of the PV panels and contact was first made with the project architect. Snowballing was used to identify participants, until no new project members were identified. In total 13 construction professionals were interviewed. The research received ethics approval from the University of Reading and was carried out in line with these requirements.

Thematic analysis using NVivo 10 focussed on identifying problems and solutions arising during the project. In addition, attention was paid to the range of different considerations which led to particular decisions and their impact on the co-development of the building and the BIPV technology. Diagrams to explore the sequence of problem and solutions throughout the build were drawn up and problem solving strategies were identified.

As a method, SCOT provides a basis to explore discrete decisions and their effect on the development of a technology; however, it is less good at identifying the effect of broader structural characteristics which shape the process (Klein & Kleinman 2002). In the case study discussed below, the use of SCOT may have obscured issues of project organisation, path dependencies or management styles, which indirectly influenced particular decisions.

5. Future Green

The case study, Future Green, is a commercial science hub which is the first stage of a mixed development which includes the science hub, commercial offices, retail outlets and residential housing. The client group included a university and a city council, along with several other strategic partners. Future Green is a seven floor mixed space building, including exhibition and office space. Occupants, renting the offices are expected to be start-up businesses within the field of sustainability. Although predominantly council owned and run the building is operated by a private company which is in charge of letting space and running the building.

The project started out as a flagship sustainability project and BIPV was used to support this statement. BIPV panels were incorporated into ten of the 12 windows on the south-west elevation of the building. Other sustainable features included a small solar thermal installation on the roof of the building, a green roof and green wall on the west elevation and natural ventilation on the upper floors. The building includes many irregularly spaced, tall, narrow windows which make a bold architectural statement against gold cladding and green vertical brise-soleil panels. The project was carried out under a design and build contract.

The analysis which follows describes the co-development of the BIPV panels and the building, from the perspective of key design decisions and the socio-technical network which supported them. Figure 1 provides an overview of the process of co-development; while Figures 2-5 present enlarged (more legible) sections of the diagram to support the discussion. Each shaded box represents a decision or action which shaped either the building (the top line of boxes) or the BIPV (the bottom line). The unshaded boxes mark key points in the co-development story.

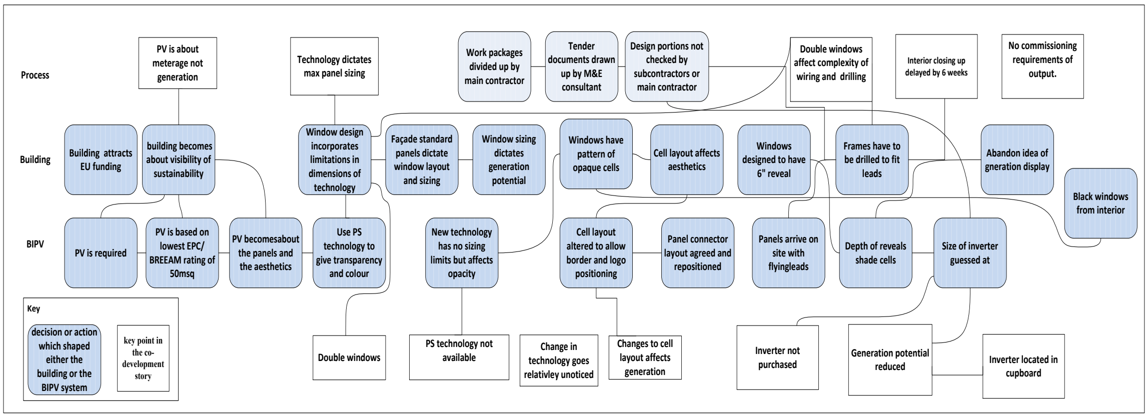

Figure 1 Co-development of BIPV and Building:

As Figure 1 indicates, the integration of BIPV is analysed as a succession of problems and solutions which led to the integration of BIPV within the window panes as a distinctive element of the glazing. Far from a simple decision, discussions around this feature passed through phases, each of which involved a slightly different problem and associated set of actors, objects and considerations. In the early stages, the architect proposed the use of thin film PV technology. During the tender phase, procurement problems led to their replacement with conventional monocrystalline cells, but knock-on effects on frame design and glazing beads were not picked up until well into construction, resulting in delays and re-work. The discussion which follows traces this decision making process.

5.1 Choice of technology

The introduction of BIPV was initially informed by the clients' early decision to attract European Regional Development Funding (ERDF)[1]. Conditions for the funding included the achievement of a BREEAM Excellent and preferably BREEAM Outstanding rating as well as an Energy Performance Certificate (EPC) rating of at least B and preferably A. Both A and B EPC ratings required the use of renewable technology.

Early on in the project, the client, architect and lead mechanical building services designer held a review of the sustainability options with a view to selecting which technologies to use. The architect and client were intent on using highly visible forms of sustainable technology so that future tenants and the general public would see that the building was green; they favoured the use of green walls and roof and solar technology (both solar thermal for hot water and photovoltaics (PV) for electricity generation). The design team considered using a conventional roof mounted PV system, but realised that the green roof would shade the panels. Instead, they suggested mounting them above the roof parapet, but this was rejected as it would not have been acceptable to the planners. In addition the PV panel frames would have had to be fixed to the roof, which would have necessitated piercing the green roof membrane and would have

[1] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/9455/National_ERDF_handbook.pdf (INCORRECT REFERENCE)

threatened water tightness. There was room for a small solar thermal installation on a separate part of the roof, but the space available was small and incompatible with a roof mounted PV system. Following these reflections the team decided to use BIPV.

Under the initial proposal the building with BIPV was set to achieve BREEAM Excellent and B for its EPC rating. For the reasons stated above, the client wanted an A rating and thus asked the mechanical engineer to come up with a design solution. He found that while only 50 square meters of PV panels were required for a B rating, 260 square meters would be needed for the desired A result. The client decided that a B rating would be acceptable, but still wanted BIPV as part of the project.

The choice of BIPV product and its positioning resulted from a succession of considerations. The architect wanted to incorporate BIPV on the large south-east elevation which was visible from the street. After looking at the building layout and the layout and positioning of brise-soleil louvres on the south east, the mechanical design engineer advised against this option as the façade had already been designed with large vertical brise-soleil louvres which would have shaded the panels and reduced efficiency. The two professionals considered incorporating the PV into the brise soleil louvres, but rejected this on cost grounds and eventually settled on using BIPV in the windows of the south-west elevation which had no brise-soleil louvres. The architect decided to specify thin film PV technology which, despite being of a lower efficiency than conventional monocrystalline technology, would give some transparency to the windows and also allow the windows to be coloured bark brown and so add to the sense of drama.

As indicated above, the decision to include a BIPV system was driven by the client's desire for a building with a strong sustainability statement, the planners' concern for energy generation and an appreciation of the interdependence of different components of BIPV and the building Figure 2 shows how the bid for EU funding and the client's wish to make a strong visible sustainability statement drove the inclusion of BIPV on the project, which then moved the frame through which the actors viewed the technology from one of electricity generation to one of visibility. This drew the architect and designers to using BIPV in the windows and so made the choice of thin film technology desirable. Decision making was thus driven by a dialogue between different actors, with different motivations. All of the actors involved were aware of the range of different considerations and the negotiations supported a well considered decision, taking into account the systemic properties of the technology and the building design.

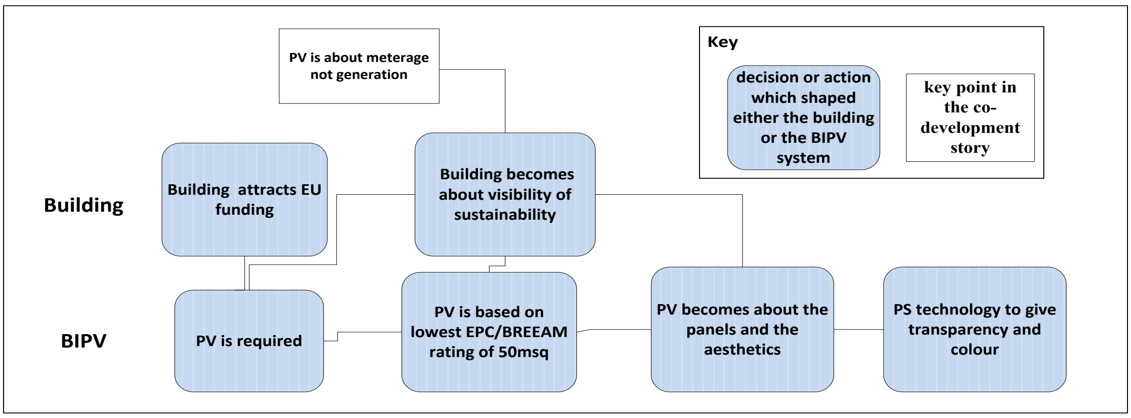

Figure 2: Choice of technology

5.2 Allocation of work packages

The process of developing tender packages for the project was also problematic. The project team continued to design the building, with the mechanical design engineers and architect developing the technical specifications and the main contractor deciding how the contracts for tender were to be allocated. When dividing up the work packages for tender the main contractor decided to include the BIPV panels in the envelope tender package and all the other parts of the BIPV system in the mechanical and electrical package for the internal work of the building. In doing so, he privileged conventional building practice over the technical requirements of the technology.

> It made perfect to put it into the envelope package, because it's no different to installing any other window, it's just got the PV components within it.
>
> Main Contractor

The M&E design consultants drew up the tender packages accordingly and included substantial design portions in each tender package for development of the design for the configuration of connections on the panels, location and sizing of the inverters and wiring from the panels to the inverters. The consultant was very clear that further integrated design between the M&E contractor and the façade supplier would be necessary to make the technology work.

> They have to liaise quite closely with the architect over the installation details, because it would ultimately be part of the façade installation, the two would have to come together and form an integrated solution.
>
> Mechanical Design Engineer

The packages went out to tender and were duly awarded. The main contractor was not aware of the requirement for detail design of the system and the contractors had not read the detail of the specification. The façade supplier viewed the PV panels as just another sort of glazing panel and this resulted in the PV panels arriving on site with two flying leads on each panel and no plan about how they were to be incorporated into the façade and penetrate the building. Some windows were mounted one above the other and this double height design made the installation even more difficult. At the same time the M&E contractor had neglected to plan how the wiring was to run from the frames and had forgotten to order the inverters. Figure 3 shows how this progressive lack of integration and design led to a delay of the internal finishing of that elevation of the building of six weeks.

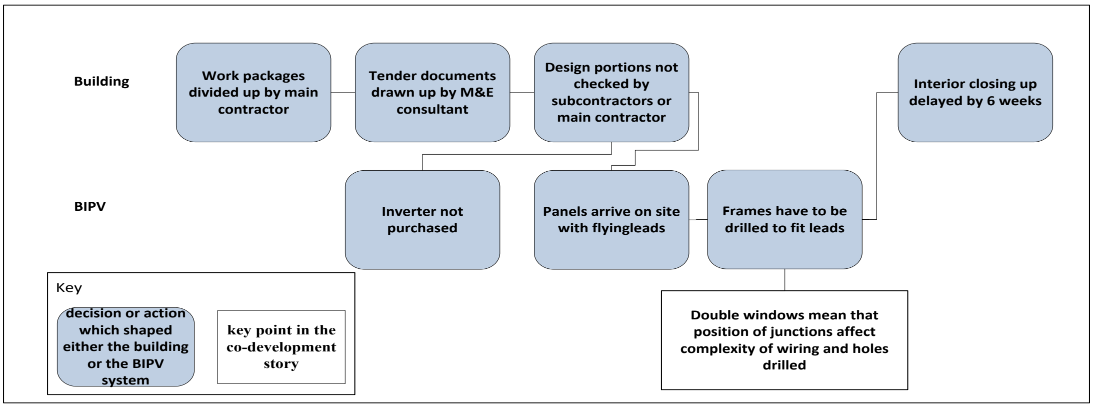

Figure 3: Allocation of work packages

5.3 Change of technology

During the tender phase, the thin film technology was replaced by conventional crystalline cells as the original system proved to be unobtainable. As the discussion which follows and figure 4 indicates, the architect made this decision based wholly on aesthetic considerations, with no consideration for the knock-on effects of his decision. It was only well into construction that the effect of using the more conventional monocrystalline cells on frame design and glazing beads were picked up, resulting in delays and re-work. In the end, BIPV contributed to a strong visual statement from the outside, coupled with a significant loss of functionality from the inside. The BIPV windows were opaque, reducing visibility, and their energy generation was extremely low. The exterior of the finished building clearly showed the inclusion of BIPV in the windows, but internally this was translated into a loss of functionality – both in terms of the transparency of the windows and in the very low PV generation. An account of the substitution of the BIPV product explains how this less than optimal outcome happened.

When BIPV was first suggested, the architect and engineers opted for a thin film technology on both functional and aesthetic grounds. As the architect explained, the brown colour of the panels would resemble wood bark and contrast with the gold façade while the translucent finish would provide light through the windows. The thin film technology had limitations in terms of the dimensions that could be manufactured; this meant that most of the PV windows would be made from two panels, one above the other. In addition, the standard glazing panel sizing for non PV windows dictated the window layout and sizing.

During the tender process the thin film technology became unobtainable and the supplier proposed to substitute it with conventional monocrystalline PV panels which would provide slightly superior PV generation, but which were not transparent. Transparency would be provided by the spacing between the PV cells, rather than as a general translucency across the whole panel. The architect and main contractor were keen to keep to the schedule and agreed that the new technology be used. The architect worked with the glazing supplier to optimise the layout of the cells and logo to have an even border and symmetrical cell spacings. The architect was unfamiliar with the differences in the two technologies and summed up the situation:

> The only difference as far as I know with that is it's the graphical display of the cells… the original specification that we had was more of a bark wood type. … it wasn't a massive issue, we just went back to an alternative specification.
>
> Architect

The knock on effects of this decision was that the changes to cell spacing affected the generation potential of the technology and the aesthetics of the windows from the inside. Instead of a semi-transparent brown wash, up to 80 % of each PV window now had blocks of black opaque cells. The other thing to pass without notice was that the restriction on the dimensions of the technology no longer applied, such that the windows could have been specified as one panel, thus reducing the number of joins and flying leads.

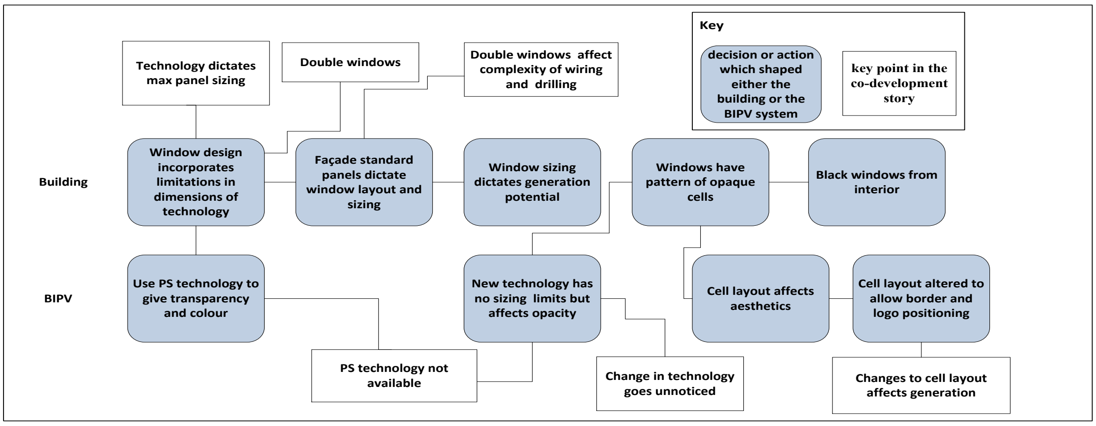

Figure 4:Co-development of building and BIPV

During the construction phase the lack of design and coordination of the BIPV system led to rapid discrete decisions being taken over frame modifications, glazing beads and wiring configurations. These decisions sub-optimised the output potential of the system and resulted in delays and re-work. In addition, an aesthetic detail for deep window-reveals resulted in shadowing of the PV cells during significant periods of the day which dramatically reduced generation further.

6. Discussion: Modes of decision making

Over the course of the project a series (and sometimes parallel set) of problems and solutions led to the co-development of the building and the BIPV. Finally, the incorporation of BIPV into the building reduced internal visibility and resulted lowered PV generation, effectively transforming BIPV from a renewable technology to an external sustainability statement.

Reflecting on how this happened, the succession of problems and solutions discussed above point to three distinct modes of decision making, including: discrete decision making, conventional decision making and integrated decision making.

Discrete decision making occurs when decisions are taken in isolation without reference to the rest of the project. In this mode, decisions are made based on the immediate situation, where immediacy refers to both the spatial and temporal dimensions. In the decision over the choice of technology, the architect addressed the issue based on his aesthetic concerns. He selected the thin film technology because it gave a semi-transparent window and because its brown colour added to the sustainable look of the building. When the technology was no longer available from the original supplier, he agreed to substitute it with monocrystalline cells, without considering that the PV technology was only one part of the larger BIPV system. As the discussion above indicates, this discrete decision had a number of knock on effects. Not only was the generation capacity reduced, but the windows became opaque. Collateral damage also occurred when original size limitations on the windows no longer applied, but were kept in the design, thus complicating wiring configurations and when the size of glazing beads needed were not altered to fit the new, thicker panels.

The term ‘conventional decision making’ refers to decisions based on standard procedures. Unlike discrete decision making, this mode takes into account broader temporal and spatial considerations, but not the specificity of the technology and the building. Like discrete decision making, this mode fails to take into account the knock on effects of the changes to components of the technical innovation. In the case of Future Green, this mode is evidenced in decisions around the procurement of technical components and the division of labour into work packages.

As the discussion above indicates, the main contractor divided up the tender work packages based on the conventional division between the envelope package and the internal mechanical and electrical fixing work. The M&E consultant was asked to draw up the work packages and allocated design portions within the packages. The result was that the visible aspects of BIPV were included in the envelope package, whilst the hidden part of the BIPV (the electrical part) was buried within the M&E package, where the design portion including sizing and procurement of the inverter was forgotten. Not only were the electrical components forgotten, but, also, the interfaces between the glazing units, the frames and the internal wiring were not considered until installation; consequent problems took six weeks to resolve.

The third mode identified in this study is integrated decision making. This involves collective consideration of the system properties of both BIPV and the building and is illustrated in the development of the initial bid for EDRF funding. In preparing the bid, the client, architect and M&E designer looked into the implications of using different forms of sustainable technology. They clarified the implications of installing a green roof and of using solar thermal installations and, based on these considerations, agreed to use BIPV on the façade instead of roof mounted PV panels. The decision to use BIPV in the windows was made once the requirements for an EPC rating of B were understood and the square meterage of PV matched the window sizing. The south west elevation was chosen for the BIPV as the implications of using the south east façade with its brise soleil panels and consequent shading was unsuitable. All the team members were in agreement that BIPV windows were the preferred solution and understood that from that point the BIPV was primarily about making an external sustainability statement, rather than making a contribution to energy generation.

A second example of the integrated mode can be found in a coordinated response by multiple project team members to on-site problems. This type of flexible, local problem solving is widely recognised as a strength of the sector. In the case of Future Green, the conventional decision to separate the procurement of BIPV into mechanical and electrical packages and the subsequent isolation of the PV glazing from the frame led to a series of on-site issues ranging from how to incorporate the flying leads into the frame and take them inside the building to how to complete the weatherproofing of the envelope when the PV glazing beads were the wrong size. As the different subcontractors were brought together by the main contractor, an integrated decision mode was developed which allowed for innovative solutions to be found.

By analysing the use of these three decision making modes across the implementation process, it becomes easier to understand how and why problems arose in the incorporation of BIPV and why the project failed to deliver on its initial aims. Far from being unique to this project, the argument is that these dynamics are characteristic of innovation in the construction sector. In the case of Future Green, the integrated mode used at the beginning of the project allowed the team to focus on the issue of sustainability as a whole. This led to a holistic solution with clear specifications for the proposed BIPV system. When the thin film PV technology proved to be unavailable, the architect adopted a discrete decision making mode and agreed to the substitution of monocrystalline cell technology, without linking the decision back to issues of generation or functionality which stemmed from this decision. The main contractor's use of the conventional decision mode in deciding work package allocations set the scene for a fragmented development of the BIPV system and a series of problems at the interfaces of both the BIPV system and the contractors on site. Integrated decision making helped to address the local issues on site and encouraged some innovative problem solving, but it could not impact the effect of earlier discrete and conventional decision taking which locked in an opaque windows and low generation outputs from an early stage for the project. The "crown jewels" were indeed installed in an eye-catching setting, but despite good intentions, proved to be hollow when viewed from a point of functionality and value.

7. Concluding Comments

In closing it seems incumbent to return to the initial research problem and ask what this analysis contributes to an understanding of technical innovation in general and sustainable innovation in particular. On one level, it documents the complexity of the decision making process and the co-development of system technologies and buildings. On another level, the distinction between modes of decision making provides the basis for a more nuanced understanding of how 'integration' might address the challenge of sustainable construction.

Whereas most scholars focus on the integration of project teams, this study suggests that formal managerial changes are far from adequate. Sustainable construction depends on a shift in the mode of decision making from discrete and conventional decisions which, while they have the benefit of efficiency, threaten to undermine client and project goals for the new technology.

The challenge is for project teams to recognise the interfaces of the technology and identify which mode of decision making is most appropriate. In the study of innovation and uptake this raises the question: "under what condition do teams engage with an integrated mode of decision making and what can be done to encourage it?" It also raises the issue of the role of contracts and formal structures and procedures in promoting conventional decision modes rather than integrated ones.

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Requirements compliance checking for existing buildings

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Abstract

Most of the building stock in Europe has been built in the sixties and nowadays it is not always fulfilling current requirements coming from binding laws, voluntary standards and clients' needs. When dealing with assets acquisition or with decisions on their reuse and refurbishment, it always takes a big effort just to understand if a building complies with current regulations, because of the lack of knowledge and laws complexity and jeopardising. This paper shows a tool able to help users dealing with the requirements compliance checking of existing buildings. The purpose of this tool is to enable decision makers in making strategic choices about their assets, by providing them the actual state of the building regarding the requirements compliance. The tool consists in a set of checklists, tailored for building function and declined in all the possible type of spaces of the building; this because each space has specific requirements to fulfil, as well as the building itself (intended as an entity). The tool uses as an input spaces dimensions, performances, characteristics but also documents and permissions; with a calculation procedure, it gives to the user a set of data. This kind of check is fundamental to take decisions about how to conduct the asset: refurbishment, handover, retrofit or simply maintenance are all options that can be evaluated only with the correct knowledge of the asset. A preliminary case study is presented here just to show the potential of this tool; to improve the compliance checking process, some characteristics (that can be automatically checked) have been implemented in Solibri Model Checker. The remaining have been checked manually with other software and all the results have been collected in the checklist developed. This tool is part of a bigger work that wants to look not only at the requirements but also at the physical state of the building (so to organise maintenance), the energetic behaviour (so to optimise consumptions) and at the adaptability potential (so to evaluate functional change alternatives).

Keywords: Asset management, requirements compliance, real estate, BIM, IFC

1. Introduction

Most of the time, especially for new constructions, checking available documents is sufficient to provide a clear situation of the compliance with laws and standards of the building under analysis. But dealing with the real estate means to face modifications occurred over years, missing and not updated documents, compliance with new standards and in general with a lack of information (Montague, 2015). This is the reason why most of the times it is necessary to review the response of the building and its spaces to mandatory and even voluntary requirements, given by either laws, regulations, standards, guidelines, clients and owners.

Therefore, it is necessary to go beyond the analysis of pathologies, service life and documents: it is necessary to provide users with a clear framework of the building compliance to requirements, divided by function (both of the building and of each single space inside it). So the objective is to create a checklist, easy to fill (no need of professionals for most of the controls), able to return to the user a clear understanding of the building, to allow, if need be, planning restoration and adjustment works.

This is also strictly related to building adaptability (Kelly *et al.*, 2011): as adaptability is the ability to accommodate changes, requirements fulfilment is a pre-requisite, necessary to allow these changes. An example is given by building functional change: a building may change its function more than once during its useful service life (Kincaid, 2000), but, even if it is technically possible, maybe the adaptation is not allowed. So this type of check completes the adaptability assessment, giving to users the possibility to plan operations not only to restore defects and pathologies, but also to restore the compliance with binding laws. Compliance checking can be also performed during the handover, both by the seller as a guarantee and by the buyer as a control.

This paper shows, after a brief state of the art related to regulatory compliance and code checking, the tool developed by the authors, with the help of a case study (an existing office building). The paper contains also a short explanation of the assessment and calculation procedure of the tool and the discussion about results generalisation and limitations.

2. State of the art

Here it is a brief description of the state of the art related to regulatory compliance in general and to code checking with automated (or semi-automated) software, in connection with BIM models. Even if using a BIM model to perform this kind of checking is not mandatory, project complexity is become so critical that needs to be handled with dedicated software.

2.1 Regulatory compliance

Regulatory compliance checking is an activity done mainly during design stages, with an increasing complexity from the brief to the final design stages; this checking is made also after construction, to check the compliance between what has been designed and then built. In a perfect world, all these data about requirements can be easily checked in the documents or directly in the building, but with the Italian real estate, built mainly in the sixties with different laws and standards, performing this check is not an easy task.

The due diligence, defined in the ISO 26000:2010 as the "*comprehensive, proactive process to identify the actual and potential negative social, environmental and economic impacts of an organization's decisions and activities over the entire life cycle of a project or organizational activity, with the aim of avoiding and mitigating negative impacts*" can be the solution to the problem. Due diligence can have wider objectives, allowing to assess several aspects of a building through an audit (defined as a data gathering procedure); also Building Condition Assessment (Re Cecconi *et al.*, 2014) can be considered a technical due diligence, as the regulatory compliance checking.

Even if this assessment spaces on a really wide range of topics (fire fighting, safety, accessibility, comfort, etc.), the evaluation process is quite straightforward and simple: a complex assessment system with weights, categories and tools is not mandatory to perform a good check; nevertheless, the complexity of the laws and standards frameworks is pushing the need of software able to automate these checking, which now imply a huge effort for designers (Malsane *et al*., 2015). On the opposite, there is the need to pay great attention to the requirements to be checked: a requirements database must be provided, so to have the possibility to check their fulfilment, space by space and for the entire building. Even if not related to buildings, an interesting example is given by Maxwell and Anton (2009), which provided an assessment system dedicated to a health record system, able to check the requirements against the current U.S. law.

Requirements can be associated to the part of the building they are related to: building (as a whole), spaces and components (including subcomponents). Building (as an entity) has to be considered in relation with surroundings (other buildings, landscape, viability, etc.), but also some characteristics have to be checked on the whole building (number of exits, height, extension, etc.). Spaces are really important for requirements compliance: most of the times the function of the space influences the requirements, so a careful space-checking must be done. Components must have some characteristics depending on the building/space function, but some requirements are also connected to single layers (especially finishing, load-bearing elements, insulations, etc.), even if they can be easily transposed to spaces. Eventually, to perform a proper requirements due diligence, many aspects must be checked, some of them can be generalised, but many others must be checked depending on the specific building.

Requirements fulfilment, together with a price list, maybe appositely implemented, can provide to the client and to decision makers the clear situation of the money to be paid to restore the building compliance, if need be, or to change the function of one or more spaces, which is a frequent activity, especially in offices and commercial assets (Kincaid, 2000).

2.2 Code checking

Going further with this topic, together with the requirements database, a tool to automatically check them should be provided: this because buildings complexity is always increasing and doing this check manually is becoming more and more hard-working. A solution to this problem can be given by Building Information Modeling (BIM) that, together with the IFC protocol (BuildingSmart, 2015), provides an instrument to ease these kinds of controls. Maxwell and Anton (2013) provided a demonstration of the potential of the code checking procedures, by applying them to a water distribution system. Malsane *et. al.* (2015) tried to translate (and optimise) the rules related to fire safety for dwelling houses in England from textual rules into computer-readable rules; as can be seen from their work, the code checking is not only a matter of using a software, but the comprehension of the rules (and the consequent transposition) is very important. This leads to the need of having a proper database of regulatory requirements to be used, not depending on the automated compliance checking tool to be used.

Despite the importance of BIM code checking, Cao *et al.* (2015), by analysing 106 BIM projects in China, state that BIM is used mainly for design (fabric and services), clash detection (during construction stage) and not too much for checking the design against building codes. Anyway the interest on BIM is constantly increasing (Market Research Reports Inc., 2015), so also this task will be soon more important.

Code checking can be performed also as an audit connected to Facility Management (Dimyadi *et al.*, 2015); authors presented methods commonly used to represent and access digital regulatory knowledge for compliance audit purposes and claimed for an open standard regulatory knowledge representation.

Solibri Model Checker (SMC – Solibri, 2015), one of the most famous instruments to performs these checks, can be given a set of rules to be applied to the building under analysis, so to check requirements and create a report (Solihin and Eastman, 2015). Also regarding BIM technologies and code checking, Dimyadi and Amor (2013a and 2013b) and Dimyadi *et al.* (2014) provided interesting data.

Not all the requirements can be easily automatically checked. As instance SMC does not make calculations, which are frequently asked during regulatory compliance checking. This is way the first part of this research focused on the definition of the requirements in a clear and comprehensible way, not related to the tool to be used to perform the check.

3. Information management

The assessment of requirements fulfilment (by law, voluntary, by the client – related to the whole building and to each single space) is a direct consequence of the current state analysis of pathologies and documents, as it completes the building picture. Requirements analysis, guided by a set of sheets and a procedure, is fundamental to understand if the building, not depending to the documents describing it, respects the laws and fulfils the function it is designed for. This analysis includes the control of:

a) requirements of each single space of the building;
b) distance among/from spaces;
c) requirements of the building as a whole;
d) distances among/from the building and other buildings and surroundings.

It is important to notice that requirements have been collected in a database for each single building function, i.e.: office, commerce, cinema, catering, school, etc.; in this way a detailed list of requirements has been obtained, updated to the law in force and attributable to each single (fundamental) space for each function.

This instrument can be used both during the design, as a checklist to control requirements fulfilment, and during use, to check their fulfilment in course of time. In addition to these two main uses, it can be an important instrument to verify the function change, even of only a part of the asset, to assess the compliance to new requirements, as it makes available the reference regulatory framework, with the related operations necessary for the refurbishment; costs can be associated to these operations, allowing to assess in a complete way the opportunity of a functional change. An assessment of this kind has several applications regard safety issues, both regarding the whole building and the activities inside.

Requirements compliance is an important theme, especially if an entire portfolio is considered: through the spaces use and the compliance of their requirements it is possible to plan modifications and so the budget for adaptation works (possibly in connection with other maintenance works).

A future development of this system is given by the possibility to assess the efficiency in space use: it is sufficient to think about how many spaces are not adequately capitalised; having the complete picture of the spaces could help in managing them at their best, avoiding waste and consequently missed incomes. The index under development can help in different situations:

a) to provide the requirements compliance situation of the portfolio, asset by asset: define the operations to be done to restore the portfolio requirements compliance;
b) to provide the requirements compliance situation of the asset, with the list of missing requirements: define the operations to be done to restore the asset requirements compliance, category by category;
c) collect professionals and operators to act properly.

4. Requirements index

Regulatory compliance checking is part of a broader condition assessment tool, involving physical (pathologies, ageing), adaptability and documents checking. Nevertheless, this part can be also used as a stand-alone assessment system. This study is now focused on tertiary office buildings, but other functions (food services, hospitals, residential, hotels, etc.) are under analysis. Buildings dedicated to tertiary activities (offices in this specific case) have been firstly analysed to get the complete list of possible spaces and zones involved (i.e. from Neufert, 2013), then a requirements list, space by space (and for the whole building) has been created starting from current Italian laws and standards. The process of this checking consists of four main steps (Figure 1):

a) Survey of the physical asset, made of the asset itself and a series of documents and drawings;
b) Creation of the digital asset, consisting of a Common Data Environment (CDE), in which information are stored in BIM models and digital documents;
c) Checking of the requirements compliance with current standards, laws and client's needs. This is done automatically (e.g. with Solibri Model Checker) or manually (when an addition data elaboration is needed);
d) Reporting of the situation and, if need be, restoration of noncompliances.

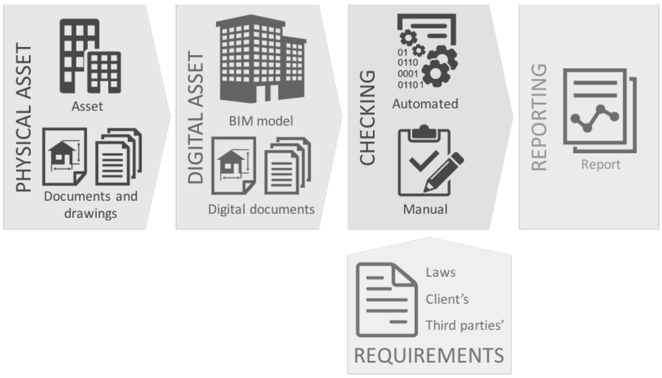

Figure 1: Scheme of the process

4.1 Requirements database

To create a metric for space requirements compliance checking, a database with a precise set of requirements is needed. This should be done incrementally: a complete set of requirements for all spaces and building functions is hardly achievable in a short term. But a robust framework can be designed to gradually collect data in an efficient and effective way. This database is only the aseptic collection of requirements, which should be declined for each specific building under assessment. Each requirement is connected to a specific space and building function (remembering that many spaces can belong to different buildings functions). Each space should be unequivocally defined (e.g. an office with less than 5 people may be different from an open space office with more than 20 people). Here it is the list of data that should be gathered:

a) object of the control: short name of the parameter to be checked (e.g. minimum floor area, maximum number of people, etc.);
b) condition of requirement satisfaction (e.g. minor than, equal to, greater than, etc.);
c) threshold value;
d) internal threshold value, given by the client, to be considered valid only if more restrictive than the threshold value given by law or voluntary standard;
e) unit of measure of the threshold value;
f) source/reference of the requirement, split in three types (each category is associated with a weight): binding law, client's need and voluntary standard;

g) type of control (this leads to different data to be checked and inserted by the operator to verify requirements compliance): visual, documents, calculation, distance and connections;
h) building type: existing building, new construction or both;
i) measuring criteria, the precise definition of how to measure the parameter to check requirement compliance.

In Figure 2 there is an extract of the database created.

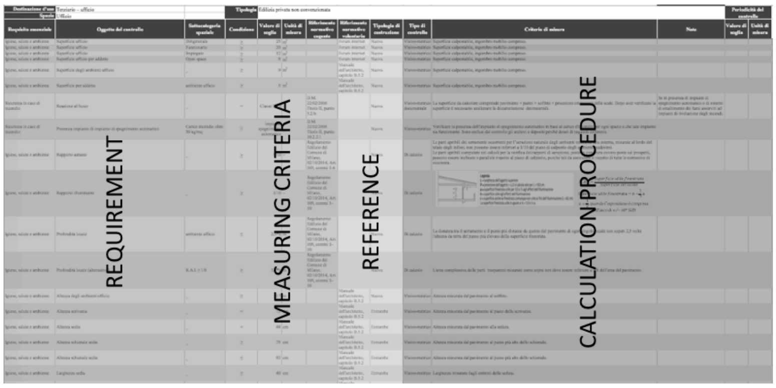

Figure 2: Extract of the requirements database for office buildings

Totally 236 requirements have been collected and associated to 9 major spaces and to the whole building; most of them are the same for many spaces, so the total number of requirements could be reduced to a handier number, if considering that they partially overlap in many spaces. 15 documents (standards and laws) related to office buildings have been checked to provide this list of requirements.

4.2 Space level

The space level is the first level of calculation of the requirements compliance. In this step the requirements database is connected to a specific building and to specific spaces inside it. The data listed above remain the same (they cannot be modified) and additional information must be added. Here it is the list of additional parameters to be filled, once selected the specific space:

a) space data, necessary to unequivocally identify it: number, name, code, space function, space typology, space net floor area, space gross floor area, measured value, document reference, requirement compliance: Y – Yes, this space requirement is fulfilled, N – No, this space requirement is not fulfilled, NC – Not Checked, this space requirement has not been checked and NA – Not Applicable, this space requirement is not applicable to this specific space;
b) adaptation, the need of adapting the space to fulfil actual and future requirements.

After the completion of all the relevant data, for each space, some indexes and key information can be calculated automatically, to define the space requirements compliance. Here the main steps to be done are reported:

a) each requirement, depending on its source/reference, has a weight (to be fine tuned with one or more case studies): 0.6 for binding law requirements, 0.3 for client's need requirements and 0.1 for voluntary requirements;
b) the weighted sum of all requirements (from 1 to n) needed is the maximum weighted Space Requirements Index;
c) the weighted sum of all requirements (from 1 to n) compliances is the current weighted Space Requirements Index;
d) the weighted Space Requirements Index is the ratio between the maximum and the current situation;
e) as the only index may be not enough to understand requirements compliance, other statistics can be extracted.

Eventually, a graphical representation of the results is a good way to understand each space situation at a glance. The red part of the Figure 3 shows the remaining score to achieve the sufficiency, given by the lack of compliance to binding law requirements.

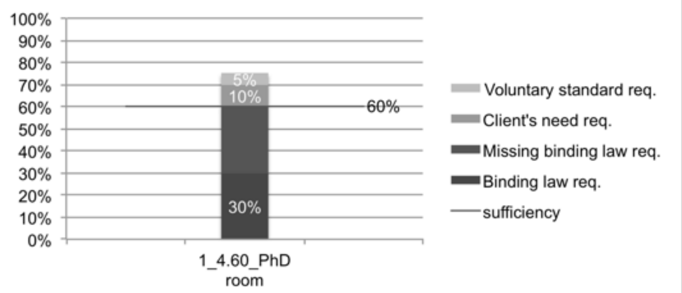

Figure 3: Example of output of the Space Requirements Index

4.3 Spatial unit level

A spatial unit is the collection of all the spaces with the same function. At this level no data are required to be filled by the surveyor. This level is fundamental for understanding building behaviour but there is the need to converge to a single result (or a small set of data); so it is explained the decision of keeping as many data as possible at the space level, using functional units and building levels only for calculations. For each function, the weighted Spatial Unit Requirements Index can be calculated as the weighted summation of the index of each space, using the the net area as a weight, which allows to consider the economic importance of the space, as it is related to the unitary cost; in addition, it is easily quantifiable and objective. Also at this level, interesting statistics about the regulatory compliance can be extracted from the assessment model. Also in this case it is possible to associate the index with a graphical output.

4.4 Building level

This is the last level of calculation of the requirements compliance index. The weighted Building Requirements Index can be calculated as the weighted average of the index of each spatial unit, using the net area as a weight, which allows to consider the economic importance of each spatial unit, as it is related to the unitary cost; in addition, it is easily quantifiable and objective. Another possible weight to be applied (instead of the net area) is an importance weight calculated with the AHP technique. The same statistics done at the functional unit level can be done also at the building level, to fully understand building current requirements compliance situation. Also in this case it is possible to associate the index with a graphical output.

The calculation procedure briefly outlined here is still under analysis and some changes will be applied after testing the it on some case studies. In addition to this, one of the best ways to perform a regulatory compliance checking is to create a BIM model (with a BIM authoring tool) and check it with a code checking software (e.g. Solibri Model Checker); this procedure perfectly works for most of the geometrical requirements, while it has some problems with analytic and textual data. Some of these issues and reasoning are reported in the §5, thanks to the application to a case study.

5. Case study

The case study aims to show the procedure and to make some preliminary tests. The objective is to test the regulatory compliance checking tool in combination with SMC. The combination of the checking tool with SMC (manual and automated checking in Figure 1) is necessary, as not the totality of the requirements can be checked with SMC. This case study has to be considered just a first step of this research, which consists of a wider programme, including building condition assessment and adaptability ratings; the final objective is to provide a complete and exhaustive view of an asset and of a portfolio. The building under analysis is an office building of the Politecnico di Milano. It has been built in the sixties as a steel warehouse and then converted into an office around 25 years ago. It has 3 storeys above ground and one under ground. Spaces are mainly dedicated to offices (for both researchers and administration), meeting rooms, rest rooms and connections (corridors, stairwells and lifts). The building has been refurbished in both fabric and services, so there is no urgent need to act to solve problems. The limited number of spaces, spatial units, the availability of data and drawings and the regular shape make this building a good case study to perform a preliminary test. The building is composed by totally 154 spaces, including shared spaces, rest rooms, technical rooms and storages. The BIM model (Figure 4) has been implemented with the following characteristics and components: layers of fabric components, illumination system, HVAC system, fire safety system, lift, fire extinguishers and rooms (with correct name, function, number of people, etc.). The model has been made with the help of eng. Hamir Hakim and Roberto Ferrari using Autodesk Revit.

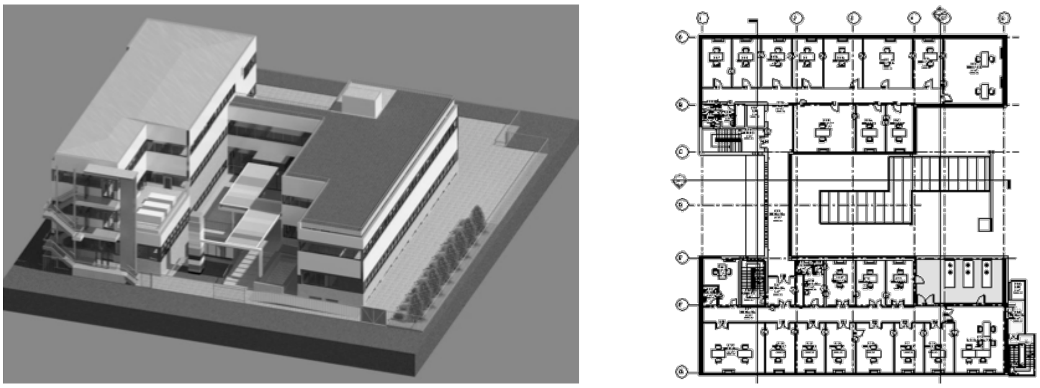

Figure 4: BIM model of the case study (left) and plan of the first floor (right)

The model has been exported from Revit in IFC, allowing to use it in SMC. The coherence of the elements imported in SMC has been checked in the information takeoff section. The requirements have been added to the SMC ruleset, with an explanation and the parameters needed to the check. As said before, it has been possible to add only a part of the requirements (more than 50%) in the ruleset (for the 9 main space categories of the office building), as many requirements were difficult to be managed inside SMC (at least in this first trial). SMC automatically gives a report with the requirements fulfilled or not and the result is that the building presents these issues: some doors (mainly of the rest rooms) have not the minimum width (not for fire safety issues), one door in the under ground opens inside the space and not outside (this issue is related to fire safety) and one office has not the minimum area required (Figure 5).

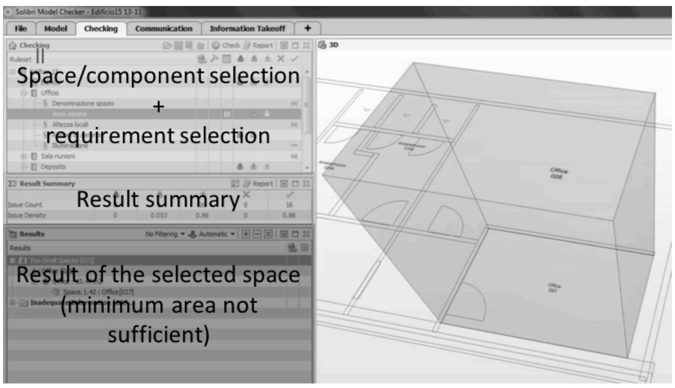

Figure 5: Example of requirement checking in Solibri Model Checker

Some other small issues have been found, e.g. one corridor in the underground has not the minimum width to be considered accessible (but the zone is used as a warehouse at the moment). All the remaining requirements not checked in SMC have been checked within the checking tool, developed in an Excel spreadsheet; among them: permeable surfaces, stairwell typologies, furniture dimensions, finishing fire rating, etc.. Authors are currently working on a way to overcome this issue, so to implement all the requirements (or at least the majority) inside the BIM model, so to fully automate the check. Also the manual checking highlighted some minor noncompliances, among them: some furniture is missing (e.g. dedicated card index cabinets) and there are no data regarding the fire resistance of some finishing (missing data are considered noncompliant). All the results coming from Solibri have been transposed into the Excel checklist (connected to the requirements compliance index of §4), so to calculate the rating associated and to have a complete view of the criticalities encountered. In general, the building has only few minor issues that can be solved without a great effort; the final rating, for both the whole building and spaces is abundantly above sufficiency (no voluntary requirements have been considered in this analysis). As said before, this case study has only the purpose of outlining the procedure and to show the process of regulatory compliance checking.

6. Discussion

The requirements compliance index has been calculated by analysing all the spaces of the buildings and also the building as a whole (distances from other buildings and distances inside the buildings, e.g. from fire exits). The requirements list was exhaustive and comprehended all the issues to be addressed by these types of controls. The BIM model analysed with SMC greatly helped in cutting the working time to analyse geometrical data, while some issues have been encountered with calculated values (e.g. the window/floor surface ratio). All the requirements checked on the BIM model have been transposed in the tool (in Microsoft Excel), so to have the complete view of the building. There is still a great effort to be paid in developing this tool, starting from a precise procedure to be followed to analyse requirements (which need to be checked in the BIM model and which not). In addition to this, the calculation procedure can be changed and improved according further tests on case studies. Nevertheless, this tool can be easily used by both technicians and asset managers (e.g. without engineering skills). The use of a BIM model and of BIM authoring tools is not mandatory to provide a correct assessment of the regulatory compliance. A possible future development of this tool, once fully defined, is to implement it in a web interface, so to be used online, maybe in connection with an external database and/or the BIM model database; using Revit DBlink it is possible to extract and interact with the database of the BIM model under analysis.

7. Conclusions

Eventually, a great effort still needs to be paid to refine this tool, as at the moment it can be considered just an initial work. The first result is the list of requirements, divided by spaces; this can be used to check requirements during design or handover and even (partially) implemented in a rule set of Solibri Model Checker, so to be automatically checked. The calculation procedure should be revised according to the results of the case studies, which are planned to be assessed in a short future. The second step to be done is to associate costs to restore the compliance with the current binding requirements, so to have a clear appraisal of the expenses to be made; the same has been done with another indicator regarding building degradation and ageing, connected to maintenance, repair and replacement costs over the life cycle. BIM technologies, together with a complete and up-to-date requirements database, could lead to important savings, safer buildings and a better management of portfolios, as the knowledge is the basis of a proper management strategy.

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Preface

The aim of this last volume of the CIB World Building Congress (WBC), 2016 *Intelligent built environment for life*, is to explore the various needs of modern construction and offer new ways and techniques to address them. In recent years, stakeholder expectations have led to political, social and economic pressure on the construction industry. Modern buildings are expected to be innovative, sustainable, resilient to hazards and other risks as well as being easy to manage. In addition, clients expect to be part of the decision process to ensure their needs are met and often tied to legal bonds with professionals, a situation that can generate conflicts.

More than 200 authors have contributed to the 98 papers included in this volume. The vast majority of this research work is led by academics (70 papers) who discuss problems from a theoretical background and suggest solutions; whilst the remaining is led by industry researchers (28 papers) who provide an insight on real life through case studies. The present research work is led by researchers in 28 countries representing east and west, north and south of the globe. We hope that product and service enhancement will result from our sharing of information and collective experience.

Papers were classified into seven areas, including:

- Procurement, finance and conflicts (10 papers);
- Stakeholder involvement and satisfaction (12 papers);
- Innovative design and construction (17 papers);
- Risk mitigation, resilience and health and safety (13 papers);
- Sustainable construction (15 papers);
- Building information modelling (BIM) (16 papers); and
- Facilities management (15 papers).

Many lessons could be learned from each area and each research paper. However, one of the key lessons to be learned from this body of international research outputs is the need to better integrate design, construction and post-occupancy management in a construction lifecycle specifically with advancement of technology and availability of BIM tools. The second key lesson is the increasing acknowledgment of resilience and sustainability as a major part of modern construction.

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Scientific Co-Chair, CIB World Building Congress 2016

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1

Procurement, finance and conflicts

Multi-organizational PMOs for Interface Management between Construction Megaprojects and Its Sociological Context in China

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Abstract

This conceptual paper aims at providing an in-depth understanding of the role of the project management office (PMO) as a coordination mechanism between its complex multi-organizational settings of construction megaprojects and the sociological context in China. In the project practice of some large infrastructure in China, the coexistence of multiple organizational PMOs (with members from several independent organizations) is a common situation to coordinate the interface of sociological context and construction mega-project. The proposed conceptual framework builds on three main foundations: social conflict theory, governance mechanisms, and, the multi-organizational PMO. The proposed methodology is based on in-depth case studies, both of which are airport projects in China. By taking a sociological perspective, this research offers a novel and promising approach to the study of mega-projects and PMOs.

Keywords: Construction Megaprojects, PMO, coordination mechanism, social conflict theory

1. Introduction

The *New York Times* had an article in an early 2015 edition, title: "In China, Projects to Make Great Wall Feel Small."(Barboza, 2015, p. B7). Among others, five major Chinese infrastructure projects were described, each one breaking some of the previous infrastructure limits. For instance, there is the Jiaozhou Bay Bridge, the world's longest sea-crossing bridge at 26.4 miles. These mega-projects are not only about engineering and construction; they are about building a national identity, said Bent Flyvbjerg, as interviewed in this article (Barboza, 2015).

Recent decades have shown a significant increase in the number of mega-projects and their value worldwide (Flyvbjerg, 2014b). In China, as elsewhere, these projects have a major impact on the global economy (Bredillet, Yatim, & Ruiz, 2010). Moreover, this tendency toward mega-projects is expected to continue with an increase in both their number and value (Flyvbjerg, 2014b). However, a worrying aspect of these projects is an extraordinary high level of failing to meet their objectives (among others, Flyvbjerg, 2014b).

Since the birth of project management in the 1950s, construction megaprojects have been a continuous and important object of inquiry, first with military projects, than extending to the construction of buildings, transportation and power systems (Peter W.G. Morris, 2013). Recently, Flyvbjerg edited *Megaproject Planning And Management: Essential Readings,* a collection of about 70 influent articles and book chapters dating from 1951 to 2012 from various contributors in the field (Flyvbjerg, 2014a). The sections of this collection proposed are relevant to understand the current issues and plural views with regards to megaprojects, which are: The History of Megaprojects, Project Post-mortems, Front-end Management, Governance and Institutions, Stakeholder Management, Finance, Delivery, Social and Environmental Impacts, Innovation, and Case Studies. Whereas some themes, related to the technical core of project management (such as planning, control, and engineering complexity) have long been studied in project management, strategic issues in megaprojects have gained more recognition in the past decades (Morris, 2013). For example, the attention of scholars has been oriented towards innovation (Davies, Brady, Prencipe, & Hobday, 2011; Miller &Lessard, 2000), governance regimes and frameworks (Klakegg, Williams, & Magnussen, 2009; Miller & Hobbs, 2005) and quest for success (Klakegg et al., 2009; Samset & Volden, 2013). However, researches on the social environment taken into consideration when studying mega-projects have been scarce, and some scholars have called for research development in that direction (Morris, 2013; Scott, 2012). From a social context perspective, there are numerous stakeholders in these projects. Their coordination and the adaptation of the mega-project to its social context is an important issue to solve.

This paper aims at proposing a conceptual framework for the study of the sociological context of construction mega-projects in China, as well as the role of the inter-organizational PMO as a coordination mechanism. Lessons learned from this research, we believe, will contribute to the theoretical and practical understanding of the management of mega-projects globally.

The following section presents the research background from the literature on three themes: mega-projects, sociological context, and the inter-organizational PMO. Following the literature review is the proposed conceptual framework, and the proposed methodology. The conclusion suggests the contribution of this paper, as well as its limitations and the direction for future research.

2. Research Background

2.1 Mega-projects

Progress in science and technology has spurred the launch of construction mega-projects globally, especially in developing countries such as China. For example, China's high-speed railway project is one of the world's largest mega-projects. However, despite their significant character these mega construction projects also bring great difficulties and challenges to project management (Flyvbjerg, 2004).

Considering the main characteristics of construction mega-projects, they involve a huge number of participants and they have significant social and economic impacts, extensive work loads, large geographical coverage and close connection to other major developments (Mok et al., 2015).

There are also different types of mega-projects, especially in terms of their level of aspiration, lead times, complexity, and stakeholder involvement (Flyvbjerg, 2014a). Construction mega-projects present challenges to project management in their complexity, uncertainty, integrated management, etc. (Sun & Zhang, 2011). Complexities in managing mega construction projects can be viewed from three aspects: technical, social and managerial. Social aspects relate to complexities from the inadvertent impact of mega-projects on the environment and social systems within their location of implementation (Li & Guo, 2011).

The research of mega-projects has reached a new stage in the context of globalization. For example, the IMEC research program on large engineering projects included the benchmark of sixty projects at an international scale to identify best practices (Miller & Lessard, 2000). Results of this influential study have emphasized the central role of project sponsors, who need to 'shape' the front-end of the project as well as institutional arrangements (defined as laws, regulations and agreed to practices) in order to allow flexibility and 'governability' of the project, which are critical for success (Miller & Lessard, 2000). Another global study is that of Merrow (2011), who concludes from the analysis of a dataset of 318 megaprojects from around the world that two thirds are failures, mostly due to endogenous factors. Finally, an important initiative to study megaprojects using a global perspective comes from Scott and his colleagues from the Collaboratory for Research on Global Projects (CRGP) of the Stanford University. In an edited book of 11 chapters, the authors, based predominantly on the 3 pillars of Scott (2008) (regulative, normative and cultural-cognitive), emphasize the importance of an enlarged understanding of the role that both culture and politics play in global projects.

As research has shown that mega-projects are qualitatively more complex and riskier than usual operations and smaller scale projects, they therefore require governance regimes that are different from those of more routine and less risky endeavours (Miller & Hobbs, 2005). Better planning methods and changing governance structures are important to counteract the main problem of misinformation about costs, benefits and risks of mega-projects (Flyvbjerg, 2007).

As other megaprojects around the world, in China, some construction megaprojects also failed to meet their objectives. For example, the PX case in Xiamen, China. The government of Xiamen planned to build the Haicang PX project, which had been agreed by the State Council, Environmental Protection Administration and National Development and Reform Commission. However, once plans were revealed to public, strong oppositions aroused among citizens in Xiamen and even incurred concerns nationwide. The government of Xiamen only focused on the economic benefits of the project before the project announcement while omitting public outreach and public opinion. At last, the government of Xiamen bowed to public opinion and shifted the project to a remote island.

Another example is the Sanmenxia Hydropower Station in China. This project was put into operation without considering the impact of sediment deposition in the Weihe River. The project was cancelled, and resulted in repeated severe flooding (Chen, Le & Ren, 2006).

These failures in meeting project targets were caused by a neglect of the social context of the projects. Increasing complexity of mega construction projects require increased study of their social context. Traditional project management with appropriate method and data cannot meet the needs of mega construction projects (Sun, Zhang, 2011.) The social responsibility activities associated with these projects need to be managed throughout (Salazar et al., 2012), and especially considered through their life-cycle (Zeng et al., 2014). Construction mega-projects have more interactions with the society and require a wider perspective for their study, such that a comprehensive point of view is needed for their study (Mao & Jia, 2011).

Besides its inherent project properties, mega-projects also have social attributes, the dominant feature in social context. The mega-project has close connections with globalization and civilization, but few articles have addressed the social analyses of mega-projects. From a perspective of social conflict theory, there are strong connections between mega-projects and social conflict (Jia et al., 2011). The social attributes of construction mega-projects include four aspects: 1) the construction project is the material basis for human survival; 2) the construction project is a matter of social activities; 3) the process of construction project is that human beings transform the world; and, 4) the construction project is the representative of social culture and civilization (Mao & Jia, 2011). It is adaptation to the social context is the ultimate goal of a construction mega-project (Tian & Chen, 2013).

2.2 PMO and the inter-organizational context

Emergence and deployment of PMOs in organizations followed the increasing use of projects in the innovation and development of economy and societies (Aubry, Hobbs, & Thuillier, 2007). Scholars have shown the wide diversity of the PMO (Hobbs & Aubry, 2010) and the difficulty to classify them empirically (Hobbs & Aubry, 2008), or explain their performance (Hobbs & Aubry, 2011). Their constant transformations have also been the object of research leading to a theoretical approach of an evolutionary process view (Aubry, Müller, Hobbs, & Blomquist, 2010) or other conceptualizations such as emptying process (Pellegrinelli & Garagna, 2009) and sustainability (Hurt & Thomas, 2009). Their role has also been scrutinised in different ways such as deconstructing the PMO to better understand their function (Crawford, 2010), or to critically assess their lack of engagement in integrating organizational change (Artto, Kulvik, Poskela, & Turkulainen, 2011), and acknowledge their impact on the knowledge management in project-based organizations (Pemsel & Wiewiora, 2013).

Most of the research has focus on the entity itself or its transformation process. Few studies have focused on the different roles of PMOs when tightly associated with activities of portfolio management with the exception of Unger and colleagues (2011), who specifically study the role of a portfolio PMO on project and portfolio performance.

In the last 10 years, research on PMOs has provided a good understanding of the phenomenon by looking at the *what* and the *how* its evolution, or in ontological and epistemological words, as a thing and as a process (Van de Ven & Poole, 2005). However, there are limitations to what the research has covered on PMOs, mainly in isolating this entity from the rest of the organization.

To our knowledge, none of the research on PMOs has studied this entity as a governance mechanism and included it within the organizational design (Winch, 2014). This missing link contributes to the difficulty of positioning project management as being part of the organization' strategy, project management being responsible of strategy implementation, and of strategy formulation, at a lesser degree (following, Jacobs, 2010). To engage project management at the strategic and institutional level (Morris & Geraldi, 2011) requires, among others, to study these governance mechanisms embedded in the overall organizational governance.

2.3 Stakeholders in the sociological context

2.3.1 Stakeholder Identification and Classification

Stakeholders include individuals, groups or organizations affected by the project, and can be classified as: beneficiaries, losers and neutral parties (Housing and Urban-Rural Development Department of China, 2014). The stakeholders of construction mega-projects can be divided into eight classifications (Mao & Jia, 2011): the government, investors, owners, contractors, volunteers, departments (e.g., NGO), the public, and other stakeholders. According to a stakeholder party-classification method, illustrated in Table 1, the eight classifications of the stakeholders of construction mega-projects can be divided into four parties: the government, the construction mega-projects, the benefited public, and the impaired (impacted) public.

Table 1 Stakeholder Identification and Classification

Four Parties	The Stakeholders
The Government party	The Planning Bureau
	The Land Bureau
	The Housing and Urban Construction Bureau
The Construction Mega-Projects party	Investors
	Owners
	Contractors
	Sub-contractors
The Benefited Public party	Groups benefited from the project construction
	The other benefited stakeholders
The Impaired (impacted) Public party	Groups impaired by the project construction
	The other impaired stakeholders

2.3.2 The Interactions between Stakeholders

The relationships between different stakeholders and their interactions are dynamic network (Miller and Hobbs, 2005). Through the four roles of different stakeholders in the practice of construction mega-projects, they form a complex interaction in a logical network during the project as shown in Figure 1(Mao & Jia, 2011).

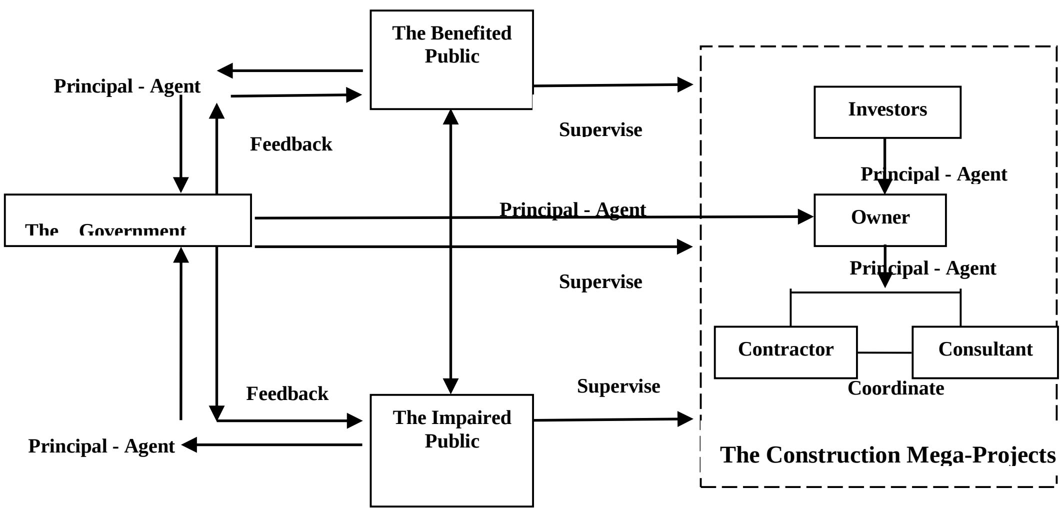

Figure 1 The Interactions between stakeholders of construction mega-projects (Mao & Jia, 2011)

In the study of the interaction between construction mega-projects and its social context, the literature focuses on social evaluation of construction mega-projects (Housing and Urban-Rural Development Department of China, 2014). But there has been problems regarding implementation of the management plan; which is, to mitigate the negative social impact of construction mega-projects. In the actual practice of projects, the establishment of multi-organizational PMOs have been shown to respond to corresponding problems (Headquarters of

Shanghai Hongqiao Integrated Transportation Hub [ITH], 2011). Therefore, we propose the following assumption from organizational perspective.

2.4 Research questions

Building on the review of the literature, the proposed research should investigate:

- The nature of the sociological context of construction mega-projects
- The characteristics of the construction mega-projects under its sociological contexts
- The role of the multi-organizational PMO at the interface of sociological context and construction mega-projects.

From what has been said above, the following research questions have been identified: RQ1: What is the impact of sociological context on the construction mega-projects?

RQ2: What is the role of multi-organizational PMOs in this relationship?

These questions will address the specific coordination tasks of the PMOs in two preliminary stages (Shizhao, 2014) of construction mega-projects: the initial proposal stage and the feasibility stages.

During the initial proposal stage, the main task of the multi-organizational PMOs is to coordinate the project planning and design, identify stakeholders of the construction mega-projects and risks the project may face. During the feasibility studies stage, the main task of the multi-organizational PMOs is to give a comprehensive analysis of the interactions between the various stakeholders and to propose measures to mitigate adverse social impacts on early phase of the construction mega-projects.

The Unit of Analysis is the PMO as a coordination mechanism on multi-organizational settings in public construction mega-projects. The level of analysis spans from the societal via, the organizational to the unit level. Thus, the study follows the suggestions for more multi-level studies (Courgeau & Baccaini, 1998; Baccaini and Courgeau,1998; Rousseau,1985).

3. Conceptual Framework

The proposed conceptual framework brings together three different but complementary theoretical perspectives. Scholars studying phenomena in organization are facing complex situations in pluralist setting (Denis, Langley, & Rouleau, 2007). In their paper, Denis et al. (2007) argue for adopting multiple theoretical perspectives to understand or to explain pluralistic contexts defined as "organizational contexts characterized by three mains features: multiple objectives, diffuse power and knowledge-based work processes." (Denis et al., 2007, p. 179). In their paper, they propose a multifaceted theoretical framework combining three theories from sociology and theory of organization: actor-network theory, convention theory and social practice theory. There is no doubt that mega-project are situations in pluralist context as the three main features can be identified:

- Multiple objectives. In mega-project context, objectives are set by a vast array of stakeholders having different, and sometimes conflicting, expectations as illustrated by Jia and colleagues (2011) in social conflicts.
- Diffuse power. Governance mechanisms generally define the formal power system and the decision making process. In mega-project, the power system is complex having multiple organizations forming a dynamic network of (Klakegg et al., 2009) in which informal power is developed making difficult (or impossible) to make a decision in a unique central locus (Miller & Hobbs, 2005). Moreover, public mega-projects do face particular situations of dual power systems – elective versus administrative. Governance frameworks developed in western world have specifically this role of regulating the power system.
- Knowledge-based work processes. Little is known at early stage of any project. Knowledge develops during the project on *what* to do and *how* to do it (Midler, 1993; Turner & Cochrane, 1993; Winter & Szczepanek, 2009).

The conceptual framework for the study of construction mega-projects in China is built on three major theoretical components: the sociological context, the construction mega-projects, and the multi-organizational PMOs. Altogether, the three components are embedded in each other, forming a coherent model having reflecting the tall ontology proper for the study of pluralism setting (Seidl & Whittington, 2014) (See Figure 2).

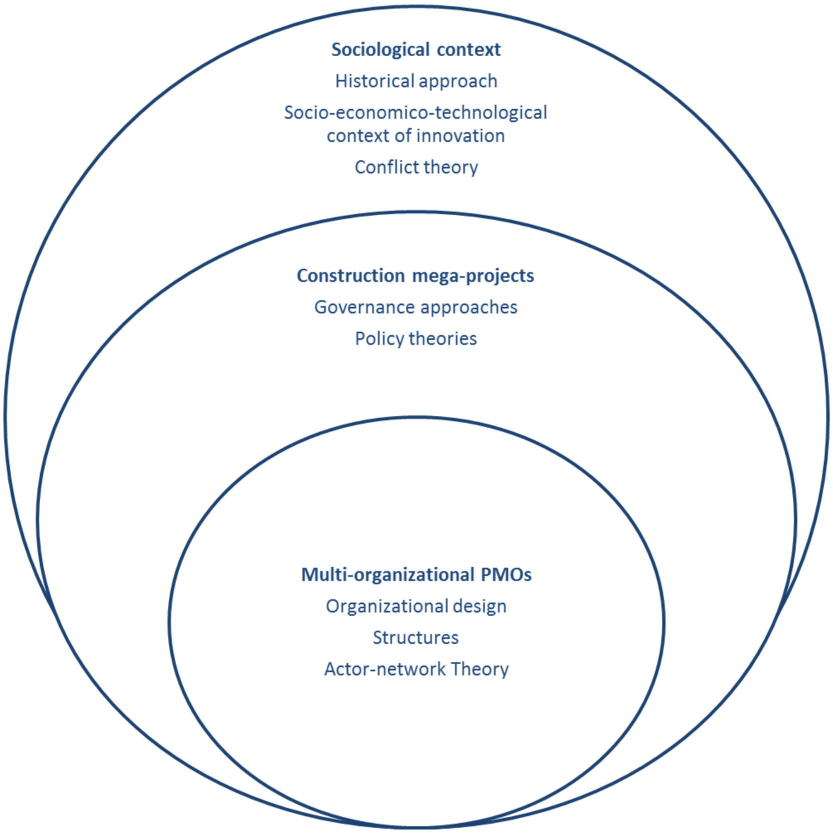

Figure 2 Conceptual Framework

Following Hughes (Hughes, 1987, 1998), innovations are shaped by their socio-technological environment, as they also shape their environment. Not only does innovations happens at a specific point in time, they are the result of the evolution and history of other elements in the environment (Petroski, 1994). For mega-projects, we will take into consideration the context in which this project happens. In some cases, project does have a long history before a decision is made to initiate the project. In social context, we will consider the conflict theory to explore the relationship between different stakeholders where tensions and conflicts are more likely to happen (Aubry, Hobbs, Müller, & Blomquist, 2010). It is very much in line with the call for turning to theories form the sociology of organizations to enlighten project management situations (Floricel, Sergi, Bonneau, & Aubry, 2013).

Mega-projects require that governance arrangements be put in place in order to clarify the formal decision-making process. Decision-making process for mega-project could certainly be looked at throughout economic theory such as transaction-cost theory (Williamson & Masten, 1999) or agency theory (Jensen, 2000). Klakegg and colleagues (2009) have identified some resonance of these perspectives in some aspects such as control, incentive, information, asses specificity, etc. (Klakegg et al., 2009). While these theories would certainly enlighten governance aspects, this research would rather turn to more institutionalism perspective with a sociological and political understanding of governance. In this sense, we adopt the paradigms view on governance where single organization manage different projects under different mix of project output (behaviour or outcomes) and project orientation (shareholder or stakeholder) (Müller, 2011). In this context, governance frameworks are good artefacts to understand the governance regime in which those construction mega-projects are executed (Klakegg et al., 2009).

Then, the multi-organizational PMO has to be understood in different aspects. A first aspect refers to the process of organizational for projects. In this aspect, we will base our work on the work of Miller (Chen & Miller, 2010; Greenwood & Miller, 2010; Miller, 2005). We will also work with the three domains identified by Winch (2014) specific to the field of project management. Description of the PMO formal structure will be done using the model developed by Hobbs and Aubry (Hobbs & Aubry, 2010). The structure will also be explored through actor network theory (ANT) to take into account the construction of the network around a certain number of artefacts, one of which being the governance framework. ANT provides a dynamic view connecting actors and non-human actants together in building and maintaining some controversies (Aubry, 2011).

4. Methodology

We develop the study's methodology following the approach of Saunders, Lewis and Thornhill (2007) by starting with the philosophical perspective, then determine the inductive, deductive or abductive approach, followed by the research strategy and the time (cross sectional or longitudinal) and methods (mono, multi or mixed method) approach, and finally determine the type of data to be collected.

A study with the indicated scope and level of analysis requires a comprehensive underlying ontology that allows for the integration of subjective societal and organizational worldviews with more objective worldviews of planning, control and coordination in projects. Therefore we take a critical realist perspective (Bhaskar, 2008). This ontology is based on three layers, namely mechanisms, events, and experiences. This ontological approach is to be put in relation with Seidl and Whittington (2014) call for adopting taller ontology aiming at expressing the organizational context in more precise terms. Here the lowest level, named *mechanisms*, represents the underlying generalizable laws or the assumptions thereof, such as those of objective planning of projects, measurable benefits of projects etc. These mechanisms give rise to the second layer, *events*. Enabled through the mechanisms, events constitute both objective and subjective representations, such as mega-projects' final products and the use of them. These events (of usage) give rise to the top layer, *experience*. This is the most subjective layer and represents the idiosyncratic experience of individuals, contingent on the events, which, again, are contingent on the underlying mechanisms. Critical realism integrates these three layers of worldviews into a single research perspective (Archer, Bhaskar, Collier, Lawson, & Norrie, 1998; Bhaskar, 1975).

To leverage existing theories for the ‘sense making’ of the data collected in the study we use an abductive approach in the sense of Alvesson and Sköldberg (2009).This approach allows for going back and forth between existing theories, collected empirical evidence, and the experience of the researchers in order to make sense of yet non-understood phenomena.

Four in-depth case studies in the sense of Yin (2009) will be done, using ‘maximum variation’ sampling to allow for broadest understanding of the phenomenon. In addition we prefer this approach over a quantitative study because of potential problems in achieving a sufficient sample size when concentrating on public construction mega-projects only (Müller, Pemsel, & Shao, 2014).

At first place, search for public documents will take place to acknowledge the media communications and their possible effects on project team. Research design will provide opportunities to capture data at different levels and from a variety of actors, as described in our conceptual framework. Data collection strategy will include semi-structured interviews with 20-30 actors for each project. Each interview will last an average of an hour and will be transcribe in Word files and then analyzed using Atlas.ti (ATLAS.ti Software Development, 2004). When possible, observations on site will take place. This will provide data on the practices in each site. Field notes will be taken and processed based on as ethnographical techniques. This should provide a good understanding of each sociological context of the projects. Documents and other artefacts on the projects or on the organizations will be collected and analyzed to provide information on the socio-politico-technological context of the project.

Different strategies will be used for data analysis following Langley (1999). Among others, grounded theory will serve as a strong inductive approach to listen to what the interviewees will have to say, graphical views will provide visual setting that is helpful in clarifying concepts, and some quantitative analysis may be possible in counting different activities or facts. In combination to these strategies, related data analysis techniques will follow the suggestion by Miles & Huberman (1994) to help make sense of large quality of data.

Validity will be ensured using the suggestions by Yin (2009). For that we do within-case and across case analysis, look for convergence and cross validation of the collected data, best possible respondents, and use theoretical saturation for interviewee sampling. Reliability will be assured through the development of a case study protocol and its usage throughout the study.

5. Discussion and Conclusion

This paper addresses problematics related to the management of megaprojects. Challenges in this field are crucial as megaprojects in general are often associated with failures in one hand, and on the other hand, the tendency is going towards more and larger megaprojects (Flyvbjerg, 2014b). Megaprojects have been defined as pluralistic contexts (Denis et al., 2007). Based on a review of the literature, this paper proposes a conceptual framework combining three layers of theoretical approaches to capture in an integrative way the pluralism setting of construction megaprojects. This conceptual framework is intended to drive a wide research taking place in China (Chen & Miller, 2010).

Novelty of this research bears on two main elements. First, as of now, the sociological aspects of megaprojects have been neglected in the research on megaprojects. This research aims at including social context and more particularly, social conflicts among stakeholders as key elements of the environment. In doing so, the context is becoming personified instead of being a grey undefined area (Seidl & Whittington, 2014). Second, the PMO is deliberately interpreted as a governance mechanism which is worth to be considered within the organizational design for projects.

There can be many perspectives to study the management of mega-projects, but from the perspective of sociology and PMO is promising. This article mix sociology and PMO to study the impact of sociological context on the construction mega-projects and the role of PMO as a coordination mechanism and give a conceptual framework which put mega-project in the social context and use PMO to coordinate them.

This paper is conceptual. This raises a first limitation as no empirical evidence comes to validate our conceptual approach. However, this is a first step for a larger research to be undertaken in the following months. A second limitation is associated with the conceptual approach based on multi facet theories. While this approach fits well pluralistic contexts (Denis et al., 2007), it may cause the analysis to stay at higher level of interpretation instead of going in depth in one single theory. Impact of this would be the incapacity to provide new theoretical insights. Globally, we think that this conceptual framework is promising for many other researches in the field of megaprojects.

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A Traditional, Large Engineering Service Adopts the Best Value Approach

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Abstract

The BV environment was introduced into the Netherlands in 2006. By 2008 testing was being done by a partnership of Arizona State University and Scenter [Sicco Santema, professor from Delft University]. In 2010, the $1B fast track projects were procured by the Rijkswaterstaat, and by 2012, the BV approach had become the "buzzword" of procurement. However, in the delivery of professional engineering services, larger, more traditional services which were built on a system of relationships between clients and vendors, MDC from the clients' experts, and the importance of "billable man-hours", the transition from a traditional approach to a best value approach is very challenging. Large traditional professional organizations naturally will have more difficulty adapting to the new approach. The BV approach utilized the expertise of experts to replace the need for relationships and owner management, direction and control [MDC.] It also places less value on traditional practices that have been used by professional services to get business [relationships and working together with the client in a trust based relationship]. The study captures the efforts of a very successful engineering firm [the largest in the Netherlands] as they attempt to become successful in this new approach. The best value team that they have put together has had outstanding results in using the BV approach to changing their paradigm.

Keywords: professional services, best value, Netherlands, Royal Haskoning DHV, delivery of services

1. Introduction to the Selection of Design Services

Professional services were always selected differently from other construction services. They were identified as professional services which used engineering principles to solve and provide solutions to owner requirements. They developed a selection system called Qualification Based System or QBS, which selected designers based on the professional's past performance, professional licenses, professional relationships and technical knowledge in the firm (Child, Sullivan & Kashiwagi, 2010; D. Kashiwagi, J. Kashiwagi & Child, 2014). The QBS system resulted in a system where the owner's selected the professional firm based on relationships, marketing brochures and firms' reputations. The selection process resulted in client's selection boards deciding who was the best qualified. In many government environment's, price was not a selection criteria. After the QBS was performed, a professional service is selected and price is negotiated. Oftentimes, it is a fixed percentage of the construction cost, and not what the actual professional services would cost.

The QBS and other similar selection systems resulted in professional services having the following practices (Child, Sullivan & Kashiwagi, 2010; D. Kashiwagi, J. Kashiwagi & Child, 2014; Sullivan & Michael, 2011):

1. Depending on marketing and relationships to get their work.
2. Professional services becoming more reactive to the clients' needs.
3. Strong relationships become the solution for engineering and design issues.
4. Design schedules becoming less important leading to design change orders and redesigns.
5. Large design services becoming more fixated on maintaining "billable man-hours" than utilizing their expertise.
6. More administrative and meeting duties than utilizing technical expertise.
7. A void of project management skills which concentrated on profit margin, efficiency, effectiveness and maximizing profit/return to the company.

These practices led to the following results (Egan, 1998; FMI / CMAA, 2004; FMI / CMAA, 2010; Sullivan & Michael, 2011; Tucker, 2003):

1. Poor customer satisfaction.
2. Clients reviewing the professional's work, and managing, directing and controlling the professional services.
3. The owners/clients' had a poor perception of designers and engineer's capability, quality of work and professionalism.
4. An inability in a large design firm to identify the expert, select the expert for a project and allow the expert to plan the project from the beginning to the end [utilizing their expertise to estimate quantities and identify the risk that other stakeholders bring to the design project and mitigating the risk by creating transparency and through a risk mitigation plan].
5. Work was procured through a marketing/relationship process called the Qualification Based System or QBS. The selection of the firm is done through an owner's selection board that decides who is the best qualified, then negotiates a contract with the selected vendor.

These design practices are in all countries and cultures [underdeveloped, developing and developed countries]. The authors have been in Africa, Malaysia, China, U.S. and Europe in which the practices are observed to be the same.

The Best Value approach has been in the Netherlands since 2007. The Rijkswaterstaat [tasked with maintaining roads and waterways in the Netherlands] delivered the "fast track projects" using the Best Value approach [known as best value procurement or BVP]. The following results were realized (Van de Rijt, Witteveen, Vis & Santema, 2011):

1. Procurement transactions and costs were minimized by 50%.
2. Construction time was minimized by an average of 25%

3. 95% of all project cost and time deviations were caused by the owner/client and their professional services.

Professional services were also procured by the BVP approach. Immediately the following problems were realized (J. Kashiwagi, Sullivan & D. Kashiwagi, 2009; Kashiwagi, 2014b):

1. The design professionals were reactive and not used to being accountable to setting a plan, identifying the deliverable to be delivered, making the assumptions that should be made utilizing their expertise, and having a risk mitigation plan that minimized the risk that they did not control.
2. The owner/client's project managers were confused and thought that the clarification period was a time to make the contractors do work to identify all the unknowns.
3. The design services faced the challenge of how to identify and utilize expertise in their own organizations.
4. Large design organizations were confused how to match their need to transform their approach from concentrating on "billable hours" to utilizing expertise.

The Performance Based Studies Research Group (PBSRG) identified the following about the Dutch Best Value movement:

1. Per capita, it was the most progressive best value (BV) effort in the world, with most number of certified experts, the largest number of BV technology licenses, more major government clients involved in best value tests and the only country where the professional procurement group [NEVI] and the professional group [RISNET], which includes the professional organization of the design firms, are all licensed in the BV technology from Arizona State University (ASU) and their technology licensing group AZTECH (PBSRG, 2012).
2. BV consulting groups proliferating the BV practices including Scenter [led by Sicco Santema, the best value visionary of the Netherlands], NEVI [3rd largest professional procurement organization in the world], Best Value Europe [organization committed to spread BV throughout Europe] and the Dutch Professional Engineering Organization which is a member of the European Professional Engineering Organization (Kashiwagi, 2014b).
3. The largest government organizations in the Netherlands were participating with the BV effort including Rijkswaterstaat, ProRail, Netherland Rail Service, waterboards, and major cities such as Rotterdam, Amsterdam, Utrecht, and Groningen (Kashiwagi, 2014b; Van de Rijt & Santema, 2013).

2. Problem: How to Transform Professional Services to a Performing Industry

For the BV effort to be sustainable, PBSRG was interested in three major areas: professional services, medical services and IT or ICT services. Professional service was a primary target because the traditional delivery of the professional services was an area where (Child, Sullivan & Kashiwagi, 2010; D. Kashiwagi, J. Kashiwagi & Child, 2014; Egan, 1998; FMI / CMAA, 2004; FMI / CMAA, 2010; Sullivan & Michael, 2011; Tucker, 2003):

1. Management, direction and control was being utilized to minimize risk.
2. It is a commodity area that was being differentiated based on relationships.
3. The professional services had a very poor customer satisfaction rating.

4. The professionals are the first to touch the delivery of construction services and were identified in the Netherlands billion-dollar infrastructure project as the source of 90% of the project cost and time deviations (Van de Rijt & Santema, 2012).
5. In PBSRG construction project tests, the design services and the owner's decision making was the largest source of project cost and time deviations. The owner's representatives and the design services were indistinguishable. They were one entity and the largest problem in the delivery of construction services (J. Kashiwagi, Sullivan & D. Kashiwagi, 2009; Kashiwagi, 2014).

To have a larger and more sustainable impact on the performance of professional services, PBSRG searched for visionaries in one of the more traditional larger professional services companies.

3. Methodology

3.1 Approach

The research approach was simple:
1. Identify one of the largest professional services company.
2. Identify if there were visionaries who understood the BV approach in the company.
3. Identify the strategic plan to transform the large organization into an organization that could utilize the BV approach to increase efficiency, effectiveness and margin/profit for their organization.

3.2 Research

PBSRG set on the following plan to meet the research objectives:
1. Present to all the large professional organizations.
2. Identify one of the organizations who had visionaries.
3. Educate and train the visionaries in the best value approach.
4. Identify if they could follow the BV approach to give their organization the ability to utilize the best value approach.
5. Convince the core group to utilize metrics.
6. Identify if the metrics can be refined to increase the support of the rest of the organization.
7. Pick a case study which shows the success of the BV approach.

4. History of BV with Professional Engineering Groups

From 2011 – 2012, PBSRG started to brief professional engineering firms. The Dutch professional engineering group [under RISNET [Dutch risk management professional group]]. In 2014 RISNET licensed the BV approach technology from ASU, and the Dutch professional engineering group is a subset of RISNET, giving access to all the training material to the engineering group. The Dutch professional engineering group under the leadership of Paul Oortwijn, started presenting the BV approach at the European Engineering Association in 2013, resulting in interest from Norway and Poland. Partnering with the Scenter group [private group which partnered with PBSRG to bring the BV effort into the Netherlands], the Dutch Best Value Procurement (BVP) book is being translated into both Norwegian and Polish languages, with the Polish book to be introduced to the Polish professional engineering group in March 2016.

In 2012, PBSRG was contacted by the second largest engineering and design firm in the Netherlands, Royal Haskoning DHV. Royal Haskoning DHV is an independent, international engineering and project management consultancy with over 130 years of experience. Our professionals deliver services in the fields of aviation, buildings, energy, industry, infrastructure, maritime, mining, transport, urban and rural planning and water. Backed by expertise and experience of nearly 7,000 colleagues across the world, they work for public and private clients in more than 130 countries on five different continents (Royal Haskoning DHV, 2014). A visionary, Elske Bosma, in the company reached out to PBSRG for some guidance, and PBSRG started a relationship to assist them become a best value expert.

4.1 Development of the RHDHV Best Value Effort

PBSRG had already researched how to transform a large organization to have the capability of providing the best value. It had to take the following approach and assumptions:

1. There is no controlling any individuals in the company to change their conceptual thinking by management, direction or control (MDC) or influence.
2. To expect anyone to change was to increase risk.
3. Visionaries had to be identified by their affinity to the concepts of Best Value (BV) and Information Measurement Theory (IMT) which include logic, consistency, leadership characteristics and proactive motivation to make things better.
4. The group should start small.
5. Education is very important to identify more visionaries.
6. People in the organization who do not understand BV, are focusing on amount of work or turnover and profit margin.
7. The BV core group will have to develop metrics that minimize decision making of the organization as soon as possible.
8. The BV group must have a mentor.

The following is a historical account of dates and activities of the development of the RHDHV best value effort led by Elske Bosma, Marcus van der Ven and Oscar Kerkhoven (E. Bosma, Personal Communication, December 9, 2015):

1. April 2012: Elske Bosma starts a BVP network within DHV
2. June 2012: Elske meets Marcus van der Ven, Oscar Kerkhoven and Fred Haarman, who gained experience with BV at Royal Haskoning DHV. They start with the effort to improve the Best Value tender success rate within the new company RHDHV. This was the start of the Best Value core team.
3. September 2013: The BV core team meets with Dean Kashiwagi. The BV core team also brings 2 colleagues of the higher management of RHDHV. Dean is very much interested in the BV effort of the core team.
4. December 2013: The BV core team presents their strategic plan to the executive board of RHDHV. The board approves the plan. A member of the execute board becomes the sponsor of the BV core team.
5. January 2014: Marcus, Oscar and Peter Edward attend the BV Conference in Phoenix, Arizona

6. May 2014: Dean visits the RHDHV's head office in Amersfoort. Over 100 employees of RHDHV attend his presentation and/or the workshops.
7. October 2014: Marcus obtains the A+ certification [Highest BV certification]
8. November 2014: The BV core team starts to give the 2.5-day Best Value course to educate colleagues for the B-certification [Entry level certification]
9. January 2015: The BV core team and 5 other colleagues attend the BV Conference in Phoenix, Arizona
10. June 2015: Dean visits the RHDHV head office in Amersfoort. Appr. 80 persons of RHDHV attend his presentation and/or the workshops.
11. October 2015: Oscar obtains the A+ certification.
12. October 2015: BV team expands group with 3 more persons [One of the three is in the higher management of RHDHV]. Of the BV core team 6 persons of RHDHV will attend the Best Value Conference in Arizona in January 2016.
13. December 2015: The core team has educated over 50 colleagues (B- certification) in 2014/2015.

4.2 RHDV Metrics

One of the objectives of the BV approach is to use metrics to minimize decision making inside and outside of the organization. The BV core team had the following objectives (Royal Haskoning DHV, 2015):

1. Show increased value of the core team activities.
2. Show that if the BV approach and the BV core team was utilized, the amount of work acquired and the success rate should increase. When the numbers become dominant enough, policies will be set by the company that help the non-BV experts to utilize the BV core team.

Table 1 shows the core teams' metrics. Table 2 then shows the metrics that minimize decision making, and will lead to changing RHDHV policies. The RHDV core team also identified a BV expert who began keeping metrics on his procurement projects [Table 3]. PBSRG will continue to work with RHDHV and the engineering consulting professional groups in the Netherlands, Norway and Poland to assist the industry to transform itself into a best value industry.

Table 1: Royal Haskoning DHV Performance Metrics to Minimize Decision Making

Performance Criteria	*2015*
# years BV core team	*3+*
# BV procurement as client PM	*12*
# BV tenders for engineering consultancy projects	*24*
# won	*11 (46%)*
# BV tenders in consortium for construction projects	*13*
# won	*2 (15%)*
# BV interview training key personnel	*50+*
# BV procurement educations	*20+*

# BV presentations	*50+*
# BV knowledge meetings	*10+*
# BV presentation for higher management	*3*
# A+ Certifications	*1*
# B+ Certifications	*8*

(Royal Haskoning DHV (2015) Best Value Performance Metrics. Unpublished raw data.)

Table 2: Royal Haskoning DHV Performance Metrics

Performance Criteria	*BV Support*	*No BV Support*
# of Tenders	*14*	*24*
Tenders Won	*7 (43%)*	*6 (29%)*
Scored 1st or 2nd in PC Submittals	*13 (93%)*	*14 (58%)*
Risk Assessment Score	*5.8*	*5.3*
Value Added Score	*6.2*	*6.1*
Level of Expertise	*7*	*5.8*
Interview	*7.4*	*6.5*

(Royal Haskoning DHV (2015) Best Value Performance Metrics. Unpublished raw data.)

Table 3: Individuals Performance Metrics on Procure Company Projects

Project	*Budget (M euro)*	*Contract value (M euro)*	*Progress*	*Time deviation*	*Cost deviation*	*Client Satisfaction*
Pumping Station Schore	*2.6*	*2.4*	*60%*	*0%*	*0.4%*	*8.4*
Pumping Station Schilthuis	*0.69*	*0.68*	*95%*	*2%*	*0%*	*7.3*
Ankie van Beek Ohrlaan	*0.56*	*0.54*	*30%*	*0%*	*0%*	*7.7*
Gemaal Essenburgsingel	*1.95*	*1.94*	*35%*	*0%*	*0%*	*8.1*
Sewage System Triangel	*1.2*	*0.74*	*100%*	*0%*	*0%*	*10*
Total:	*7.00*	*6.30*				

(Royal Haskoning DHV (2015) Best Value Performance Metrics. Unpublished raw data.)

5. Conclusion

The professional engineering organization in the Netherlands has been proliferating the Best Value approach and the Information Measurement Theory (IMT) concepts. They have been successful in moving the technology into Norway and Poland. PBSRG has identified and is mentoring the second largest engineering firm in the Netherlands, RHDHV into increasing its BV capability and utilizing metrics to minimize the decision making in their organization.

The following have been successfully achieved in this case study research which uses mixed methods to verify the changes. The results include:

1. Selected Royal Haskoning DHV as the large engineering service.

2. RHDHV selected a core team.
3. Core team educated their organization and used metrics to show their activity.
4. Core team refined their metrics to show their organization that the core team should be utilized to increase their competitiveness on potential projects.
5. Identified a BV expert to run BV projects. The BV projects were extremely successful.

The RHDHV organization has BV capability. They will become more competitive and successful as they continue to change their paradigm. Their case study shows that a large organization whose traditional paradigm do not match the BV approach, have the capability to transform itself into the BV paradigm. Their success ensures that the Dutch BV effort will be more sustainable.

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Experience with the Use of Building Commissioning Advisor - from Design to Operation

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Abstract

The increased focus on building energy performance has intensified the need to ensure consistency between energy requirements, design, construction processes and operation in construction projects. With the introduction of the new Danish DS 3090 standard, "The commissioning process in buildings - installations services in new buildings and major renovations" it is expected that this consistency can be ensured. Building Commissioning is a comprehensive quality-assurance process that can be used to ensure and document that a building's systems and installations are designed, installed and tested to comply with the client's requirements. However, experience and knowledge of the impact of the commissioning process on the construction process and the building's performance in practice is still insufficient.

In order to shed light on the role of energy commissioning in construction and on how well it functions, this paper report from the design phase of a large municipal school project in Copenhagen. This project has strict requirements for the building's energy performance, as previous municipal projects have realized a large gap between the calculated energy consumption in the design phase and the actual energy consumption in operation. Hence, Copenhagen Property has chosen to test whether the use of a commissioning adviser can contribute to a process that ensures that operation and use of the building is already mainstreamed in the design stage of the building's technical systems.

The method in the research project is explorative, which means that focus is on the specific use of commissioning in order to learn from the experience and translate it according to Copenhagen Property's long-term strategies, including the need to establish a new internal infrastructure between operations, planning and construction. Drawing on ethnographic methods and theories, this paper will analyse and discuss what the use of a commissioning adviser in the design stage means for the interaction between design and operation. It may seem that "technical solutions" are made before “ongoing learning processes” in which new themes are articulated and understood across the different knowledge boundaries. Since there is a tendency for "technical solutions" to remain after a project, it seems that a solution strategy to develop standards and new consulting services could lead to increased fragmentation of construction projects.

Keywords: Commissioning, construction project, property management, design phase

1. Introduction

There has been increased focus on commissioning in Denmark in the wake of the increased complexity of the buildings' technical systems. At the same time, more advisers have started offering commissioning as a consultancy service to their clients. In 2013 the Industry Initiative Value-Added Construction-process published instructions on the commissioning process, and in 2014 the new Danish standard, DS 3090, "The commissioning process in buildings - installations services in new buildings and major renovations" was published. In the standard, a commissioning process is described as follows:

"*The commissioning process for a building is a quality-assurance process that is performed to obtain, verify and document that a building's technical facilities, installations and systems are planned, designed, installed and tested, and that they are operated and maintained so that they meet the requirements for the total economy of the building, requirements in building regulations and other legislation as well as the client's clearly defined requirements.*" (DS 3090, 2014).

Therefore, there are many expectations to what commissioning can add to the construction sector. Furthermore, there is ongoing debate as to whether commissioning should be introduced as a legal requirement for large buildings.

From the client side, several large property managers have started to develop ways to make performance requirements for building projects. However, R. O. Agustsson and P.A. Jensen indicate that even if commissioning is gaining momentum in Denmark, there is still a long way to go before it is common practice in construction. They also point out that high performance is not guaranteed throughout the life of a building, even if it is high in the beginning of the operating period. To maintain high performance, it is also necessary that the staff is able to operate and maintain the building systems.

Knowledge transfer between construction projects and operations departments is not a new area, either in practice or in research. However the new focus is on buildings' technical systems. In connection with the integration of facility management (FM) knowledge in the design process, Per Anker Jensen argues that the challenge of integrating FM in the design process is the transfer of knowledge. He points to four mechanisms that are in play in the transfer of knowledge:

- *"Codification of knowledge from building operation, which can increase the awareness among designers.*
- *Competences among facilities managers, which can increase the awareness among designers.*
- *Power to ensure that designers take considerations for building operation seriously by using the competences of facilities managers.*
- *Power to ensure that codified knowledge from building operation is used by the design team." (*Jensen, P.A.; 2009 p. 131-132*).*

P.A. Jensen points out that there are several ways to integrate operations considerations into the design phase, including direct involvement of FM managers, the use of specialist consultants and/or specialists from FM providers. He argues that continuous involvement of FM in a building project is best placed in the FM function which will subsequently be responsible for the building, as they need to know the building and can influence building design on the basis of their knowledge of the client organization and end-users (Jensen, P.A. 2009).

Coordination of knowledge in heterogeneous networks in emerging areas in construction

In construction projects, there is a need to coordinate knowledge across many different professions. Commissioning is presented as a quality-assurance system that can help to ensure that the building's engineering and installations work in operation, after the building has been handed over, but what is commissioning?

Integration of information across different professions, professional groups and users in relation to new priorities is thus not only about how data and information flow between the various actors. It is also about the various actors' opportunities to use the information locally in a meaningful way, i.e. as a basis for architects and engineers in the design process and as a basis for operations departments to formulate their requirements for operation in construction projects. In Denmark, new priorities in construction, in this case an initiative concerning the energy performance of buildings, are often followed up by new standards, which include new types of consultant services and coordination-tools. Drawing on ethnographic methods and theories, this paper will analyse and discuss what the use of a commissioning adviser in the design stage means for the interaction between design and operation. The theory of boundary objects in particular is used to analyse the ways in which commissioning supports the need for knowledge sharing across the construction project and the operations department. This approach has been chosen to enhance the analysis of information integration as a knowledge-sharing process across knowledge boundaries. The different objects are characterized according to the typology of Star and Griesemer (1989) and Star (1999, 2010). Each of these boundary objects has different structures that allow them to coordinate knowledge sharing in different ways across communities. Star and Griesemer (1989) have developed four different types of boundary objects from their empirical analysis. They are:

Repositories: "*These are ordered piles of objects which are indexed in a standardized fashion*" (Star and Griesmer, 1998 p 410), (e.g. a library or museum). Individual can use or borrow from the pile for their own purpose. They do not need to negotiate difference in purpose.

Ideal types: "*This is an object such as a diagram, atlas or other description which in fact does not accurately describe the details of any one locality or thing. It is abstracted from all domains, and may be fairly vague. However it is adaptable to a local site precisely because it is fairly vague*" (Star and Griesmer, 1998 p 410).

Coincident boundaries: "*These are common objects which have the same boundaries but different internal contents*" (Star and Griesmer, 1998 p 410), (e.g. a map). "*Work in different sites and with different perspectives can be conducted autonomously, while cooperating parties share a common referent"* (Star and Griesmer, 1998 p 411)

Standardized forms: *"These are boundary object devised as methods of common communication across dispersed work groups"* (Star and Griesmer, 1998 p. 411). *"The advantages of such objects are that local uncertainties are deleted"* (Star and Griesmer, 1998 p 411).

The key objects that are described in the commissioning standard are: Cx meetings, Cx log, and Cx scrutiny. In the case study, the different elements are described with regard to whether they act as boundary objects across the communities. In the case described in this paper, the essential knowledge boundaries that the objects operate in are defined as being between client, energy consultant, operation-team, and Cx adviser. Since the focus is on the design-phase technology, suppliers and contractors are not currently involved. Each community is described with respect to how knowledge is localized, embedded and invested (Carlile, 2002). The way the different communities at micro level use the different objects depends on how the various objects are able to transfer, translate or transform information across the knowledge boundaries, as well as the various communities' ability to use the information in a meaningful way locally. Carlile (2002) has found that knowledge needs to be transformed between knowledge boundaries in connection with product development. It is not enough to transfer or translate information across knowledge boundaries. In this case, it is not a product-development process, but establishment of a new infrastructure across different knowledge boundaries to handle new requirements, and therefore it can be perceived as a parallel to a product-development process. The analysis highlights how the communities relate to the different objects and the importance of the information integration.

2. Research setting and methods

2.1 Setting

The case is from the design phase of a large municipal school project in Copenhagen. The aim of the project was two-fold: to build a new school that meets the requirements for building energy performance, both in the project phase (designed / intended) and operational phase (the actual use), and to test commissioning as a method to obtain the objective. The central actors in the construction project in question were the City of Copenhagen, a Danish architectural firm, a Danish energy engineering company, and an engineering company functioning as client adviser on the project, including the commissioning adviser function. The original purpose was to examine the possibilities for commissioning in the construction industry. Since only a limited number of studies with this focus have been reported, an inductive, qualitative approach based on an in-depth analysis of the case was chosen.

Two social factors played a significant role in the project's genesis. In 2006, the Danish Building Regulations (BR06) introduced a new requirement for the energy performance of buildings based on energy frames, which represents a shift from descriptive regulation to performance-based regulation. The use of energy frames as the main requirements of new construction was a result of the EU Directive on Energy Performance of Buildings. With the shift from descriptive to performance-based regulation of energy requirements for buildings, the need arose for new energy solutions in the construction industry. This increased focus on, and requirements for, the energy performance of buildings challenged both traditional project-organized companies and large operating departments. The need for information integration across construction projects and large operating departments in order to handle these challenges is not only about sharing new types of information across actors. It is also about developing new relationships between practices of information integration within a project setting and an operations department setting, respectively. Vertically within the project, there is a need to develop and articulate the client's technical requirements so that the technical requirements can be input to the design team in the design-process. This is a knowledge-sharing process across architects, engineers and operation teams in construction projects. Longitudinally across portfolios of buildings in major operating departments, there is a need to integrate operational experience with technical systems as a platform for articulating technical requirements for new buildings and to qualify operational departments for performance-based operation.

In 2014, the new Danish Commissioning standard was released and introduced as a way to handle information integration across the construction project and the client. This raises the question of the impact of the standard on the knowledge transfer between the construction project and the operational department.

In connection with the construction of schools in The City of Copenhagen, three units are relevant:

1. Children and Youth Administration, which handles the ordering function of the school and is responsible for user involvement.
2. Construction Copenhagen is the client organization of Copenhagen Municipality and is responsible for carrying out construction of the school.
3. Copenhagen Property, which manages and services the properties owned by the City of Copenhagen and is subsequently responsible for operation of the school.

Copenhagen wants to be CO2-neutral in 2025, which places special demands on the energy performance of municipal buildings. Much experience indicates that today there is often a gap between the designed - and hence projected energy consumption - and the actual energy consumption of buildings, which means that it can be difficult to achieve the desired CO2 reductions. To meet these challenges, in the recent years Copenhagen Property has among other things:

- Reorganized and strengthened the energy operational organization
- Initiated the From Build to Operation (BtD) project to support the interplay between Copenhagen Construction and Copenhagen Property with special focus on early involvement of operational experience and requirements in the design phase of

construction projects. At the beginning of the school project, Copenhagen Construction was part of Copenhagen Property, but was later demerged as a separate unit.

- Increased focus on data and data systems, including facility management systems

In connection with the construction of the new school, the municipality has entered into a contract with a commissioning adviser (Cx adviser). In this connection it is Copenhagen Property's intention to put a clear focus on the energy consumption of the new building and its optimum operating options. The Cx adviser has to coordinate incoming client data regarding requirements for technical facilities and follow-up on meeting these. The contract refers to the standard "commissioning process for buildings - installations in new construction and major renovations", but the consultant services have been adapted to the needs of Copenhagen Property. This means that it is intended that the roles of the Cx adviser is to support increased contact and dialogue between Copenhagen Property and Copenhagen Construction.

2.2 Data

With respect to the qualitative approach, data is collected through observations, qualitative interviews and building case documentation. The construction project was followed in the period 2014 - 2015, when the school was designed. The design process was divided into four phases: program, outline, project and main project. At each stage, the client adviser completed a review of the project documents. The commissioning-function was handled by the client adviser and therefore scrutiny in connection with the commissioning process has been coordinated with the cross-scrutiny process. Since focus is on commissioning, Cx meetings in particular have been observed continuously throughout the design period. In addition, special working meetings occasioned by the commissioning process have been followed. In connection with the observations, it was noted, 1) which actors use the various potential boundary objects and what they use the objects for, and 2) the themes brought up at the meetings and the decisions that were taken. In addition, all documents and minutes of meetings were collected. In the study, the research team had access to the project web, meaning that all documents from the project have been available, including basis, prepared project proposals and all examination reports.

Qualitative interviews were conducted with the client, the Cx adviser, the architect, the energy consultant responsible for the design of all the technical facilities, the operation coordinator and the operation officer working with energy systems, and finally an employee from the department that ordered the school. All interviews were of one-hour duration. The interviews were conducted as a semi-structured interviews, in which the central themes were: local work-tasks, local work-processes, the use of methods, theories and tools in the work-processes, success parameters for a well done job and perception of the commissioning-process' contribution with respect to the improvement of information integration between the various actors. All interviews were transcribed.

3. Tentative findings

In the following the four central communities are described with respect to how knowledge is localized, embedded and invested (Carlile, 2002) and the impact of the standard on the knowledge transfer between the communities.

3.1 The client

The client is an architect and has many years of experience. The client's task is to put the project organization together to solve the task that has been ordered and comply with the City of Copenhagen's policies. In this case, the Children and Youth Administration ordered the school and the Culture and Sport Administration ordered the sports hall. They are responsible for formulating visions and making functional requirements for the project. Historically, both administrations have developed general functional requirements which may form the basis for the preparation of a building program. There had never been a tradition of involvement of the operational users of a building from so early in the building program. In this sense this commission initiative is new. The client's task is to get the services performed in the construction sector's contract system, which includes preparation and conclusion of contracts with architects, engineers, specialist consultants, contractors and client advisers – all those who need to help to carry out a construction project. Furthermore, it is the clients' task to follow up on all agreements that are made, and in this way the client has process responsibility. Process responsibility is about running the process so that the ordering body and all the various construction companies deliver on time, so that the process does not become blocked through the various phases. The key person within the client organization (Copenhagen Construction) the client work together with is a lawyer with respect to the tender documents and contracts and the manager of the department. In addition, the client adviser is the client's main sparring partner. The client perceives the Cx adviser as the Copenhagen Property client adviser. The technical staff in Copenhagen Property has previously had the problem that they have primarily performed emergency operations and have had no time for planning and maintenance. By supporting participation of the technical staff in the construction project with a Cx adviser, the client has experienced that the operational department has become a better project participant, in the sense that the Cx adviser has helped the department to qualify their input for the design process. The regular Cx meetings and the ongoing scrutiny make it possible for the client to take decisions on technical aspects. In previous projects, the client had to spend time searching for the relevant staff in the operating department. The client thinks the Cx log as the Cx advisers' documentation that he has done his work. The client experienced that the commissioning process adds operational experience to the construction project important and challenges the design team on their solutions. Scrutiny processes mean that the client has a denser net to assess the project documentation at each phase, which means that the client can comment on the project documentation, where in the past the client often simply accepted the project documents. The client is very careful to keep the various actors in their roles, and experiences that it can be difficult from time to time to keep the Cx adviser and the team behind him in his role. There can be a tendency for technical staff to come with proposals that are not appropriate since the client thereby risks that the design team can disclaim responsibility by referring to the Cx adviser, who represents the client.

3.2 The operational department

Two years ago, a task force group was set up with four members from Copenhagen Property and Copenhagen Construction, respectively, to develop a concept for participation by Copenhagen Property in construction projects. The group have partly developed an operational log in which they have gathered experience from operations; partly as a process structure for participation in the construction project. The operation of the municipal property is shared between a local operation, with staff from the local users of the property, and a central operation, with Copenhagen Property's own technicians. The structure of the process is that the operation staff should be involved in the conceptual design, project proposal and just before delivery in order to prepare the operating personnel to take over the building. The aim is that the users (end-users, local operations staff and Copenhagen Property's own technical staff) should be able to use the building appropriately and take ownership of it. There have been major problems in deliveries of the new buildings where the users have not been able to figure out how to use and operate the building, which costs a lot of time and money for Copenhagen Property. Therefore, Copenhagen Property has experienced a need to be involved in construction projects as a way to clarify expectations as to: the type of building the users want, how technically complex it must be and the type of skills required by the local operational staff. The task force group follows a number of projects and holds meetings every 14 days. They arrange workshops for colleagues and are continuing their work on the operational log and the process concept. The coordinator's task is to involve the right people from Copenhagen Property at the right time in the construction process in relation to reviewing project documents, including ensuring that they receive information and submit comments for scrutiny on time. The Cx process in this project is an extended process in relation to BtD. In this process, the coordinator has involved technical staff from four different areas: the emergency operation, ventilation, electrical installations and energy management. There is only one engineer with experience within control systems in Copenhagen Property, so he is often busy. He has been involved in the Cx process but has largely left his work to the Cx adviser. In this project, the operational log was split into a Cx log and an operational log. For the coordinator and the technical staff, this meant that they left responsibility for issues in the Cx log to the Cx adviser. Conversely, they used many resources to attend more meetings than usual. The Cx adviser was perceived as the consultant. The coordinator experienced that the Cx adviser was active himself, which she prefers. In other situations, she has experienced Cx advisers expecting that themselves (Copenhagen Property) have to know what different solutions mean and what they should choose. In these situations, the coordinator will retain the Cx adviser in the role as the expert who is to help them. The coordinator assesses that in this project the operational staff have had good opportunities to influence the design process, but this is not necessarily because of the Cx process. The energy consultant company, who are responsible for the technical design convened four workshops concerning plumbing, building automation, lighting and electricity, and fire from the beginning, but this was not part of the Cx process. Already in the making of the construction program, there was much openness on operational requirements and experience. The coordinator perceives the process as a situation in which there is knowledge from each side of a date. In the process, both sides become aware of problems and challenges with design and use of technical systems, for example, she assesses that the Cx meetings strengthen this process and it is constructive that the Cx adviser manages the meetings and gathers the threads. A second version of the operating log has been made based on all projects in which it is used. The adjustment is about reformulating the requirements so they can be better understood by consultants; reformulating simplifications so there are no contradictions; taking out requirements because they are covered by legislation; and adding new conditions. It is a dynamic tool which evolved from being a communication tool into a technical program basis. Entering construction projects involves a responsibility. From sitting outside and criticizing to the active participation and being responsible for the choices made is an issue for the technical staff. At the same time they mentioned that they have had a better understanding of the construction project, the choices taken and the priorities. This also means that the requirements for the operation must be substantiated and not just based on personal opinion. The operational log was therefore sent around to the technical specialists in-house in Copenhagen Property to ensure that the foundation was as it should be. This process has been a learning process and taken time. The function of the log today is to ensure that Copenhagen Property is heard in construction projects.

3.3 The energy consultant

The energy consultant company, which is responsible for the design of the technical system, is a medium sized company. The company is part of the team set up by the main consultant for the design process. The energy consultant distinguishes between integrated energy design, traditional design and follow-up, including the commissioning of the various phases of a construction project. Integrated energy design is about having a dialogue with the architect right from the start of the design process as a way to integrate energy considerations in the design of the building. In this project they used integrated energy design from the start. The energy consultant perceives the strong focus on operation and maintenance early on in the building program as in this construction project as an unusual but important aspect. In this way the operational employee can be seen as a new user. When technicians design the technical systems they use different calculation methods, simulation tools, standards and regulatory basis. The main success criteria for their work are to deliver projects that clients are subsequently satisfied with. It can often be difficult for clients to communicate what it is they want, also because they are often not close to the users. It is best when clients are fully aware of their ambitions for the new buildings. From the consultant's perspective, he believes that the client will have to pay too much for commissioning as it is organized in this project. He is baffled as to why the consultants who designed the systems are not brought in to ensure the operations and the handover to the operational staff, as it is these who know the system best. Now a Cx adviser is paid to follow the entire project. At the same time the Cx adviser has no responsibility for the design. The energy consultant believes that the problem is that the Cx adviser gathers and coordinates a lot of information for the various users to use, but he does so without responsibility. The energy consultant and his team therefore need to check all information, since they are responsible. The consultant points out that the Cx adviser does not do something he should not do in advance. The energy consultant has the perception of the Cx adviser as the client's adviser, including the role that the Cx adviser must gather information from operations and coordinate their contributions. The energy consultant experiences that it is a clear benefit to the process if a Cx adviser arranges to obtain and systematize operating experience and creates forum (Cx meetings) in which a dedicated group of people meet and discuss operation, maintenance and user-oriented features of the building. The commissioning process has meant solutions that users could relate to have been presented early on in the different phases and this has given rise to a number of considerations together with the users early in the project. The process has pushed the focus on user needs and experience to operate the building to earlier in the design process. The consultant's experience with scrutiny is that it has worked well with the various users, but it has given rise to problems with the client-adviser team, i.e. third parties. The user base is the finished building and the issues related to the operation. Third parties, who are also technicians, however, asked about issues that seemed as if they were on a wrong level of detail in relation to the level of the individual phases. The energy consultant assesses that the level of detail for the various design phases is a gray area, and that he experienced problems with both the language and level. The energy consultant perceives the operational log as a collection of everything from small to large. He does not consider the users' requirements in the operational log and in the review as mandatory requirements, but more as a matter of dialogue and clarification from both sides. In contrast to this, the scrutiny comments made by other engineers (third parties) have the style that they think things should be done differently. For the energy consultant, the interaction with the operating team in particular has been good and this counteraction would be beneficial each time in a design process. Scrutiny comments have also had the function that the energy consultants have been able to lean on them and thereby strengthen their own arguments against the architect in the design process. For example it was often pointed out that the technical rooms were too small, and this became the final argument for the architect, who conversely had trouble getting the area consumption to meet the objectives for the building.

3.4 Cx adviser

The Cx adviser comes from a large consulting firm. He has many years of experience in the engineering field. He works with both technical design and commissioning, and he believes it is necessary to design in order to make commissioning lead to constant updates based on the latest standards, techniques and experiences. Furthermore, commissioning means that you know the conditions for a design process, for example the conflict between the architects' prioritization of design and the engineers' need for room for technology and pipes. The Cx adviser perceives that the key success factors of his work are that the building works from the first day and how the building can be serviced has already been thought about. He sees the commissioning process as a task on how to use the various standard templates to achieve a good result, and in this process the Cx adviser is very dependent on the input from the operation. The Cx adviser feels that it is an advantage that there are many users from operating activities, as it gives them the opportunity to understand all the choices that need to be taken in connection with a construction project. Copenhagen Property and Children and Youth Administration are also challenged in terms of the interface they have built around their two-part operation. The two-part operation has meant that certain concepts for solutions have been established that are not necessarily optimum from the standpoint of energy. Therefore, it is beneficial to have both parties in the commissioning process. He believes it is necessary to separate the operational log and the Cx log as many things in operational log are outside the scope of the technical systems that are the commissioning task.

4. Discussion

After several years of increased demands on buildings' energy performance in Denmark, the experience is that there appears to be a large gap between the designed and expected energy consumption in the design phase and the actual energy consumption during operation. This has centred focus on the need for information integration across construction projects and large operating departments. In Denmark, commissioning is one of the upcoming methods for handling this problem. Commissioning is a quality assurance system that is designed as a project delivery. However this analysis shows that the transition towards design and operation of buildings with high energy performance is not only about the creation of information integration across the design phase and use phase based on existing knowledge, which can be ensured through a quality assurance system on each project. Rather, there is a need of development and adaptation of practices of the involved communities based on a mutual learning process. This raises the need of evaluating critically which potential boundary objects that may function as information integration structures in construction projects and support communication and coordination across design and operation of buildings.

The experiences from the case shows that the different commissioning objects are not stabilized as boundaries objects that coordinate work processes across the various actors. The tendencies are that the different objects structures information integration in different ways and new dilemmas emerge in the interaction between the various actors. The findings illustrate that (i) all communities benefit from the Cx meetings, where information is transferred, translated and transformed across the different communities. The meeting structure has contributed to the operational department have had a better understanding of the construction project, the choices taken and the priorities, which in turn may have contributed to a generalisation of the operational log. At the same time the increased possibility of knowledge creating across the boundaries, may shape new priorities in the design work in favour of operational conditions. (ii) The Cx-log is not established from the beginning with articulated client requirements for the technical system, but is built up through the design process as a common checklist. This point to the fact that client requirements for the technical system it is not common knowledge that already exist. From the perspective of the energy consultant, priority of operational conditions and visibility of the "new user" can qualify the client's requirements for the building. This makes it easier to deliver a building that lives up to expectations. However the technical system is separated from other operational condition, which may increase the risk of a low priority of other operational condition. The new version of the operational log as earlier mentioned may have the potentials to be a new boundary object in future projects to increase collaboration across actors on the building's energy performance. (iii) The Cx scrutiny is a standardized scheme in which all the different communities have the opportunity to comment on the project documentation in the different phases. The results show that where the users and the operations department commented on the different solutions and had clarifying questions, the client adviser's technical staff suggested new technical solutions. In this way, the two columns of the scrutiny table act as two competing engineering paradigms rather than qualification of the design team's proposal. From the client's perspective, increased process documentation may increase the client's possibility for controlling the project material. However use of scrutiny may also take time from the design process as it takes time to fill in answers in the table. In addition competing engineering paradigms may keep both design methods and solutions in traditional design mode. In worst case it may take focus from adaptation and development of new design methods and solutions based on experiences from operation of buildings.

The experience from this case suggests that instead of maintaining the technical solutions in the form of standard methods and new consulting services, which follows as a natural extension of a project focus, it may be more appropriate to consider the various ways this process can be organized. Aspects of commissioning can contribute to this, but this solution should be challenged on the relevance of each element and where the function should be placed.

1. When placed with a third party, this function can increase the control aspect of the client, but will conversely be a costly solution. At the same time, it can give rise to competing engineering paradigms, which can detract focus from the new user and inhibit development of new design methods based on new perspectives.
2. When placed with the consulting engineers, this function can support the development of new design methods and be a natural development of their design delivery. Costs can be reduced, since there will not be two engineering consulting companies that have to know the technical system in detail, but conversely control aspects will be reduced.
3. When placed with the operational department, this function can strengthen their capacity on this area and support their organisational development, but it may require specialist knowledge that can be difficult to maintain in operation organisations

5. Conclusions

In the context of new priorities in construction, there will always be a need for new forms of information integration between new actors. It may seem that "technical solutions" are made before "ongoing learning processes" in which new themes are articulated and understood across the different knowledge boundaries. Since there is a tendency for "technical solutions" to remain after a project, it seems that a solution strategy with development of standards and new consulting services could lead to increased fragmentation of construction projects. In addition the case illustrate that the commission process influence not only knowledge sharing across different communities but also the distribution of roles, responsibilities and control. Based on these results it will be useful to know more about, the socio-technical aspects of the development of new forms of information integration in construction projects in the context of new priorities in construction.

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Text Analytics on Construction Tender Documents for Project-Oriented Risk Mining

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Abstract

Construction tender documents contain owner's project requirements so that a contractor can make project plan. However, tender documents might not always be clear and adequate. Furthermore, since there are many potential project risks behind the documents, close analysis on tender documents should be implemented. This paper discusses a project-oriented risk mining approach which could detect and extract project specific risk factors based on text analytics. From the risk mining process composed of text mining step, risk classification step and risk assessment step, project specific risk factors could be effectively managed initially. Furthermore, the project-oriented risk mining approach is expected to effectively reflect project characteristics to the project risk management and could provide contractors valuable business intelligence.

Keywords: Tender document, Risk management, Project-oriented management, Text mining

1. Introduction

Contractors can understand owner's design intent and requirements from the tender documents. However, the tender documents might not always be clear and adequate. Brook (2004) indicated that major problems associated with quality of information in drawings, specifications and bills of quantities include missing information, late information, wrong information, insufficient detail, impracticable designs, inappropriate information, unclear information, provisional information, poorly arranged information, uncoordinated information and conflicting information (Laryea 2011).

Besides, as construction projects are getting bigger and more complex, especially in international projects, close analysis on tender documents is very required. Although the tender documents are crucial for understanding project characteristics, tender document analysis is not sufficiently conducted in many projects. According to one of the major contractor's internal survey, most of cost overrun factors in international projects are related to construction tender documents, such as poor review on ITB (Instruction To Bidders), design errors and omissions, and discrepancies among tender documents. This shows tender document study should be managed from a risk management aspect since many potential project risks are existed behind the documents.

There are many concerns regarding risk management skill as many contractors suffer major losses in international projects. In the view of risk management's life cycle, the effect of risk management in the early stage is greater than the late risk management while available information is poor at a beginning step. Because tender documents are the only information available at the project initial phase, document-based risk analysis should be conducted. Moreover, unclear and wrong information in the tender documents should be clarified in order for maximizing initial risk management effects.

Even though the importance of early risk assessment and management have been emphasized, however, current risk management practice at the project beginning step does not fully deal with project risks. Majority of typical risk management studies focus project's external and unexpected risks on such as political risks and financial risks. Those external risks are hard to manage and prevent, risk management should be concentrated on project inherent risks.

In the real construction world, there are many situations where the quantitative and detailed information to evaluate uncertainty is not available. These conceptual factors can be expressed in qualitative or linguistic terms, that is, so called fuzzy information (Kangari, R. and Riggs, L. S. 1989). This explains those linguistic risk terms should be managed in order to assess project's potential risk factors. Therefore, this study suggests a project-oriented (internal) risk-mining framework which can detect and extract project-specific linguistic risk factors based on text analytics for tender documents.

2. Background

2.1 Overview of current research

Extensive research has been done in risk evaluation and risk management at the project beginning step. Zhi, H. (1995) developed a method of managing various risks for overseas construction projects and how to effectively identify the vital risks in overseas projects. Gunhan and Arditi (2005) evaluated risk factors affecting international construction projects by surveying the executives in charge of international construction of large U.S based contractors. Sonmez et al. (2007) presented a quantitative methodology to determine financial impacts of the risk factors during the bidding stages of international construction projects. Lin and Chen (2004) suggested bid/no-bid decision making by using a fuzzy linguistic approach. In that approach assessments were described subjectively in linguistic terms, while screening criteria were weighted by their corresponding importance using fuzzy values.

However, almost the whole risk evaluation and risk management studies are weighted toward high level of risks, such as political risks and financial risks, not project-oriented (low-level) risks. Moreover, most existing risk assessment systems are based on quantitative techniques which require numerical data. However, much of the information related to risk analysis is not numerical. Rather, this information is expressed as words or sentences in a natural language (Kangari and Riggs 1989). Besides, many researches relies on survey-based statistical analysis which could be easy to have biased personal opinion and experience. That are the reasons current risk evaluation and risk management studies does not fully deal with each project's characteristic. Therefore, this study approaches from the bottom of the project risks, which is document-based analysis and project-oriented (internal) risk analysis.

2.2 Research Objective and Research Question

Risk management is typically carried out during a whole project life cycle. If risk evaluation is not sufficiently performed and project risks are not fully detected at the project beginning step, however, potential project risks could be presented during the project. In other words, successful project performance cannot be guaranteed without pre-emptive risk management in the project early stage.

Based on this premise, this study suggests a framework which gives a concept of project-oriented (internal) risk mining in order for preventing and minimizing of great losses caused by poor risk evaluation at the project initial phase (tendering process). To extract project-oriented risks, this study concentrates on project tender documents which includes many project potential risks. However, close analysis on huge amounts of tender documents is always a challenging task since the tendering period is not enough. Furthermore, tender documents might not always be clear, consistent and adequate. Thus, text mining concept is adopted in this study in order to analyse large amounts of tender documents and extract related risk factors. The project-oriented risk mining process is expected to be used as bid decision making materials so that contractors can judge whether the project is profitable or not in advance.

From the previous literature review, not only project external risk (high-level risk) factors but also project-oriented risk (low-level risk) factors should be managed in the early stage of construction project. Because project tender documents contains many information about project characteristics, this study should start with analysis on tender documents. The concept of this study has been named as "Project-oriented Risk Mining". In order to proceed the study the following questions should be addressed in advance:

- What type of risks should/could be solved?
- What kinds of project-oriented (internal) risks are existed in tender documents?
- How to identify project-oriented (internal) risks?
- How to extract/mine text-based risk factors?

What are the proper evaluation method for various types of risks?

3. Research Framework

3.1 Project-Oriented Risk

Project-oriented risk could be defined as project-specific risk factors which exist project inside. Project-oriented risk is related to the quality of tender documents' information in drawings, specifications and bills of quantities included missing information, wrong information, insufficient detail and impracticable design, etc. Poor quality tender documents can lead to inaccurate estimates, higher margin in bids, claims and disputes (Laryea 2011).

From a review on previously performed project documents, we could derive some risk types associated with tender documents as follows:

- Problems caused by specific clauses or terms written in tender document
- Problems caused by omitted information in tender document
- Problems caused by discrepancies between information
- Problems caused by wrong information in tender document

Those types of risks related to the tender documents could be identified as project-oriented risks, and those risk factors should be detected at the tendering process for successful project.

3.2 Text Analytics for Tender Document

Tendering is one of the stages in a construction project that requires extensive information and documents exchange. Such tender documents often contain the information about a client's project plans so that a contractor can price it (Laryea 2011).

Tender documents may include (Designing Buildings Wiki 2015):

- A letter of invitation to tender
- The form of tender
- Preliminaries : including pre-construction information and site waste management plan
- The form of contract, contract conditions and amendments. This might include a model enabling amendment for building information modelling (BIM), making a BIM protocol a contractual document
- A tender pricing document (or contract sum analysis on design and build projects)
- Employer's information requirements for BIM
- Design drawings, and perhaps an existing building information model
- Specifications

Since tender documents are contractual documents, the information written in tender documents have legal force. If a contractor misses some wrong information or omitted information in tender documents during tendering process and decides to proceed the project, the contractor should take the risks which could be arise due to the wrong or omitted information. To prevent and take pre-emptive action on the project risks hidden in tender documents, tender documents analysis should be managed from a risk management aspect.

Because construction tender documents are written in text which is unstructured data, various type of data analytics, such as text analytics, are required. Text analytics helps analysts extract meanings, patterns, and structure hidden in unstructured textual data. The term "text analytics" has evolved to encompass a loosely integrated framework by borrowing techniques from data mining, machine learning, natural language processing (NLP), information retrieval (IR), and knowledge management (Chakraborty G. et al. 2013). Text analytics is useful method to analyse great amounts of documents with short tendering period. Text analytics enables to have term frequency and related terms in documents so that potential risk factors existed in tender documents could be detected.

3.3 Text Analytics for Tender Document

This study defined the concept of risk mining as a progressive methodology which detect unstructured textual data, and categorize risk types, and assess them. Figure 1 shows the project-oriented risk mining framework. This framework is divided into two parts, which is risk identification step and risk mining step.

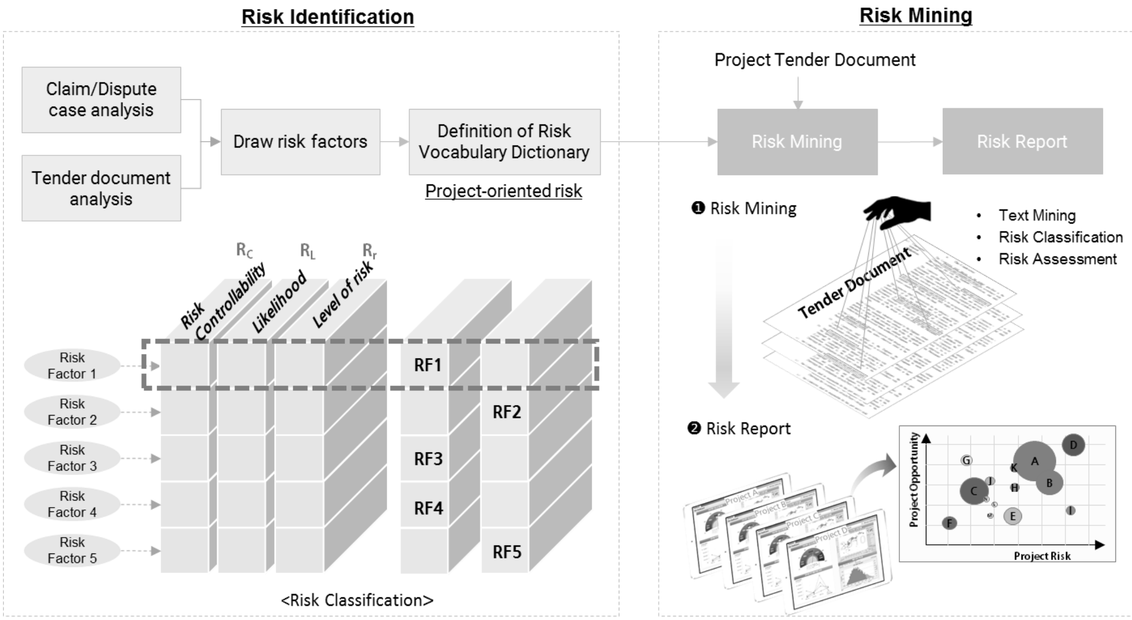

Figure 1 Project-oriented risk mining framework

'Risk Identification' step is based on two types of literature review, previously performed project's tender document analysis and construction claim/dispute case analysis. From the previous project cases which experienced losses because of a poor analysis on tender documents, we could understand what issues written on tender documents influenced the project's success and fail. Those issues might be the type of project-oriented risk factors. Another way to draw project-oriented risks is investigation into construction claims and disputes related to the tender document problems. Since claims and disputes are caused by project various risks, we could figure out project-oriented risk factors from claims and disputes cases. Those risk factors derived from the literature reviews could be collected in order to define risk vocabulary dictionary. The risk vocabulary dictionary could be used at the 'Risk Mining' step during imported project tender document's risk assessment.

In the 'Risk Mining' step, newly imported tender documents are firstly text-mined according to the risk vocabulary dictionary, and each risk terms are categorized by risk categorization step, and finally evaluated at the risk assessment step. The result of risk mining is summarized as a risk report. The risk report shows project risks and project opportunities so that risk mining results could support project bid decision making.

4. Illustrative Example

To illustrate the proposed research framework, this study performed risk identification step as an illustrative example using construction cases on adjudication. In this example, we investigated into construction adjudication cases in order to identify risk factors. Project-oriented risk factors could be figured out from the claims and disputes cases. For the purpose, 549 adjudication cases were collected from 1999~2015 in UK construction industry. Text mining for analysis of construction adjudication cases was conducted using SAS Text Miner 13.1.

Since this illustrative example was performed for extracting project-oriented risk factors from the claims and disputes cases, the adjudication cases which written in text was analysed according to the following steps. Text import, text parsing, text filtering, and text clustering. Text importing is the first step in the text mining process. Collecting and setting up textual data is performed in the text importing step, and the source data is imported into the text mining tool. The textual source data is called as 'corpus'. Corpus is a large set of texts, and they are used to do statistical analysis and hypothesis testing (Wikipedia 2015). After the text data is imported, it is ready to be analysed.

Once the text-based documents are imported, the documents should be disconnected in order to quantify information about the terms. This step is 'text parsing' step which convert the collected textual documents (unstructured form) to a structured form using vector representation.

Table 1 Results of text parsing (partial)

Terms	***Role***	***Term Frequency***	***Document Frequency***
adjudicator	*Noun*	*13,772*	*343*
decision	*Noun*	*10,520*	*366*
clause	*Noun*	*5,331*	*261*
payment	*Noun*	*5,394*	*327*
notice	*Noun*	*4,668*	*315*
issue	*Noun*	*4,465*	*355*
pay	*Verb*	*4,026*	*347*
provide	*Verb*	*3,794*	*352*
cost	*Noun*	*3,645*	*321*
agree	*Verb*	*3,477*	*363*

There are two broad-based approaches to analysing text. The first is the bag-of-words method, where the basic assumption is counting words in the text, plus understanding how these words are syntactically (structurally) related to each other in regard to laws of grammar, etc. This method is sufficient to summarize and classify text documents. The second approach, which is linguistic, posits that truly understand and classify text, you have to move beyond syntax (structure) to semantics (meaning of words). In order to apply either approach, the text document is first parsed to find the words contained in it (Chakraborty G. et al. 2013).

The first step of text parsing begins with breaking down the text stream into terms. Texts in the documents are tokenized and normalized during text parsing step. Table 1 shows the result of text parsing of construction cases on adjudication. Typically, ignoring parts of speech, ignoring types of entities and attributes are additionally conducted in order to make text parsing more simple and fast.

Next step is 'text filtering'. Text filtering eliminates extraneous information caused by the presence of noise terms and other terms, so that only the most valuable and relevant information is considered. Moreover, user-defined terms could be excluded at the text filtering process. Some general construction terms, such as 'contractor' and 'construction', etc., was added to the stop list to focus on the terms and documents that are most likely to enhance the result. Creating appropriate stop list is crucial in obtaining valid and useful results. Figure 2 shows the text filtering process using stop list.

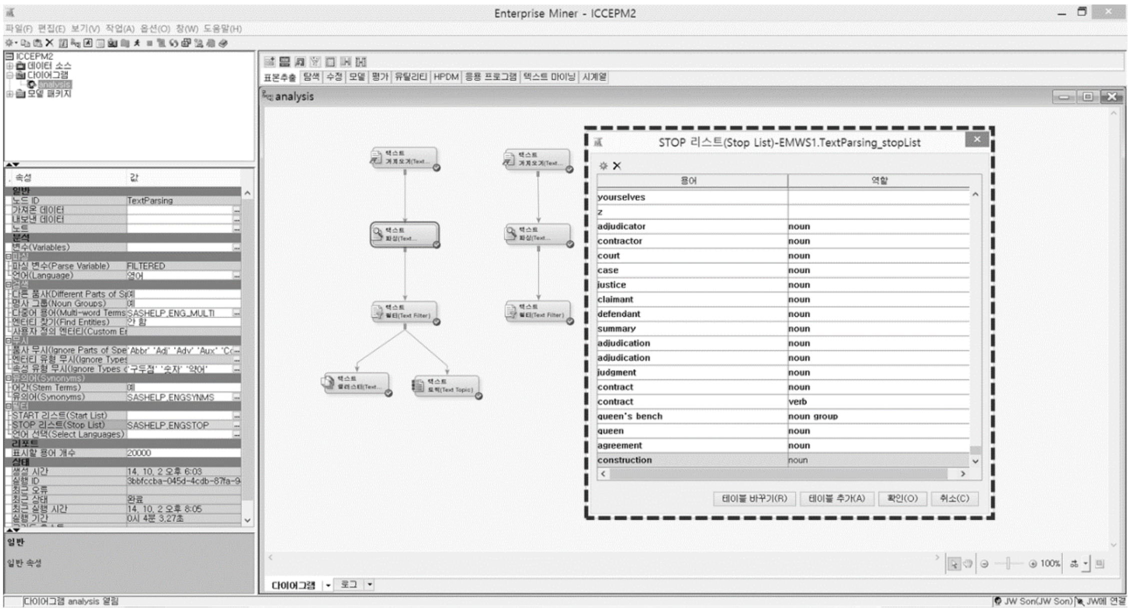

Figure 2 Text filtering process using stop list

After text parsing and filtering is finished, 'text clustering' could be performed in order for grouping a set of related risk terms. Text clustering is the task or grouping a set of text words that wards in the same cluster are more similar to each other than to those in other clusters. Text clustering enables to define, discover, and modify sets of topics contained in the documents. In order for text clustering two algorithms are available. The expectation maximization algorithm clusters documents with a flat representation, and the hierarchical clustering algorithm groups clusters into a tree hierarchy. Both approaches rely on the singular value decomposition (SVD) to transform the original weighted, term-document frequency matrix into a dense but low dimensional representation (SAS 2014).

Table 2 is the text clustering result of construction adjudication cases. Each word included individual cluster represents each clustered documents. However, the clustered words do not give detail information about cluster's distinction. Even if the word groups were made by some clustering algorithm, it is difficult to define individual cluster's distinction without understanding the context where the term is being used. Therefore, examining full text and related sentence where terms are being used should be performed repeatedly to define each cluster's topic. As a result, 6 clusters were identified as follows:

Table 2 Result of text clustering

Cluster 1	***Cluster 2***	***Cluster 3***	***Cluster 4***	***Cluster 5***	***Cluster 6***
damage	*breach*	*completion*	*structure*	*change*	*cost*
delay	*design*	*plan*	*installation*	*document*	*fee*
date	*document*	*debate*	*industry*	*clear*	*solicitor*
notice	*contract*	*certificate*	*supply*	*engineer*	*pay*
extension	*evidence*	*damage*	*light*	*variation*	*evidence*
provision	*place*	*complete*	*site*	*breach*	*money*
payment	*detail*	*submission*	*house*	*comply*	*letter*
claim	*price*	*cross-claim*	*fee*	*dispute*	*instruct*
challenge	*site*	*doubt*	*contend*	*state*	*submission*

- Cluster 1 : Liquidated damage related terms
- Cluster 2 : Design liability related terms
- Cluster 3 : Practical completion related terms
- Cluster 4 : Site establishment liability related terms
- Cluster 5 : Variation related terms
- Cluster 6 : Payment related terms

The result of text clustering could be used to define risk vocabulary dictionary. The risk related terms by risk type is potential risk factors, and those terms enrich the risk vocabulary dictionary. By drawing risk factors from many cases, risk vocabulary dictionary could be used at the risk mining step during imported project tender document's risk assessment.

5. Discussions

This study discusses a project-oriented risk mining approach which could detect and extract project specific risk factors based on text analytics. Moreover, a part of risk identification step which is included in research framework was conducted as an illustrative example using construction cases on adjudications. However, the result from the adjudication cases should be linked to the result from tender document analysis which did not deal with at this illustrative example. Since all the terms derived from the adjudication cases might not directly matched to the tender documents, further study should be required to make project-oriented risk mining framework more effectively. If the study of previously performed project's tender documents will be followed later, more practical risk factors could be derived. Using those risk factors, project-oriented risk mining process could be more materialized with computer-aided skills in the future study.

6. Conclusions

The purpose of the study is to propose a new approach for managing text-based project-oriented risks. Since available information in the early stages is not enough and clear, identifying owner's design intent written in tender documents is important for proceeding construction projects. However, current risk evaluation and risk management studies dose not fully deal with project risks. Thus, this study presented project-oriented risk mining approaches from the bottom of the project risks, which is document-based analysis, using text analytics techniques. Although the illustrative example was only a part of drawing project-oriented risk factors, this study is one of the meaningful attempts to investigate unstructured text data in construction field. Furthermore, the project-oriented risk mining approach is expected to effectively reflect project characteristics to the project risk management and could provide contractors valuable business intelligence.

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Complexity and Energy Performance Contracting: the Case of Street Lighting

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Abstract

There has been a renewal of public-private partnership (PPP) in France after 2004. Until 2013, this procedure was relatively popular to deliver integrated solutions to public authorities who were demanding for packaged product and service delivery. Street lighting projects aiming at reducing electricity consumption are dominant among PPP. These projects are a category of energy performance contracting (EPC). The question is why EPC is dominant for street lighting projects and not for buildings. A case study focusing on a street lighting project indicates that they are less complex. Uncertainty is limited and beneficiaries have no influence on the end result whereas occupants can have a strong impact on the energy consumption of a building. Moreover, formal contracts are adapted to this type of projects with limited uncertainties and relational governance can be limited.

Keywords: PPP, complexity, governance, public lighting, energy performance contracting

1. Introduction: private finance procurement in France

France has a long experience in private finance procurement. It concerns mainly infrastructure projects where an asset (such as a road) is provided for which users pay directly. The first concession arrangement was signed in 1554 for the construction and maintenance of a canal over a period of ten years (Bezançon, 2005). During the 19th century, the concession system was dominant for all public works. Contractors were systematically associated to maintenance works for six to ten years. More recently, during the sixties, concessions mainly concerned public infrastructures such as bridges, tunnels, urban facilities and roads (motorways). Under this scheme, the concessionaire is partly paid by the users of the public service conceded.

During the late eighties, some schools and prisons were delivered under a Design, Build, Operate and Finance scheme. However, the procurement method was opaque and it led to illicit agreement practices between contractors. Thus, public private partnership (PPP) for buildings was banned for about ten years and the development of the market in France was delayed. However, most large French contractors were able to benefit from the PFI experience in the UK.

At the beginning of the 21st century, there was a strong debate for the renewal of PPP in France. Architects were strongly opposed to any kind of PPP for buildings. They considered that contractors would become relatively more powerful and that financial issues will took over architectural matters. Conversely, large contractors saw PPP as an opportunity to modify their traditional business models and to move into new kinds of value-added activities. Between 2002 and 2004, several ministries (home Affairs, Justice, Health and Defence) introduced a new legal framework for projects concerning facilities such as prisons, police stations, and healthcare facilities. Finally, in June 2004 a new law was enacted to spur partnership contracts ("Contrats de partenariat"). It was strongly influenced by the Private Finance Initiative in the UK. From June 2004 to December 2013, 194 contracts were signed representing an investment of approximately 14 billion euros (table 1).

Table 1: Economic value of Partnership contracts at the end of 2013[1]

Actors	*Projects signed*	*Investment (million €)*	*Global value (million €)*
Local authorities	*145*	*4 119*	*10 185*
State	*49*	*10 346*	*26 436*
Total	*194*	*14 465*	*36 621*

Source : CEF-OPPP (2014)

Knowing that public investment reaches about 90 billion euros every year, the vast majority of investments in the French public service is still procured through conventional means. Partnership contracts were mostly used for buildings at the State level, and for urban facilities, at the local level (table 2).

Table 2: Sectoral breakdown of partnership contracts signed at the end of December 2015

Actor / Type	*Local authorities*	*State*	*Total*
Building	*34*	*32*	*65*
Sports and cultural infrastructure	*22*	*2*	*25*
Energy / waste	*11*	*11*	*22*
Urban facilities	*63*	*0*	*63*
Information and communication technologies	*13*	*4*	*17*
Transport	*10*	*6*	*16*
Training	*0*	*1*	*1*
Total	*153*	*56*	*209*

Source : MAPPP (2015) - http://www.economie.gouv.fr/ppp/contrats-signes

[1] After 2013, the number of deals collapsed. 9 and 6 projects were respectively signed in 2014 and 2015.

Among urban facilities, street-lighting is dominant. These contracts aim at refurbishing street lighting in order to reduce the electricity consumption of local authorities. As such, they can be associated to energy performance contracting (EPC). According to the European Parliament's definition (2012), "*energy performance contracting means a contractual arrangement between the beneficiary and the provider of an energy efficiency improvement measure, verified and monitored during the whole term of the contract, where investments (work, supply or service) in that measure are paid for in relation to a contractually agreed level of energy efficiency improvement or other agreed energy performance criterion, such as financial savings*".

Partnership contracts have seldom integrated issues dealing with energy performance in buildings. Conversely, cutting energy consumption was the main target of PPP focusing on street-lighting. The aim of this paper is to understand this gap.

To launch a partnership contract, it is necessary to prove that the project is "urgent" or "complex" or brings value for money. More than 90% of PPP projects were considered as complex.[2] Thus, the paper will examine the notion of complexity in construction and its impact on project governance. Then, a case study focusing on street lighting will be presented. The aim of the discussion will be to understand why energy performance contracting is dominant in street lighting projects and frequently omitted in building projects.

2. The impact of complexity on governance

2.1 Complexity in construction project

It is widely recognised that construction projects become progressively more complex (Baccarini, 1996). This complexity is also put forward by Hobday (1998) who introduced the notion of complex products and systems (CoPS) to characterise one-off projects. While the focus is on the production process with goods and services, the emphasis with CoPS is on design, project management, systems engineering and systems integration. Several dimensions characterise complexity: the degree of technological novelty, extent of embedded software in product, quantity of sub-systems and components, feedback loop from later to earlier stages, uncertainty/change in user requirements… As construction is moving away from its production-based focus and is developing new service activities (financing projects, operating and maintaining systems…), interfaces are multiplied, and project complexity becomes stronger. Project management does not anymore concentrate on the internal project team and external supply chains. It also integrates downstream service delivery. (Alderman et al., 2005).

This move from the building activity to the service provided by the built environment (Carassus, 2002) is accompanied by a change of procurement. Traditional design and build contracts based on input specifications are more and more replaced by service-led contracts where the output to

[2] A new law will be enacted soon. The aim is to simplify all sector-specific legislation and to comply with the European directive on public markets. According to the first draft (July 2015), partnership contracts will only be signed if they offer value for money.

be delivered is specified. The competitive dialog procedure is particularly adapted to these situations since it helps to match the demand of the client with the possible solutions that contractors can offer (Hoezen et al., 2010). According to Lewis and Roerich (2009), it is possible to assess the complexity of the procurement process in terms of two dimensions: performance complexity and infrastructural complexity. The first refers to "*a function of characteristics such as the level of knowledge embedded in the performance*" (p.127). The second refers to "*the complexity of the infrastructure through which performance is enacted*" (p.128). According to this framework, traditional design and build contracts based on input specifications would be considered as less complex in terms of performance than service-led contracts which go further than design and build and encompass operation and maintenance.

Complexity can change over time. Wang and von Tunzelmann (2000) show that each functional area of the firm (technology, markets and products, production processes, administration and management) is in interaction with each other and that the evolution of the complexity of one function will impact other functions. Complexity will also depend on the competencies developed by public authorities. This issue is central for the European Commission (2004) who considers that a public contract is particularly complex when the contracting authorities*: "(1) are not objectively able to define the technical means (...) capable of satisfying their needs or objectives, and/or (2) are not objectively able to specify the legal and/or financial make-up of a project*."

2.2 Complexity in EPC

Simple building constructs cannot be associated to CoPS. Conversely, EPC for buildings are complex on several dimensions:

1. Design based on collection of information and data, and dynamic thermal modeling and simulation: Dynamic thermal modeling and simulation is a complex activity as illustrated by the frequent gap between predicted energy performance of buildings and measured energy use once buildings are operational (de Wilde, 2014).
2. Works such as the removal and installation of efficient heaters, measurement and monitoring equipment, insulation of buildings, cover a broad range of activities and usually involve subcontractors. Moreover, works usually concern buildings with different architectural style, different year of completion…and require the development of specific technical solutions. Works are also done in occupied buildings and they have to take into account the occupants to avoid disturbances and conflicts.
3. Operation and maintenance of buildings: the performance of these activities is based on day-to-day maintenance but also on occupancy conditions. To reduce the impact of users during the operation of the building, the operator may develop actions to promote environmental awareness. The complexity is due to the necessary cooperation between two actors (the operator and the occupants) with antagonist goals.
4. Project financing: The financial arrangement is very complex. There are mainly two financing approaches: self-financing or third-party financing (Lee and al., 2015). In some cases, project financing is made with a mix between debt and equity. Public authorities

who are not familiar with these complex financial schemes regularly receive the support of lawyers and financial consultants.

5. Measurement and verification: they are the cornerstone of EPC since it is used to allocate risks between the ESCO and the client, to assess energy savings and reckon penalties / bonuses, to monitor equipment performance and to improve operations and maintenance (USDE, 2015). There has been effort to standardized M&V by developing protocols. Moreover, technological development in monitoring and data mining techniques have contributed to improve performance predictions and building energy management decision-making (Ahmed et al, 2011). However, this is still complex since it is difficult to get reliable building operation data before the signature of the contract and to monitor behavioural changes during the project life time.

Moreover, project complexity is influenced by the experience of the stakeholders with EPC projects. Energy Service Companies (ESCOs) which are at the core of EPC are not equally developed among countries. Bertoldi and al. (2006) classified French ESCOs in the “second European league”. Similarly, public authorities who have a great experience with delegating the management of public services are still not familiar with performance contract and performance procurement process. As indicated by Hartmann et al. (2010), public authorities need to develop capabilities to contract for service-led projects and manage the relationships with their service providers. Developing simultaneously contractual and relational capabilities is difficult since contractual documents are still the main references.

2.3 Governance issues

Developing a transaction cost analysis, Winch (2001) considers that low asset specificity, low transaction frequency, and high uncertainty characterise construction. According to this theoretical framework, hierarchy should be preferred to drive construction procurement because of the uncertainty surrounding the project (unknown natural conditions, temporary coalition between actors, unique features of each project). However, market governance is the most adapted to clients’ preferences since asset specificity is low (resources required are available from a large number of suppliers and contractors) and transactions are not frequent (even experienced clients do not procure many buildings every year). The move toward service-led projects modifies this framework and requires more contractual safeguards to mitigate the uncertainty (Hartmann et al., 2010). According to Bijlsma-Frankema and Costa (2005), the effectiveness of control of formal contracts depends on three elements: (1) the codification of the tasks and the behaviours, and the measurability of outcomes; (2) the monitoring of the actions performed by the parties; (3) the creation of a structure that enforce the contract.

However, formal contracts are difficult to specify for service-led projects since outcomes are frequently intangible. Moreover, service-led projects have a longer lifespan and are subject to technological changes. Specifying everything ex-ante would raise transaction costs and render the contract difficult to enforce. Indeed, it would be necessary to create a specific structure in charge of monitoring opportunistic behaviour and applying contractual clauses. This would be costly and would create additional complexity. Consequently, it is more efficient to accept incomplete contracts, to introduce some contractual flexibility and to rely on relational governance and trust between partners to avoid conflicts. "*Relational governance refers to those inter-organizational exchange mechanisms that are not sanctioned through formal contractual positions (…) but are manifest in custom and practice*" (Roehrich and Lewis, 2010, 1157). Relational governance has its own enforcement mechanisms such as threat of social sanctioning and reputation effects. Formal contracts and trust are complementary. The negotiation process that leads to the contractual agreement is frequently at the origin of a common understanding between parties. The contract also offers protections necessary for the creation of a relationship based on trust. It is a solution to enforce the trust between partners and to limit opportunism.

3. Case description: the EPC dealing with street-lighting in two municipalities[3]

3.1 The project and its context

The PPP project concern two municipalities: city A and city B hosting respectively 117 000 and 23 000 inhabitants. Most street lighting facilities of city A were outdated (more than 45 years old) and highly inefficient. In 2007, 26% of the 5298 lights would have required to be replaced within five years and 40% within two years. The power of the lighting system was also defective. Consequently, the network was not anymore safe and reliable. Operation and maintenance were entrusted to municipal employees and outsourced to one company who signed a one year contract renewable three times. The situation of the neighbouring city (B) was less dramatic. Only 25% of its 2 647 lights had to be replaced in the short run. One private partner was in charge of operating the network. Indeed, in 1994, this city signed a PPP including financing, operation, maintenance and renewal of street lighting and traffic lights.

Annual operating costs were different between cities. City A spent about EUR 335,000 each year. City B with a network twice as small spent EUR 400,000. In 2004, competencies dealing with street light were transferred to a regional community. PPP was seen as the solution to modernise the lighting network and to introduce environmental criterion and energy performance objectives. City A had a limited borrowing capacity and was not able to borrow €30 million for the modernisation of its public lighting network.[4] City B already experienced PPP and was also looking for a solution to finance, renovate and operate its network.

[3] Since there is apparently nothing in the literature about street lighting the case study approach appears appropriate. It is based on face-to-face interviews with the client, the legal consultant, and two people representing the private partner. A report comparing the conventional public procurement process and the PPP option was also used as complementary source of information.

[4] At that time, PPP was still seen as a way to account public investments as off the balance sheet. According to the Eurostat rule in 2004, it was possible to classify investments made through PPPs as non-governmental if the construction risk and either availability or demand risk were transferred to the private operator. Thus, debt hiding was a motivation for PPP. Since 2011, both existing and new projects have to be considered as public debt. "*On the balance-sheet, the capital value of the investment is recorded within the assets, while the already-paid investment and the remaining debt are recorded within the liabilities*" (Buso and al, 2013).

The criterion of complexity has been put forward to justify the PPP procedure. Both municipalities did not have the technical know-how to refurbish street lighting. Moreover, the regional community who represented both municipalities and took in charge the project had no expertise to assess the level of investment and to operate and optimize the energy related installations.

Legal, financial and technical consultants assisted public authorities during the redaction of the comparative analysis and the competitive dialog. According to the public sector comparator, PPP offered the best value for money both in terms of costs and service quality. The call was launched in December 2006. The first round for the competitive dialog was organised in September 2007 and the second in November. The contract was awarded in June 2008 and signed in July for 20 years. The company, who won the competition for the deal, covers the entire value stream of public lighting, from design, to renovation works and operation. Consequently, there was no need to create a Special Purpose Vehicle as for most PPP projects. The company borrowed money to one bank. The initial costs of the deal reached EUR 92.3 million. However, it was renegotiated during refurbishment works due to a decrease of interest rates. Thus, the final deal reached EUR 86 million over the 20 year period.

3.2 The complexity of the project

According to Wang and von Tunzelmann (2000), complexity covers several dimensions: the technology, the markets and products, the production processes, and the administration and management. The complexity of this project mainly concerned the technological and organisational dimensions:

- A large part of civil engineering was performed with micro slicers[5] in order to reduce both the time in which roads cannot be used and the quantity of excavated volume. The private partner also anticipated future works by performing all civil engineering during the first three years of the contract. In the future, when a cable will be laid, no additional trench will be opened. This approach minimised the environmental impact and the nuisance caused by the construction sites.
- The use of the micro slicers completely changed the organization and the conduct of the project. The work was closely coordinated with private companies in charge of managing the gas network and relevant community services. The objective was to avoid interventions from municipal employees shortly before or after the action of the private partner. A specific team was also created to inform residents about the works in progress. Moreover, to optimise the micro slicers, trenches had to cover a length of 500 meters for one week. Such length was unusual and required further communication.
- The installation of a centralised control station was another major innovation. It is commonly used for building but it was the first time for public lighting. Moreover, a wireless network was set up to link luminaires to the central station. This solution aimed

[5] With the traditional approach, the company digs a trench of 80 cm deep and 40 cm width while with this technique, the hole is limited to 35 cm deep and 15 cm width. This technology is traditionally used for the installation of fiber optics in the countryside.

at monitoring the intensity of every light[6] and providing complementary services to local authorities (such as video protection, tricolour stop lights).

3.3 Results

The private companies renovated 70% of the street lighting system on time (at the end of the contract, 95% of the park will be renovated).[7] By concentrating most of the renovation works on the first three years, the goal of the company was to reduce as soon as possible the power of the network by 38% and to reach its energy performance objectives on the long run. Over the 20 year period, total energy consumption has to reach 94 GWh. If the savings are not achieved, the private partner will pay compensation. Conversely, gains will be invested in energy performance works. However, there are no yearly milestones. The private partner just needs to write a report every year in order to present how contractual obligations are respected. Public authorities also hired a subcontractor who ensures that the private company adheres to the performance and standards stipulated in the contract.

After two years, the energy consumption was slightly over its target. However, the private partner was still optimistic since the centralised control station was not operational in both cities during the first years of the contract. Moreover, life cycle costing approaches were not neglected because the operator contributed to the elaboration and he success of the deal. According to Swaffield and Mc Donald (2008) and Rintala (2005), this issue is frequently ignored in PPP projects because budgets are constrained, clients are unable to understand the maintenance requirements and the associated costs, and there is a lack of information about the different options and about the past performance of products. Moreover, operators have usually less influence on the service provision solution than contractors. Consequently, operational solutions are not frequently optimised.

Both partners considered that the contract lacks flexibility, particularly to resolve unforeseen actions. For example, the contract does not mention that the private partner is responsible for exceptional lighting events such as the National Day or the “Night of the Stars”. So far, the private partner accepted to support these costs. However, he would like to open a special account for financing contingencies that were not anticipated and to introduce information disclosure for this account in order to preserve the stability of the agreement.

The public person in charge of following the contract was satisfied with the service quality. However, he was sceptical about the length of the contract. Even if the best technology available were selected[8], several technological changes may affect street lighting system and the actual contract may create a lock-in effect.

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[6] Lights can be shut down in streets that do not need to be lighted in the middle of the night.
[7] The competitive dialog helped the laureate to improve its initial offer. His first proposal was to renovate 62% of the candelabra over a period of five years. In addition, at the end of the twenty years contract, only 88% of the Park would have been renovated.
[8] At this time LED technology was not considered as the most interesting option. It was twice as expensive as other technology available. Moreover, there was a lack of feedback studies for LED.

4. Discussion

The main objective of this paper was to understand why energy performance contracting was dominant in public lighting projects following a PPP procurement process and frequently omitted in building projects. To answer to this question, it appears first necessary to compare the complexity of EPC for buildings and public lighting. The five aforementioned dimensions can be examined: design, works, operation and maintenance, project financing, and measurement and verification.

Design: design is usually integrated in order to achieve higher energy savings. Lots of data are frequently missing in these types of projects even when the preferred bidder is selected. Time and money spent for data collection (information on buildings / current state of street lighting) are probably similar. However, dynamic modelling and simulation are more complex for buildings since the users (operational hours, behaviours…) have a strong influence on the results. Conversely, user will not interfere with the operation of street lighting system. Moreover, architectural issues are omnipresent in building projects but limited for street lighting.

Works: in both cases, it is necessary to coordinate a large number of subcontractors. Before and during the works, communication with the residents / the users of the buildings is a key action. In the case study, technologies used during the refurbishment of street lighting were innovative. Moreover, 70% of the park was renovated over a three year period. All these elements increased the complexity of the works. The implementation of a centralised control station appears as complex for buildings as for street lighting systems.

Operation and maintenance: in the case of public lighting, it is a standardised process. Unforeseen events are limited (e.g.: light time can be anticipated for the length of the contract). In buildings, it is harder to anticipate the evolution of the activity. For example, occupancy may vary according to the activity from one year to the other. Thus, uncertainty is stronger.

Project financing: there is a large spectrum of financial arrangements. Complexity varies from one project to the other. Apparently, it is as complex for buildings as for street lighting. However, the risk supported by the financing party is probably stronger for buildings because of the frequent gap between predicted energy performance of buildings and measured energy use once buildings are operational.

Measurement and verification: establishing the baseline is probably the most difficult task of EPC for buildings. The conceptual framework published by the U.S. Department of Energy (2015) for quantifying the savings resulting from energy efficiency equipment, improved operation and maintenance, is complex. Even if the steps are well defined, each item is subject to interpretation and several options are available. The public lighting project presented in this paper does not reflect such a high level of complexity.

Table 3 summarises complexity of EPC projects in the cases of street lighting and buildings.

Table 3: Complexity of EPC: public lighting versus buildings

Dimensions	*Level of complexity on a scale going from 1 to 5*	
	Public lighting	*Buildings*
Design	*3*	*5*
Works	*4*	*4*
Operation and maintenance	*2*	*5*
Project financing	*3*	*4*
Measurement & Verification	*1*	*4*

According to table 3 based on the author's experience with EPC in buildings (Bougrain and al. 2014) and the case study, street lighting projects integrating design, works, operation and maintenance, appear much less complex at the operational level than building projects. The absence of users who interfere with the operator and the predictability of most events occurring during the life of the contract, limit the risk. Moreover, the codification of the tasks and the measurability of outcomes are easier to implement. Thus, the control is more effective. Formal contracts seem adapted. Conversely, uncertainty is strong for EPC in buildings. Actions performed by private partners such as ESCO, are difficult to monitor. Users can adopt opportunistic behaviour. To mitigate these aspects, cooperation based on trust is essential for the success of a project.

The limited complexity of street lighting projects at the operational stage, probably explains why these projects represented about 40% of partnership contracts signed by local authorities (table 2). The paradox is that complexity was frequently cited by public authorities to justify PPP for street lighting. Conversely, the high level of complexity of EPC for buildings in operation and the uncertainty attached to this contract, explained probably the infrequent use of EPC in building projects.

5. Conclusions

The case study indicates that EPC for street lighting are very complex during design and construction phases. This complexity decreases when one moves downstream to the operation of the public network. This is due to a diminution of uncertainty: most events having an impact on the performance of the network in operation are predictable. Conversely, EPC in building projects tend to face unforeseen events during the operation: cooperation between occupants and operators is subject to tensions; protocols to measure and verify energy consumption are standardised but their implementation is still complex. This difference of complexity has an impact on the governance of each project. While pure contractual relationships may be adapted to EPC in street lighting projects, relational governance needs to be introduced in EPC for buildings. Trust can compensate the uncertainty surrounding these projects.

By investigating only one case study, the research has limitations. Further research is required to extend applications to this field. It would be interesting to examine how complexity evolves over time and impacts on governance.

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Life-Cycle Economics of Rentable Prefabricated School Facility Units in Municipal Real Estate Procurement

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Abstract

The purpose of this paper is to study the economic feasibility of rentable prefabricated spatial units as a part of the public real estate procurement strategy. Ensuring the resource effectiveness of the municipal real estate procurement is a matter of great significance. In 2013, the gross investments of the Finnish municipalities were approximately 4.7 billion euros from which the investments on real estate were 1.7 billion euros. Thus, the investment decisions should be made based on thorough life-cycle analysis. However, the prevailing practice of public real estate procurement weights strongly on initial costs.

Recently, there have been indications of interest toward industrially produced spatial units. Rapid product delivery times combined with the spatial flexibility provided by the systems can be considered as the main benefits when compared to more traditional forms of construction. Also, the diminishing quality risks made possible by the controlled facility environment in the production phase can be seen as a major advantage. Studied business model – which relies on renting – helps to transfer the risks related to functionality of the building from the municipality to the unit provider. The research hypothesis is that using rentable prefabricated spatial units helps municipalities to avoid costs related to difficulties in predicting future space requirements.

School properties where chosen for the analysis because of the ongoing public debate considering, for example, health hazards caused by mould and moisture damage occurring in this type of buildings. Net present value (NPV) method was used to compare the municipal life-cycle costs of two school property investment alternatives in Finnish context. The comparison was made between municipality developing and owning a school property and renting the wooden spatial units needed.

The results suggest that different kinds of municipalities can benefit from prefabricated rentable spatial units. The feasibility of spatial modules improves compared to the property built using traditional methods the more the amount of students fluctuates during the analysed time period. Additional benefits include the reduced need of school transportation as well as enhanced social cohesion made possible by children attending the school in local neighbourhood together with friends from the same area.

Keywords: Prefabricated spatial units, public real estate procurement, school facilities, municipal economics, life-cycle economics

1. Introduction

Enterprises should always aim to deliver products that meet the customer's needs as well as different legislative requirements as cost effectively as possible (Asiedu, 1998; Janz and Westkämper, 2007; Niazi et al., 2005). Similar thinking can be extended to the public sector and its services, such as education facilities or even entire residential areas. Efficient procurement practices are playing an essential role when striving to meet these goals. Both in the private and public sector, different investment options should always be evaluated using proper tools to guarantee as effective use of resources as possible. This particularly applies to real estate developments since those are recognised as capital heavy long-term investments. Thus, municipalities should be long-sighted when analysing the economic outcomes of these projects.

Recently, there have been indications of interest towards rentable industrially produced spatial units. Rapid product delivery times combined with the spatial flexibility provided by the systems can be considered as the main benefits when compared to more conventional building methods. In addition, the diminishing quality risks made possible by the controlled facility environment in the production phase can be seen as a major advantage. Studied business model – which relies on renting – helps to transfer the risks related to functionality of the building from the municipality to the unit provider. The amount of modules can be swiftly adjusted when there is a change in space requirements, for example, because of demographic changes in the area. Aforementioned leads to the following research hypothesis: Using rentable spatial units helps municipalities to avoid costs related to failures in predicting future space requirements.

In Finland, the school properties have been a topic of public debate in the past couple of years. According to Reijula et al. (2012) 12–18 % of the schools and day cares in Finland are affected by considerable moisture and/or mould damage. Because of this 172 000–259 200 children could be exposed to different health hazards. When thinking of how to replace the school properties that are damaged beyond the renovation threshold, the municipalities are forced to make a decision between renting and owning new properties. The economic impacts should be carefully studied especially when the population of the school-aged children in Finland is predicted to decline rapidly in the future (Official Statistics of Finland (OSF), 2015a). Thus, owning of a permanent solution with possible low utilisation rate in the near future is questionable to say the least.

In this study, the net present value method is used to compare the life-cycle costs of two different kinds of school property investment options from the viewpoint of municipality: First, where a municipality invests to a property which is built using traditional production methods mainly relying on prefabricated concrete sandwich wall elements and hollow core concrete slabs, and second, where the municipality rents the spaces required from the manufacturer of wooden spatial units. What makes this study unique is the fact that it is the first of its kind to combine the predictions of the student population development and the cost data of municipal real estate procurement and thus providing evidence how the variation in the demand of space over time impacts on the economic equation. The next section covers the relevant literature considering public real estate procurement and prefabricated spatial units. In the third section, the data for the analysis as well as applied research method are described. The fourth section presents the results of the LCC-calculations carried out. The final chapter includes conclusions and discussion about the relevance of the results as well as underlines the need for future research.

2. Background

It has been estimated that in 2011 the total expenditure of EU member states on education was on average 5.25 % of their GDP respectively. In Finland, the government carries an essential role in providing educational services thus the corresponding number is a bit higher being 6.76 % (Eurostat, 2015). In 2013, the investments of Finnish municipalities were approximately 4,7 billion euros from which the investments on real estate were 1,70 billion euros (Finnish Ministry of Finance, 2015). It is safe to say that municipal real estate procurement plays a major role from the viewpoint of national economy.

Statistics Finland has presented a projection that the population of children that fall into the category of compulsory education (aged 7–16) will decline rapidly in the upcoming decades *(Figure 1)*. The estimation was made based on the assumption that the birth rate remains constant in the future and the mortality continues to decline in a similar fashion as when comparing the data from 1987–1991 and 2010–2014. Migration is assumed to be 17 000 persons per year between 2016 and 2065. (Official Statistics of Finland (OSF), 2015a.) However, the areal differences in population development should not be overlooked. The demand for educational facilities is likely to continue to increase in the centres of growth and decline elsewhere.

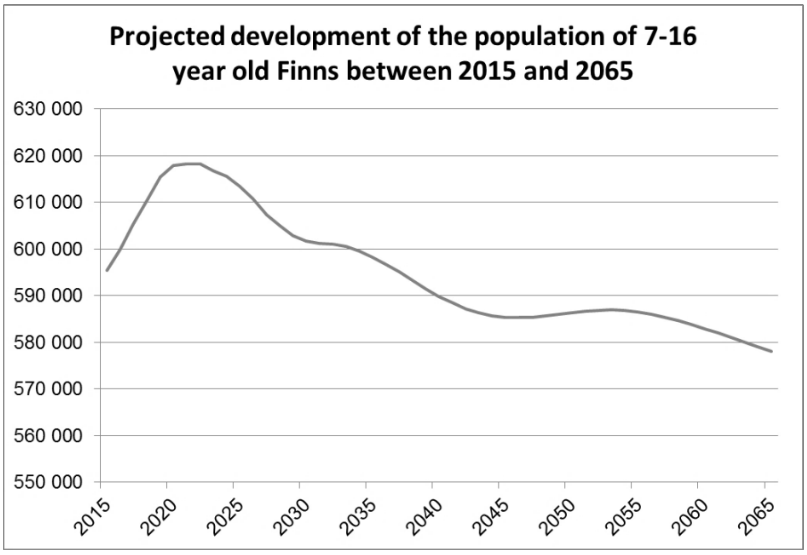

Figure 1: Projection of the development of the amount of children between 7-15 years old in Finland between 2015-2065 (Official Statistics of Finland (OSF), 2015a).

The amount of schools owned by the Finnish municipalities has declined rather rapidly since 2005 *(Figure 2)*. In 2005 Finnish municipalities owned approximately 3 300 school properties and that number has decreased to 2 400 by 2014. However Due to the increase in unit size of new school and tendency to close down the smaller units, this statistic can be deceiving because it does not take into consideration the actual volume of school buildings.

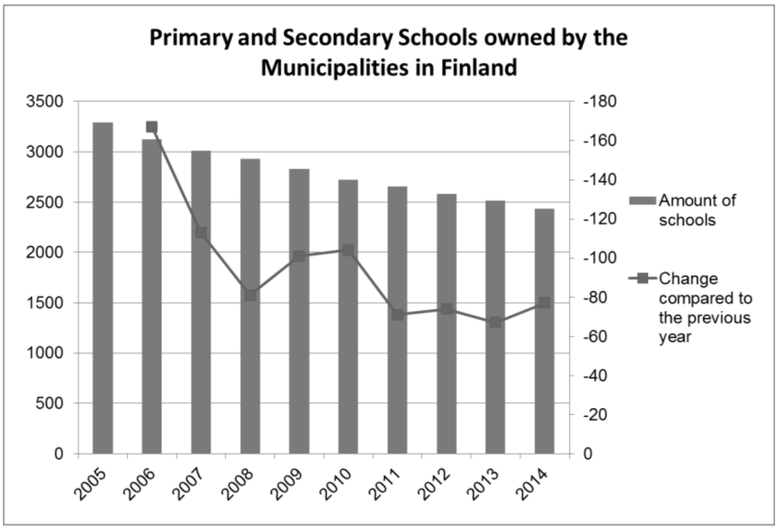

Figure 2: Primary and secondary school buildings owned by the municipalities in Finland between 2005–2014. The line graph presents the annual change (vertical axis on the right).(Official Statistics of Finland (OSF), 2015b)

Public procurement has been covered from many different angles in the existing body of literature. Most countries have a strict legislation considering public procurement of services and goods. Public tendering procedures have been a predominant mechanism for granting construction contracts in municipal sector. Usually the choice between the bidding contractors is made weighing strongly on the tender price. However, there are some studies showing that this practice leads to lacking quality and prolonged project deliveries (Cheng et al., 2000; Drew and Skitmore, 1997). Because public procurement is responsible for significant share of demand of goods and services, it is often seen as major source for potential innovations (Aho et al., 2006; European Comission, 2005; HM Treasury, 2004). However, Edler and Georghiou (2007) argue in their article how despite public procurement representing a key source of demand for the firms, for example, in construction, health care and transport industries, the potential of using public procurement for source of innovation has been largely ignored conceptually as well as in practice.

Environmental and sustainability related aspects of prefabricated buildings are well documented. Jaillon et al. (2009) investigated in their study how utilising prefabrication in building construction could help to mitigate the growing problem of building waste generation in Hong Kong area. They found out that the average waste reduction level was about 52 % compared to the conventional on-site construction projects. Bonamente et al. (2014) used LCA approach to model carbon and energy foot prints for different size buildings. The results indicate that the main environmental impacts arise from the operational phase of the buildings. Similar results were found by Faludi et al. (2012) who studied the life cycle impacts of a 5000 ft^2 prefabricated commercial building constructed in San Francisco. However, it was also stated that in the case of nearly zero energy buildings impacts from manufacturing are the most dominant. Pons and Wadel (2011) concentrated specifically on the environmental impacts of prefabricated school buildings in Catalonia. Using simplified LCA modelling, they compared the CO_2-emissions of four technologies; non-prefabricated building technologies as well as prefabricated school facilities made out of wood, steel and concrete. The results show that prefabricated solutions have lower environmental impacts through analysed time period. However, according to the study there is still room for improvement in the processes to further reduce the CO_2-emissions and especially the waste generation related to manufacturing and recycling.

The economic literature considering prefabricated spatial units is very limited. The report of National Audit Office (2005) claims that in British context construction projects carried out using modern methods, such as modular spatial units, are usually more expensive than the ones applying the more conventional methods. However, there is an overlap in the price ranges thus in certain conditions modern techniques could prove to be more cost effective. Pan et al. (2005) argue in their study which is based on survey of the top 100 housebuilding firms in UK that the cost savings of the off-site manufacturing are achieved, for example, in the areas of reduced risks and maintenance costs, shorter construction times and cost certainty.

This study contributes to the existing body of literature by being the first to focus on the municipal school property investment in Finnish context by combining the official cost data from various sources and the student population projection provided by Statistic Finland. The result is the most comprehensive analysis yet regarding the subject and can be used as a starting point when aiming for decision-making based on facts in the field of public real estate procurement.

3. Data and Methodology

In this paper, life-cycle cost (LCC) analysis is carried out to compare the economic feasibility of two different educational facility investment alternatives from the perspective of a municipality. The analysis was made between renting a school property built using prefabricated spatial modules, and the traditional alternative, in which a municipality invests to a new property and owns a building after development is finished. The analysed investment alternatives are not based on real-life counterparts. However, the cost data used in the analysis is gathered from different official sources. The main purpose is to provide information about the economic feasibility of rentable spatial units compared to more conventional method of construction by taking into account differing costs of the investments throughout their life-cycle. Also, the presented approach makes it possible to figure how the changes in the student population impact on the economic feasibility of the studied alternatives.

3.1 Data

For the purposes of the LCC calculations the data was acquired from various official sources to perform a comparison between the studied investment alternatives. The values of different variables and the data sources are listed in *table 1*.

Table 1: The municipal expenditures of the analysed investment alternatives.

Municipality invests to a new school property			**Municipality applies rentable prefabricated spaces**		
Variable	**Value**	**Source**	**Variable**	**Value**	**Source**
Amount of students	250/214	Official Statistics of Finland (OSF), 2015a	Amount of students	250/214	Official Statistics of Finland (OSF), 2015a
Required floor area	4 500 m^2	Finnish National Board of Education, 2012	Required floor area	4 500 m^2	Finnish National Board of Education, 2012
Investment cost	2 308 €/m^2	Haahtela and Kiiras, 2015	The costs of foundations and utilities	103 €/m^2	Haahtela and Kiiras, 2015
The cost of maintenance	8,2 €/m^2	Lonka et al. 2012	Transportation and installation	250 €/m^2	Parmaco Ltd., 2015
The annual growth rate of real maintenance costs	2,8 %	Official Statistics of Finland (OSF), 2015c	Monthly rent	14 €/m^2	Parmaco Ltd., 2015
Annual inflation rate (15 year average)	1,8 %	Official Statistics of Finland (OSF), 2015d	Annual inflation rate (15 year average)	1,8 %	Official Statistics of Finland (OSF), 2015d
The annual cost of technical deterioration	2,3 % of the investment cost	Nippala et al. 2006	The annual real increase of the rent	1,2 %	Parmaco Ltd., 2015

City of Kouvola was chosen as the location for the theoretical example for a school facility investment. Kouvola is situated in southeast Finland about 140 kilometres northeast from the Finnish capital Helsinki. In the end of 2013, the population of Kouvola was 86 926. Kouvola was chosen for the study area because in 2014 a school for approximately 250 students situated in the city was closed down. Another reason for the selection is the fact that according to Statistics Finland the population of the city is declining (Official Statistics of Finland (OSF), 2015e) which supports the assumptions made in the analysis. All of the expenditure variables are presented in the current price-level of Kouvola region.

Only the costs differing between the two investment alternatives were taken into account. In Finland, the technical quality of the new production practically always follows the requirements set in the part D3 of the National Building Code (Finnish Ministry of Environment, 2011). It defines the minimum requirements considering the energy efficiency of new buildings. Thus, the specific heating energy consumption (kWh/m^2) can be assumed to be similar between the two studied alternatives. When combining this fact with the predominant position of the district heating in the Finnish building stock, the utility costs in the both alternatives are very similar and thus are omitted from the analysis. Land value is not considered in the analysis based on the fact that comparison is made between two exclusionary investment alternatives for the same geographical location. In both cases, the floor area of space required is expected to be the same 15 m^2/student. The main differences between the investment alternatives are the large initial capital cost and the cost of maintenance and technical deterioration included in the alternative where municipality invests to a new school property. The costs of maintenance as well as the cost of deterioration are included in the monthly rent in the second alternative. However, also in the case of rentable spatial units there are some initial construction costs including the building of foundations and surrounding utilities as well as the costs of transportation and installation of the units. The cost information regarding the rentable spaces was provided by Parmaco Ltd. (www.parmaco.fi) which is one of the few manufacturers in Finnish real Estate market producing and renting spatial units aiming to reach similar architectural and technical quality as more conventional developments.

In this study, the residual value of the investment alternatives was ignored. This is mainly due to the fact that if municipality procures the spaces using the renting model the ownership of the modules stays on the manufacturer who will reclaim them after the service agreement ends (if there is no redemption rights clause in the contract). In the case of municipality developing and owning a new facility, the residual value is really hard to define. Technical value based on the age of the building can be quantified using various methods but the specific characteristics of education facilities make this problematic. Large school facilities are not often appealing from the perspective of real estate investors. Usually they require significant amount of alterations to modify the spaces to support other possible activities. In the case of demolition, residual value can even thought to be negative if the costs of the demolition process and waste management are taken into consideration.

3.2 Net Present Value method

Net present value method (hereinafter referred to as NPV) can be used to estimate the life-cycle costs of the investment alternatives. The NPV method is based on the time value of money, meaning that a cash flow in the future is less valuable than an identical cash flow today. The two most central reasons behind this phenomenon are inflation/deflation and a simple fact that a present cash flow can be invested immediately to earn future returns, whereas a future cash flow cannot be invested yet. The NPV method takes the time value of money into consideration by discounting the future cash flows by an appropriate discount rate. The mathematical form of the NPV equation used in our model can be written as follows:

$$NPV = \sum_{t=0}^{n} \left(\frac{Expenditures_t}{(1+r)^t} \right) \tag{1}$$

Where: t = cash flow period
r = the chosen discount rate
n = calculation period

In the model the cash flow period (t) is one year, whereas the analysed calculation period of a development project (n) is 26 years. Choosing a proper discount rate (r) is one of the most crucial elements in any type of medium- to long-term investment calculation. The discount rate describes the yield requirement for the investment, including the perceived risks, capital costs as well as desired profits. As a rule of thumb, the minimum discount rate should be at least high enough to cover the financing costs of an investment. A high discount rate gives more weight to cash flow events at the beginning of the analysed life-cycle. Thus, usually investments with low initial capital costs seem more tempting when using high discount rates. Instead, the lower the discount rate, the more the impact of the cash flow events occurring further in the future will have on the results of the analysis.

There is an extensive academic literature on the uncertainty related to public investments and selection of a proper discount rate (e.g. Arrow and Kruz, 2013; Arrow and Lind, 2014). Woodward (1997) states in his article that the appropriate discount rate in LCC analysis varies from 3 percent to over 20 percent depending on the nature of the investment and investor. For the purposes of this analysis, a real discount rate of 5 percent is used. A real discount rate does not include inflation/deflation, whereas the so-called nominal rate does. Whenever a real discount rate is used, the cash flows discounted must be presented in real values as well. The utilisation of real rates and costs is chosen because it is really hard to predict the inflation for long calculation periods. The significance of this matter grows the longer the calculation period is.

4. Results

The economic feasibility of school facility investments was studied comparing two alternatives: First, where a municipality invests to a property which is built using conventional construction methods, and second, where the municipality rents the spaces required from the manufacturer of wooden spatial units. In addition, two alternative student population development scenarios were studied. One where the amount of students stays constant through the studied time period and other where there is a decline in student population. The decline was modelled based on the estimation presented by Statistics Finland.

The results based on the calculation scenario where the amount of students is assumed to stay constant throughout the calculation period (2015–2040) are presented in *Figure 3*. It is noteworthy that the renting model does not include costs for the first year of the studied time period. This is based on the assumption that after the foundations and other preliminary works are finished the modular building system is really fast to put together. However, when building using more traditional methods, the development will take at least a year for the project of this scale. From the figure can be seen that the cumulative discounted costs of the renting model by pass the ones caused by owning the property in 2037 (22 years after the start of the development). In other words, if the purpose of the municipality is to own and use the property longer than 22 years it is more cost effective to develop and own the property. Alternatively, if the strategy is to keep the property only as long as the students can be located to other facilities in the area and the required time is shorter than 22 years the renting model will be a better choice from the viewpoint of economics.

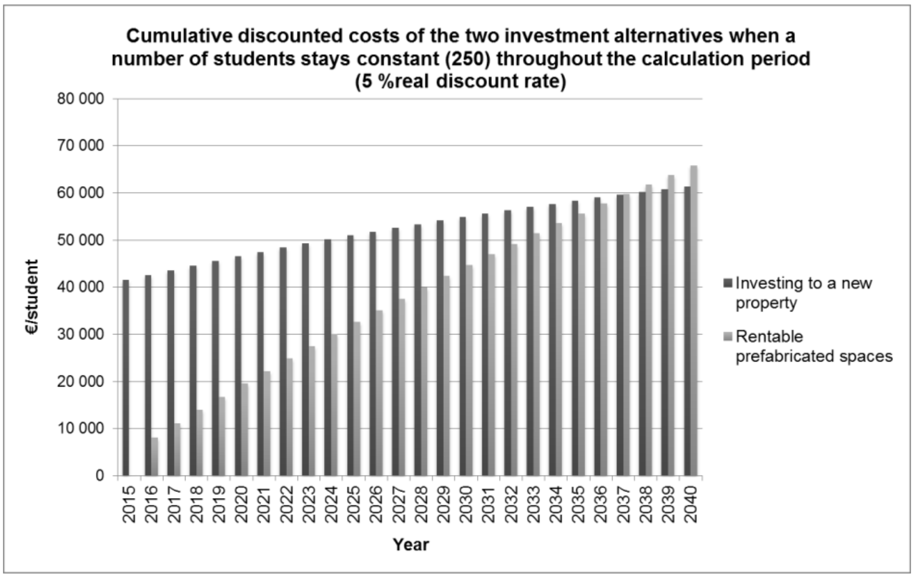

Figure 3: Cumulative discounted costs of two studied investment alternatives assuming that the amount of students stays constant during the calculation period.

One benefit of the rentable prefabricated modules is the fact that the system is spatially very flexible and responses well to changes in space demand. The calculation results presented in Figure 4 support this claim. This scenario is based to a projection made by Statistics Finland about the population development of school-age children in Kouvola, Finland. In 2015, the student population is assumed to be 250 and according to the projection it decreases to 214 by 2040. In addition, the amount of spatial units is adjusted in every ten years (2024 and 2034) by removing the units not needed anymore because of the decline in the student population.

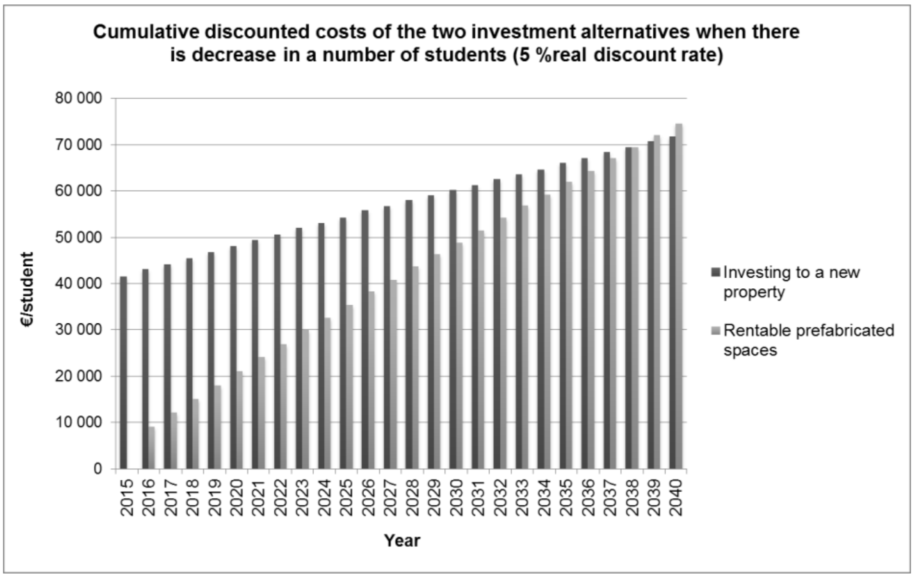

Figure 4: Cumulative discounted costs of two studied investment alternatives assuming that the amount of students declines during the calculation period according to projection made by Statistics Finland.

By comparing the previous two figures it can be seen that the decline in the student population favours the rentable spatial units because of the system's ability to adapt to a new situation. The break-even point moves to year 2039 which means that that renting the facility is now more profitable if municipality plans to own the property 24 years or less. It should also be noted that the selection of the discount rate affects a great deal to the results. The higher the discount rate, the more it favours the renting model. This is due to the fact that high discount rates favour the investments with low initial cost, and the significance of the future renting costs diminishes.

5. Conclusions and Discussion

It is foreseeable that different kinds of municipalities can benefit from prefabricated rentable spatial units. The results presented in this paper suggest that rentable prefabricated spatial units should be considered as an option especially in municipalities that have an uncertain future and thus will have a decrease in population of school-aged children in forthcoming decades. The same phenomenon is present also in growing cities where the amount of children may vary drastically by city districts. The feasibility of rentable spatial units improves when comparing to a property built using traditional methods the more the amount of pupils fluctuates during the analysed time period. Also it is worth mentioning that avoiding the unnecessary transportation of children brings many economic benefits, reduces the environmental impact, and may even enhance social cohesion when the children may attend the school in local neighbourhood together with friends from the same area.

It should be noted that the holistic economic analysis considering the procurement of any public construction project is far more complicated issue than just an LCC-calculation covering the variables related to building and maintaining properties. Every project is its own unique entity requiring customized analysis to determine the best performing procurement method. Regarding the educational services, there are many real-life cases where municipalities have tried to achieve budgetary savings by closing out schools and locating the students to other schools in the region. Usually the savings have not been reached because of the analyses are not including all of the externalities caused by the change. For example, closing down a school usually leads to costs in other areas such as transportation, re-establishing the teaching groups elsewhere, the necessary spatial modifications in substitute school, lost state subsidies, etc. Evaluating different alternatives is a complicated task. However, because of the long lasting effects and capital heavy nature of these investments, the tools and decision-making should be approached with the significance of the matter in mind.

One interesting, yet underexplored, area is so-called hybrid-models where permanent parts of the property are complimented with the prefabricated spatial units. This would enable to capitalize on the benefits related to both systems. This kind of system when in balance would make the use of the cost effectiveness of conventional construction methods and the spatial flexibility of prefabricated spatial units. However, if the Finnish municipalities continue to rely heavily on owning the public properties and procurement procedures emphasising strongly the role of the initial investment costs, the focus should be on flexible designs where the alteration of use can be carried out with minimal changes leading to increased resource effectiveness.

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Water Gaps Connecting Neighbours from Conflict to Co-operation by Applying Scarcity Index

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Abstract

According to the latest reports of United Nations, the biggest challenge facing the world at the present and in the next decades is water scarcity. Trans-boundary water resources from history to present either lead to cooperation or to confrontation and conflicts.

For the last six decades, it has not been possible to solve the Arab-Israeli conflict, and the water issue has been raised as one of the keys for solving the conflict or having a successful discussion.

The history of the water conflict in the Middle East began by the foundation of the Israeli state in 1948. Since that time Israelis have tried to secure the state water supplies using different water resources in the area. The rapidly growth of the driving forces (Nexus) has become a source of numerous conflicts with their neighbours.

The whole area has suffered from water shortage and unsuccessful managing of the water resources. Palestinians, Israelis, Jordanians, Syrians and Lebanese are sharing the major part of their water resources, the Jordan River and the aquifer of the West Bank and Garza Strip being the main sources of water resources for Israelis and for the Palestinians. Dividing the land will not be a solution to water gaps. It is likely to make the situation even worse.

Several methods and tools have been developed worldwide to assist the riparians to manage their own shared water resources, part of which are technical and other social -political methods. Scarcity index is one technical numerical method developed to assist the parties to allocate the shared water resources and to assist on recovering the water gaps. Based on the mentioned methods numerous agreements have been made and discussions have been held between the riparians to achieve peace and co-operation. Some of them have been implemented, the other remain open due to the political changes in the area.

Keywords: modelling trans-boundary water resources, water conflict, water balance and scarcity, Middle East water

1. Introduction

Worldwide water resources are unevenly distributed and they are generally scarce in arid and semi-arid zones such as the Middle East. Lack of water, growth of tensions, distrust as a consequence of poor relations, use of force to solve conflicts and inefficient management and use of water resources are the problems besetting water resources and the Arab-Israeli shared natural resources in particular.

This paper aims at contributing to resolve the complex relationship between riparian parties resulting from mutually shared and limited water resources in general, with special focus on the Israeli-Palestinian shared water resources.

The specific purpose of the paper is to find sustainable ways to evaluate and allocate trans-boundary water resources and to determine the scarcity of water resources in the Israeli-Palestinian area.

This paper refers to a model for calculating and evaluating the water scarcity index for the present as well as for the long-term future based on analysing the rules of the international water law and the role of the United Nations in sharing and allocating the shared water resources. The computation is based on evaluating the expected demand as a consequence of population growth.

This scarcity will increase with time due to the rapid population growth, drought, as well as other constraints. With the expected population growth the gap will be approximately some 40 percent in the Palestinian and 60 percent in Israeli areas by 2020. There is an urgent need to maintain a balance in water use between the parties in the area, to reduce water scarcity, as well as to bridge the water gaps.

A joint vision based on sustainable development is formulated for the application at hand as well as alternative scenarios. The one based on joint cooperation is selected. For implementing this scenario, alternative strategic means are presented. They include especially minimizing water use, re-using the water, looking for new options for increasing the total number of water sources, and strengthening the cooperation between the parties. To support the developed model, integrated water resource management, building of institutions and development of human resources are investigated and some alternatives are suggested.

Since the water scarcity around the world can be a result of lack of accessibility, water quality deterioration, fragmentation of water management, decline of financial resources, lack of awareness by decision makers, and endangering world peace and security. The Palestinian and Israeli water conflict is an example including of the two last parameters.

When considering the major driving forces that determine the development of the mankind and its environment, we have to first set the time scale that we want to look at. To put the analysis in the framework of sustainable development, the most appropriate scale would be one generation backward and one ahead. This scale is typically used in global assessments. In this frame, the following issues are the major driving forces:

- Population growth, especially in the developing countries

One indicator for the water scarcity based on this driving force is explained later in this paper (Asheesh scarcity index), in which the author completed his case study 2002.

- Urbanization and other patterns of migration
- Changes in climate, environment, and nature
- Economy, and human capital, technology, and industrialization.

The main question which should be asked is how we can control these forces and how the international community controlled them during the last three decades.

One driving force of the above mentioned clearly appearing currently in the whole world is the migration to Europe which is a consequence of unsustainability and lack of water resources which is related to domestic use or agriculture in which will effect food production aspects and energy need (the Nexus).

2. Water sharing and riparian rights (international and national level)

The Israeli-Palestinian Water Joint Commission (WJC) announced a joint declaration for keeping the water infrastructure out of the cycle of violence and from becoming a source of conflicts. The Israelis and Palestinians view the water and wastewater sphere as the most important matter and strongly oppose any damage to water and wastewater infrastructure. The two sides are taking all possible measures to supply water and treat wastewater in the West Bank and Gaza Strip, even in the difficult circumstances of the Intifada movement that started in 2001. The two sides wish to bring to public attention that the Palestinian and Israeli water and wastewater infrastructure is mostly intertwined and serves both populations. Any damage to such systems will harm both Palestinians and Israelis.

In order to for this effort to succeed, the joint commission works based on mutual cooperation and support of all the population, both Israeli and Palestinian. The general public is asked not to damage the water infrastructure in any way including pipelines, pumping stations, drilling equipment, electricity systems and any other related infrastructure. The two sides also call on those involved in the crisis not harm water resources, the professional teams that conduct regular maintenance or repair damage and malfunctions to the water and wastewater infrastructure. Both sides wish to take this opportunity to reiterate their commitment to continued cooperation in the water and wastewater spheres.

In the United Nations proposal for water management and international sharing of water resources declared in 2000, the right to water was one of the essentials to be achieved, right to a standard of living adequate for the health and well-being of himself and family" (Universal Declaration of Human Rights Article 25, United Nations 2000). The right was to be for everybody regardless of his/her financial status. In recognition of the absolute need for water for survival, governments should regard the quantity of clean water necessary to ensure a decent standard of living for all people as sacred. An adequate supply of water must also be reserved for preservation and natural regeneration of the environment. Priority should be given to allocating the limited water resources according to the purpose of the use (Asheesh, 2003).

In the Palestinian-Israeli case the inhabitants of Israel and the Palestinian Territories share their main sources for drinking water. The largest resource is the Jordan River. Compared to other rivers in the Middle East like the Euphrates, the Tigris or the Nile, the Jordan River is a rather modest one – in length as well as in flow. Its main tributaries are the Hasbani, Dan, Baniyas and Yarmuk. The first three rivers converge in Israel, north of the Lake of Galilee, to form the upper Jordan River. Only the Dan originates within Israeli borders. The Hasbani springs lie in the part of Lebanon that was until June 2000 incorporated into the occupied Israeli security zone in southern Lebanon, and the Baniyas water drains from the Golan Heights – a territory formerly under Syrian control and since the war of 1967 occupied by Israel (Asheesh, 2003).

A holistic view needs to be taken of the water resources problem in the Arab world including the Israeli territory. The following aspects should be considered: Water requirements are calculated on a minimum basis known as "minimum water requirement" (MWR) which is 1,200 cubic meters/year (CM/Yr). The population of the Arab world is presently nearing 235 million; the quantity of available water per person is about 750 CM/Yr, which is below the MWR. If the population reaches 295 million by the year 2020, then a person's share of water will drop to 575 CM. If the average population growth is 25 per thousand, then the water requirement will reach 295 billion CM by the year 2020, i.e., a deficit of 120 billion CM. (Tamimi 2012).

Water struggles and water resources conflict will be always the key for peace and stability in the area. Using force over water resources undermine these goals in long term. For example the Nile conflict and water allocation have been between the parties. Appeared after almost 100 years. The Kenyan government decided to build a new dam to secure their sustainable water resources and energy. The Arab-Israeli water conflict parties should learn a lesson from this case. The water issue always weave as the most difficult and changeable issue of the five conflict issues in the Palestinian and Israeli the other issues in dispute, Jerusalem, borders, settlements and refugees are not so susceptible to the same effective and often usefully politically silent solutions provided by socio-economic development.

2.1 Framework for negotiation and cooperation

It has been widely accepted that the political, economic, social, technical and environmental (PESTE) and resource problems directly affect regional and international security. Although these PESTE aspects have not been so far sufficiently incorporated into the approaches to reduce the risk of water conflict, a framework needs to be constructed that encourages scholars and policymakers to apply new tools, to set new priorities, to organize responses, to recognize water rights, share control and monitoring and portioning of water resources and to eliminate a range of environmental threats to peace and security (Asheesh 2001a). Based on the mention the main question is how a Palestinian State should approach the principles of sovereignty and cooperation over water.

In October 1994, a peace treaty between Israel and Jordan was signed which addresses water allocations, sharing of water information, and joint management policies for the Jordan River Basin. The Convention on the Non-Navigational Uses of International Watercourses based on article 6 of the treaty reads as follows:

The Parties agree to recognise the rightful allocations of both of them to the waters of the Jordan River and the Yarmouk River and Araba/Arava groundwater in accordance with principles set in Annex II of the Jordan Intelligence Agency agreement (JIA 1998).

The Parties jointly undertake to ensure that the management and development of their water resources does not harm the water resources of the other party.

The Parties recognise that more water, to meet their needs, should be supplied through various methods, including projects of regional and international cooperation.

Parties agree to search for ways to alleviate water shortage and to co-operate in the following fields:

- Development of existing and new water resources
- Prevention of contamination of water resources
- Mutual assistance in the alleviation of water shortages
- Transfer of information and joint research and development in water-related subjects.

Unless all the people who depend on the resources concerned are included in the agreements, conflicts will pertain. In particular, definitions of equitable utilisation of existing water resources must be negotiated and applied. These negotiations include discussing the priority of using the resources, like in the Israeli-Palestinian and California cases and other cases in other parts of the world, to resolve the wrestling between the demand for domestic and agricultural or urban and rural sector (Gleick 1996). The framework for cooperation will help in the formulation of criteria and prioritisation of the realisation of any of the proposed activities. As the water authority in the area is presently unorganised and the water itself is a quickly diminishing natural resource, direct involvement and efficient cooperative water administration is obviously essential and thus this factor cannot be handled separately from the technical issues.

Based on the above mentioned understanding between the both sides, the Palestinians and the Israelis, the joint water institutional framework could strengthen the management of the operation and maintenance of the shared water resources.

The precondition for formation of such a framework is that the respective parties start to base their understanding of the need to improve the water situation on trust, good faith and respecting each other’s sovereignty. In this way using the water resources may happen in a reasonable and equitable way in accordance with the rules of the international joint committees (Israelis and The Palestinians). A joint water framework may be built first through negotiations about allocation the shared water respecting the hydrological distribution of the sources (and not according to geographical areas) and second in spirit of cooperation.

In light of the above, the following joint water framework could be considered in Palestinian-Israeli negotiations over water issues. The joint institutional framework illustrates the future administration and management functions in the area (Figure 1).

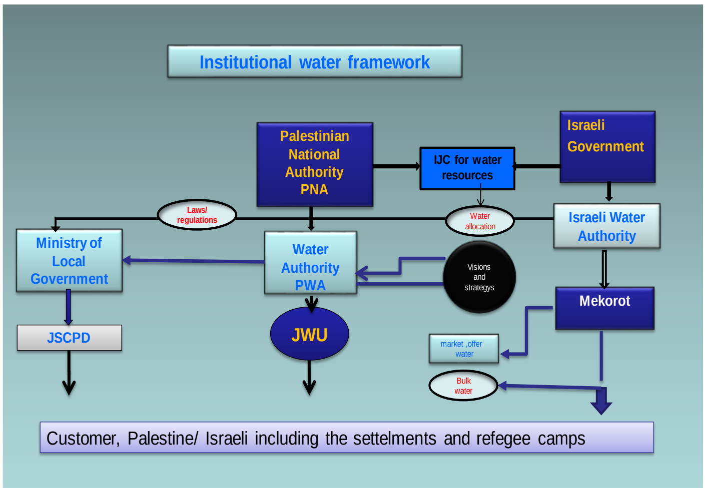

Figure 1 Institutional framework for arrangement of water resources and services

The role of the Water Authorities of both sides is to control and monitor the shared resources, since the sub roles of Jerusalem Water Undertake (JWU) and Joint Services Council Provider Department (JSCPD) to provide the services to the Palestinians side and Mekorot (Israeli water providers) to the Israeli side are essential to the framework.

The framework for cooperation should include the management of wastewater also, which poses a risk to the environment, since the groundwater lies relatively close to the surface and is easily contaminated (Nashashibi 1995). There are only a few wastewater treatment plants in the area, and the wastewater network is not large enough. Consequently, proper planning and locating of treatment plants and expansion of the wastewater network make up an important part of this research. Water re-use, which represents a new possibility to increase water resources in the area, can eventually help conserve significant amounts of fresh water, but much more research is needed to determine how water could be re-used in agriculture and industry.

According to (Kuttab & Jad 2000), three major issues concerning the Israeli-Palestinian conflict have to be analysed and ranked with regard to cooperation in water resources by the Palestinian West Bank and Gaza Strip Territories and the Israeli state.

The first issue relates to water resources that originate and are discharged completely in the Palestinian West Bank and Gaza Strip. The most obvious example of this sort is the Eastern aquifer resulting from rains within the catchment area east of the hydrological line that crosses the West Bank towards the Ghor Valley.

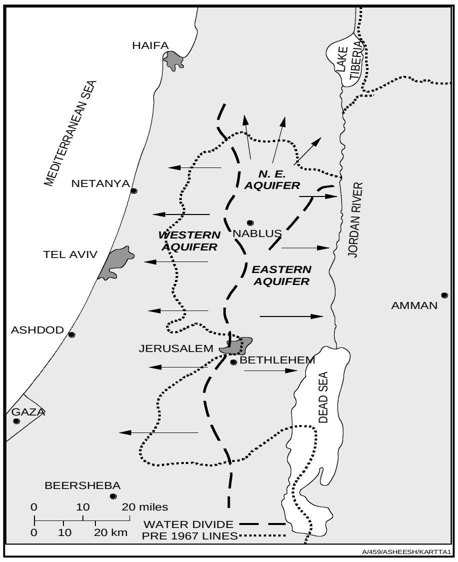

Figure 2 The hydraulic line locates the aquifer basin in the West Bank (Asheesh 2003)

The Israeli West Bank Mountain Aquifers have three general basins. The west aquifer, providing more than a half of the total yield in Israel, is called the Taninim aquifer, the second aquifer is the northern aquifer and the third one is the eastern aquifer. The last one lies on, and enters the West Bank. The second and the third aquifers as well as the most important west aquifer, qualify as trans-boundary basins, and any water distribution solution should be based on principles of sharing the watercourses under international law.

The second issue relates to the riparian waters, which flow into the Jordan River. The Palestinians in the West Bank together with Jordan, the State of Israel and Syria share these resources. Despite the absence of clear precision, there are sufficient guidelines in international law pertaining to surface water.

The third issue pertains to water resources resulting from rainfall in areas west and northwest of the hydrological line and which feed two main aquifers that are shared with the State of Israel. The major portion, about 80 percent, (Asheesh 2000) of the waters in these aquifers originates from the West Bank catchment areas.

The aquifer itself flows and actually straddles the border between the two areas with the majority of it found in the West Bank Territories. The consumption of water based on withdrawal from those aquifers (the eastern and northern aquifer) it shows that the main and the biggest share is consumed by the Israeli settlements in the West Bank area.

Since the shared water resources between the neighbours are the main issue for peace and security, the cooperation on the operation and maintenance of the water system in general is the main key in the hands of the decision makers on solving the gaps of water in the current situation and securing the demands for long term. The joint institutional water framework to joint water authorities on both sides, water Authorities which can be based on the recognizing the right of both nations and based on the international water right declared by the international water law.

3. Indicators for International Water Gaps and Water Stress

In the past 20 years many indices have been developed to quantitatively evaluate water gaps and needs. Several indicators has been made to avoid conflict and to promote the cooperation and to prevent the conflict, struggles and distrust of controlling of the water resources.

The Falkenmark indicator is perhaps the most widely used measure of water stress. Gleick (1996) developed a water scarcity index as a measurement of the ability to meet all water requirements for basic human needs. Ohlsson (2000) integrated the “adaptive capacity” of a society to consider how economic, technological, or other means affect the overall freshwater availability status of a region. The UNDP Human Development Index (HDI) is a widely accepted indicator used to assess these societal variables. The International Water Management Institute (IWMI) used a similar water scarcity assessment though on a slightly larger scale across the entire globe. They conducted an analysis that considered the portion of renewable freshwater resources available for human requirements (accounting for existing water infrastructure), with respect to the main water supply.

Indicators of physical water scarcity include: acute environmental degradation, diminishing groundwater, and water allocations that support some sectors over others (Molden, 2007). Countries having adequate renewable resources with less than 25% of water from rivers withdrawn for human purposes, but needing to make significant improvements in existing water infrastructure to make such resources available for use, are considered “economically water scarce” (Seckler et al., 1998).

Freshwater scarcity is commonly described as a function of available water resources and human population. These figures are generally expressed in terms of annual per capita water and mostly on a national scale. The logic behind their development is simply that if it is known how much water is necessary to meet the human demands, then the water that is available to each person can serve as a measure of scarcity and these human demands (Asheesh 2003) (water right) can be identified by the riparian themselves. This can be schemed and established the visions and strategies of the shared water resources (the case of the Palestinians and the Israeli shared water).

4. Water Scarcity Based on Papulation Growth (the scarcity index)

Combining the population growth with the minimum water requirement (MWR) water gaps have been calculated, Table 1 illustrated the water gaps for some of the Middle East countries. This estimation was made disregarding the impact of the Syrian civil war. Since the war started in Syria millions of Syrians escaped from their homes to the neighbouring counties like Jordan, Lebanon and Turkey, which most likely escalates the water stress in those countries.

Based on the population growth the prediction equation1 is illustrated as follow:

$$A_n = A_x\left(1 + {}^{p}\!/_{100}\right)^n$$

Equation 1

Where

A_n: number of inhabitants

A_x: Current number

P: Growth percentage

n: Prediction length

To apply the term of minimum water requirement for all parties the following calculation for water projection for 2015 illustrated in Table 1 was carried out.

Water shortage can be calculated according to water minimum water requirement illustrated in the table1. The total water requirement used in the table assumes that the riparian are using the potential water resources in equitable reasonable way. Water uses in the area are divided as follows: domestic use 120 m3/C/Y (Shuval 1994) in addition to the demand for the industrial uses is 10% 25% from the total use, and 70% for the agricultural uses. The Israelis currently are using 300 l/c/d in the settlement areas for different purposes.

Table 1 Minimum water requirement for some of the Middle East countries

Area	*Population in 2013*	*Population in 2025*	*Water resource potential (Million m3/Y)*	*Total water per capita per year in 2013 (m3/P/Y)*	*Total water per capita per year in 2025 (m3/P/Y)*	*Total MWR in 2025 (Million m3/Y)*	*Total excess or shortage (Million m3/Y)*	*Growth rate (%)*
Israel	*8*	*9,5649*	*1500*	*187,50*	*156,823*	*2152,113*	*-652,1127*	*1,50*
Jordan	*8,5*	*13,6088*	*1100*	*129,41*	*80,830*	*1117,621*	*-17,6206*	*4,00*
Palestine	*3,88*	*5,8629*	*300*	*77,32*	*51,169*	*481,494*	*-181,4945*	*3,50*
Syria	*18,2*	*25,3506*	*10500*	*576,92*	*414,191*	*2081,921*	*8418,0795*	*2,80*
Lebanon	*5,8*	*6,8530*	*3700*	*637,93*	*539,906*	*562,806*	*3137,1938*	*1,40*
Turkey	*79,4*	*94,9321*	*105000*	*1322,42*	*1106,054*	*7796,297*	*97203,7027*	*1,50*
Egypt	*89,85*	*135,7695*	*60000*	*667,78*	*441,925*	*11150,072*	*48849,9283*	*3,50*

4.1 Water scarcity and the balance of water resources based on the scarcity index calculation

Balancing of the system is accomplished by covering the gaps or preventing the depletion of water resources and monitoring the relation between the inputs and outputs of the system *equation 2 is* presenting the parameters related to the balancing the system. In the case of depleted national or international river basin aquifers, covering of gaps or controlling and stopping the flow of the shared transboundary aquifer can be an alternative to balancing the situation inside and outside the system on the national and the international level, the scarcity index is an indicator that shows developments in the water situation of a riparian country. It points out the size of the gaps that should be covered or amounts to be returned into the system in order to secure the balance between available water and water demand.

$$W_{sci} = (W_{av} / W_{tad}) - 1$$

Equation 2

Where

W_{sci}: Water scarcity index

W_{av}: Available water resources in shared basin (in the state)

W_{tad}: Total annual demands for all riparian/states

The scarcity index developed reflects the relationship between the water system inputs and outputs from the system based on population growth in a given time. The scarcity index is expressed as a shortage or gaps (expressed as percentages), as the relationship between the parameters of available water and demands as illustrated in Equation 3. The main element of the equation is population growth, which determines all demand parameters in the water sector.

$$Wsci = \left(\frac{\alpha}{\left(\left[\frac{100}{100-p} \right] \beta \exp^{\lambda \Delta t} (\varepsilon + \gamma + \delta) \left(\frac{100}{100-\kappa} \right) + h + b \right)} \right) - 1$$

Equation 3

Where:

W_{sci} : Scarcity index

α: Input into system (A or B riparian)

ε: Annual domestic demand (m3/c/y)

γ: Demand for green areas (m3/c/y), it depends on population growth

δ: Demand for irrigation (m3/c/y)

λ: = Ln (1+r), population growth rate

Δt: Length of time for which the estimation is made, the period can be calculated as the difference between the present and the future (t-k);

β: Population

t: Present time

h: Yearly evapotranspiration of water, depends on climate of country

b: Water needed to maintain the environment, depends on the length and depth of the water body

k: Estimated losses

p: Industrial demand as a percentage, depends on country structure, its value can be determined as 15-25 percent of the domestic demand

5. Conclusions

Over more than 30 years in conferences and seminars worldwide, experts have been talking about managing the international water resources and improving the cooperation between the riparian parties. All these talks and papers remain a theory. Still the United Nation agreements and conventions remain on paper and not binding any party. The riparian parties are not learning the lessons and there is more and more suffering due to water gaps and water stress. In this paper two Mathematical methods were illustrated to help the parties in allocating the shared water resources, the two methods, the minimum water requirement (MWR) and the scarcity index, are just a tools developed to help the riparian to manage their national water resources also.

While the MWR method gives an indication of the shortages for a certain period, the second tool describes in detail the water gap and the way how to save water and how to control and recover the gap.

Since these two methods and worldwide others methods developed to assist the international community to avoid conflicts but few of those riparian are considering and applying them. Several of the riparian are using water as a weapon and water resources as a good to solve country economic crises in the upstream downstream cases.

In global scale a lot of tools and methods have been developed, water engineers finding them as useful tools, but unfortunately the decision makers are not understanding the means of these tools.

The International Joint Institutional Water Framework in the areas of conflict can be also one tool to push the parties for cooperation, the role of the international community as a mediator is to support the decision makers in being active to support their local water authorities to participate in the established joint Institutional Framework and as well as developing the joint capacity building programme.

Clearly, migration to Europe as a consequence of unsustainability and lack of Nexus is a phenomenon affecting the whole world currently. Water rights and international law should be followed and recognized. Cooperation between the riparian should be continued even when players at high political levels are changing. Exchanging the data related to renewable water, operation, demand and services on all levels should be continued.

Implementation of the United Nations' rules to riparian should be done to all shared water resources without any enforcement limitation.

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Mediation in Construction Disputes: A Review of Turkish Case

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Abstract

Construction contracts often become subjects of disputes, mostly as a result of multiparty, time barred and complex nature of construction projects. Construction disputes are remarkable both by their values and numbers, so it takes money and time to resolve them. Although litigation is the customary way of resolving construction disputes, alternative dispute resolution techniques have been developed to obtain shorter and better dispute resolution. Mediation, for example, as an Alternative Dispute Resolution (ADR) method is viewed as "beneficial, allowing an element of a dispute to be settled, narrowing the disputes or contributing to a greater understanding of the other side's case generally". Alternative Dispute Resolution techniques have been used in countries like UK, USA, for many years and considerable experience have been gained since then. In UK, researches reveal that construction industry is well aware of ADR methods and effectively uses them to resolve disputes. For Turkish construction sector, on the other side, ADR techniques are not as familiar as they are in UK. “Law on Mediation in Civil Disputes No. 6325”was enacted in 2012, though it has been rarely used since then, especially for commercial and construction cases. Using mediation as a dispute resolution method in construction cases is currently an unfamiliar process for Turkey; Industry professionals have little knowledge about mediation, legal professionals approach mediation suspiciously and there is limited knowledge about what could be expected from mediation in relation to commercial cases, especially construction disputes. This paper aims to find out and discuss the developments in use of Mediation as a dispute resolution method for construction cases in Turkey since enactment of Turkish Mediation Law in Civil Disputes. After a review of past literature and researches on mediation as an alternative dispute resolution method for construction industry in Turkey, cases referred to mediation since the enactment of “Law on Mediation in Civil Disputes No. 6325” has been analysed in order to find out current practice. Results reveal the fact that mediation has rarely been used by construction industry until now.

Keywords: Construction Disputes, Mediation, Alternative Dispute Resolution

1. Introduction

Alternative Dispute Resolution methods have emerged as an alternative to traditional litigation due to their ability to provide faster, cheaper and undisclosed solutions to commercial disputes. Although alternative dispute resolution methods such as mediation and arbitration have their roots in ancient laws of Middle East as old as 1800 BC (Boulle 2005) or ancient Far East approaches to dispute resolution (Özmumcu, 2011), modern usages have mainly emerged in early 20th century from USA and Western Europe. Of these methods, arbitration has provided a convenient method to dispute resolution, especially for cases that emerged from contracts related to international commerce. 1958 New York convention has offered the parties who hesitated to go to local courts for disputes arising from international contracts, a relative protection in signatory countries. (1958) Fast globalisation of international markets has been seen as a factor in parties' willingness to use ADR methods, thanks to their pragmatic character. (Tanrıver, 2006) Growth of international trade from Second World War moved away side by side with growth of usage of Alternative Dispute Resolution processes. Large expansion of capital movements and international investments after Second World War can also be seen as a catalyser for rising interest in ADR methods. (Newcombe and Paradell, 2009) Besides its advantages, arbitration process still constitutes an adversarial process and costs could be high. Gradual, stepped dispute resolution methods have been adopted to overcome these difficulties. Flexible, hybrid methods that provided cheaper solutions for dispute resolution process became popular in commercial as well as construction contracts. (Arıcı, 2012)

Turkish case has followed its Western counterparts in adopting ADR methods to find cheaper solutions for dispute resolution and prevent litigation whenever possible. In context of Mediation, a special legislation was enacted by Turkish Parliament that regulates Mediation in Civil Disputes in 2012. This paper aims to discuss use of mediation in construction disputes by comparing survey results conducted between construction industry professionals prior to enactment of law and official statistics published since enactment.

2. Way to "Law on Mediation No.6325"

One of ADR methods, used as a pre-litigation method, is mediation. Mediation has its origins in traditional Far East dispute resolution culture. Its modern use in construction contracts has emerged first in US and spread to UK (Özmumcu, 2011). It was started being used in early 1990s in UK, though its progress in construction industry has been slow until late 1990s. However, researches conducted in UK on use of mediation reveal that construction industry is now well aware of ADR methods and effectively uses them to resolve disputes. (Gould and King, 2010)

On the EU side, EU Commision has encouraged member and candidate countries towards enacting legislation concerning usage of Alternative Dispute Resolution methods in commercial disputes. In 1999, the Heads of State or Government of the Member States "called for the creation of alternative, extrajudicial procedures for dispute resolution in the Member States in order to improve access to justice in Europe". (Europa Press Releases, 2008)

On 2002, EU Commission presented a Green Paper on alternative dispute resolution in civil and commercial law. The objective of Green Paper (2002) was presented as "to initiate a broad-based consultation of those involved in a certain number of legal issues which have been raised as regards alternative dispute resolution in civil and commercial law." The paper listed the interest in ADR in European Union then, according to three main reasons; increasing awareness of methods, legislation encouraging usage of ADR methods and political priority given by EU Institutions to promote ADR methods.

In 2004, European Commission adopted its Proposal for a Directive (IP/04/1288) establishing rules on civil procedure to ensure a sound relationship between mediation and judicial proceedings. The European Code of Conduct for Mediators was launched in 2004, developed by a group of experts as a self-regulatory instrument, to deal with matters concerning issues on accreditation and appointment of mediators. The Code of Conduct (2004) stated that it was aimed at setting out "a number of principles to which individual mediators may voluntarily decide to commit themselves, under their own responsibility. It may be used by mediators involved in all kinds of mediation in civil and commercial matters".

On 23 April 2008, European Parliament approved the Directive on certain aspects of mediation in civil and commercial matters. Directive aimed to "facilitate access to alternative dispute resolution and to promote the amicable settlement of disputes by encouraging the use of mediation and by ensuring a balanced relationship between mediation and judicial proceedings." Directive stated that member states shall adopt necessary laws, regulations and administrative provisions into national law to comply with the requirements of the Directive.

Trends in Turkey have also evolved towards adopting special legislation regulating use of ADR methods. Although, concepts of ADR methods such as mediation, conciliation are seemed as unfamiliar to Turkish Law, Turkish Law contained concepts of compromise, settlement agreement and similar concepts in various laws. However, rather than being regulated under a special law, various laws contained provisions including these concepts. (Özmumcu, 2011)

Since 1990s, in tandem with developments in Western countries, an increasing academic interest in ADR methods could be seen in Turkey as well. Process of adaptation of national laws in compliance with EU Regulations as part of EU accession process and the ongoing academic debates on regulating ADR under special laws opened the way for the "Law on Mediation in Civil Disputes No. 6325". A commission was formed to prepare draft law and various legal sources were considered in preparation of draft. Draft law was approved in Turkish Parliament in 07.06.2012 and was enacted. Provisions of Draft Law were generally in compliance with EU Directive and before its enactment it was stated by the researchers that the Draft Law "provides the main directions for possible implementations in the Turkish construction industry". (Dikbaş and İlter, 2008)

3. An overview of "Law on Mediation in Civil Disputes"

"Law on Mediation in Civil Disputes No.6325" stresses that mediation employs systematic techniques, it is a voluntary process and requires the participation of an impartial and independent third person with specialty training. (Clause 2.1) Article 3 defines voluntariness and equality as basic principles of mediation. Confidentiality, one of the most important strengths of ADR methods when compared to litigation is dealt under Clause 4. Article 9 states that mediators are liable of carrying out their jobs carefully and impartially. Article 13 states that resorting to mediation can be done "before filing a law suit or during the course of a law suit" as long as it is done on basis of agreement of both parties. Article 15 provides the opportunity for the parties to choose their own mediation procedures. Parties shall not be bound by strict rules and procedures can be chosen on a flexible basis. Article 17 determines the circumstances when a mediation process is considered to be concluded. Under Article 18, agreement of parties is considered. In compliance with the flexible nature of mediation, no rules on the scope and form of the agreement are imposed on parties.

In respect of agreement, it is stated that unless the parties will desire the agreement to have the force of a verdict, the document will be subject to general provisions. Article 19 requires that Ministry of Justice "shall keep the register of the persons who attained the authority to mediate in private law disputes". Under Article 20, only persons who hold an undergraduate law degree with at least five years of experience are allowed to register as mediator. Article 22 determines that any person willing to register as a mediator shall receive a "mediation training". Article 33 deals with the situations when the rule of confidentiality stated in Article 4 is violated. Violation of confidentiality may result in imprisonment up to six months and prosecution of the offence depend on complaints.

4. Mediation in Turkish Construction Industry

Research conducted in 2008 by Dikbaş and İlter reveals that Turkish construction industry was unaware of the mediation as an ADR method. Findings at the time revealed that prior to enactment of Mediation Law, %85 of respondents of research have never been involved in mediation process as part of resolving disputes arising from construction contracts. On the other hand, Dikbaş and İlter point the fact that 90% of the respondents said that they would consider using mediation.

Another survey conducted prior to enactment of Mediation Law seems to support these results. According to the survey, conducted in 2010 by Gül and Acar, participants from construction industry stated that they use mediation as a dispute resolution technique between never and rarely for disputes arising in international markets and they rarely use mediation for disputes arising in local markets.

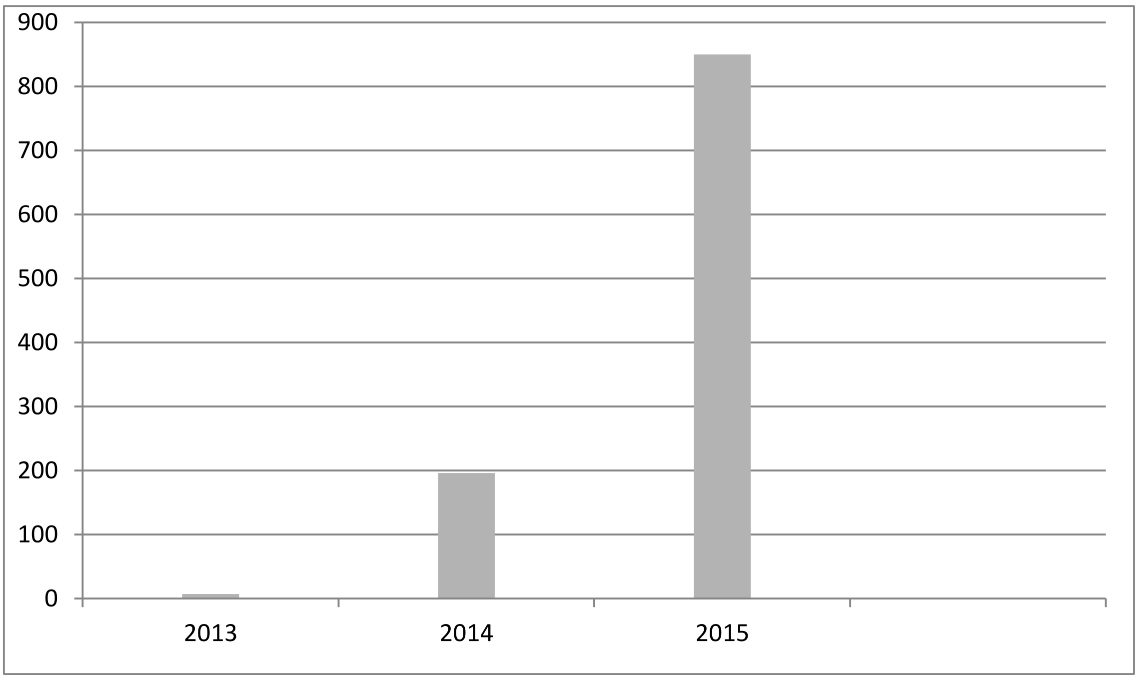
Another data obtained from construction industry professionals in 2012, by Arıcı, reveal the level of knowledge on ADR methods. Survey was conducted in 2012, in the same year with enactment of Mediation Law. According to survey, public officials working in construction projects have little to medium knowledge on mediation. For those working on contractors, knowledge of mediation seems to be between medium to high. The same survey reveals that public officials have been involved in a mediation procedure between “rarely to sometimes”. Contractors on the other hand have responded that they have been involved in a mediation process in past projects between “never and rarely”.

Findings of the surveys conducted by Dikbaş and İlter (2008), Gül and Acar (2010) and Arıcı (2012) seem in line with each other. It seems that level of knowledge has slightly increased from 2008 to 2012 while mediation experiences of industry participants have been rare.

More than 3 years have passed since the enactment of Mediation Law and Department of Mediation established under Ministry of Justice after the enactment of legislation, publishes the statistics about mediation regularly since then. Statistics reveal that in only 1053 cases mediation has been chosen as a method for dispute resolution. When compared with huge number of cases dealt in civil courts, 2.024.056 new cases were brought to civil courts while number of open cases reached as high as 3.293.090 over the year, number of disputes referred to mediation seems marginal.

Number of cases referred to mediation, on the other hand, seems to increase rapidly; only 7 cases were referred to mediation in December 2013, number increased to 196 in 2014 and 850 in 2015 until the end of October. This rapid increase may be parallel to the increase in rising number of mediators and increasing awareness in public as a result of efforts to promote ADR by using advertisements, panels etc.

Table 1: Number of civil cases referred to mediation from December 2013 to October 2015 in Turkey

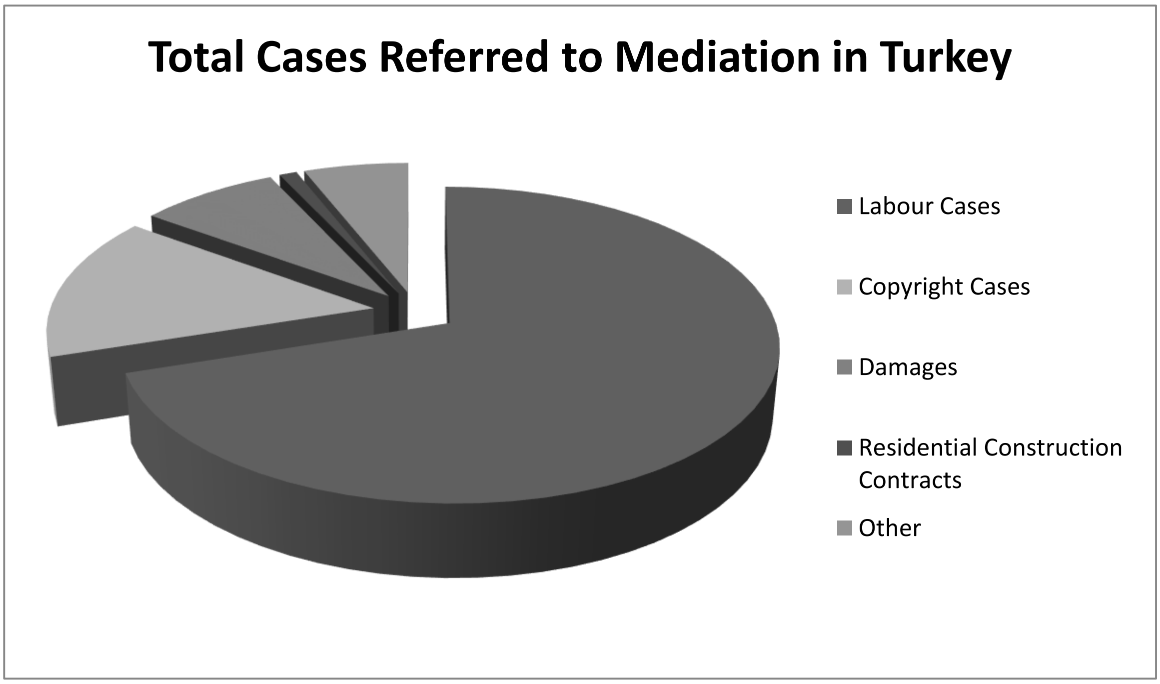


According to official statistics, construction industry hardly seems to consider using mediation until now. Number of cases concerning residential building contracts between landlord and contractors referred to mediators are only four. Of these four cases, two were referred in 2014 and two were referred in 2015. Three of these cases were resolved with an agreement between parties, while one case could not be resolved by agreement.

Statistics are published according to the subjects of cases and cases under headings "compensation" may involve disputes related to construction contracts. However, only 82 cases arising from damages were referred to mediation and this constituted an overall %8 of total cases.

Statistics reveal the fact that 70% of total cases referred to mediation were cases related to labour law and 15 % were related to copyrights. This large number of cases containing disputes arising from employment contracts might be commented as a continuance of familiar practices since the Labour Law contained provisions regarding conciliation even before the enactment of Law on Mediation in Civil Disputes.

Table 2: Distribution of total cases referred to Mediation in Turkey according to their subjects



5. Conclusions

This paper aimed at getting a balance of Turkish Mediation practice, in the context of Turkish construction industry, after the enactment of Law on Mediation in Civil Disputes in 2012. Pre-legislation researches and post-legislation statistics were compared to provide an overview of current situation.

Surveys conducted by researchers in 2008, 2010, 2012 respectively showed that Mediation practice was unfamiliar for construction industry. However, slight increase in awareness prior to enactment of legislation and positive approach of industry participants towards using ADR and mediation in future disputes provided a suitable background for future of ADR and Mediation in Turkey.

However after three years of mediation experience, an analysis of statistics reveals the fact that mediation is still an unfamiliar and unknown process in Turkey. Besides large number of cases referred to courts each year, a marginal number of cases were referred to mediators. Of these cases, construction cases remain insignificant in portion, which indicates the unwillingness or unfamiliar approach of the industry participants towards using new methods in dispute resolution.

On the other hand, rapid increase in cases referred to mediation each year, increasing awareness of society due to strong support of public bodies, time and cost problems arising in arbitration processes as well as in litigation and the trend that was followed in Western countries all point to an increased use of mediation by construction industry in future.

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Housing Dispute Settlement System in Japan; Part 1 - The housing dispute settlement system and the background to the legislation

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Abstract

In this report, we summarize the Japanese system for settlement of housing disputes.

We will detail the background of the legislation and the establishment of the system, along with its current state and operational results.

We posted two related abstracts to WBC16. In the first abstract, we report on the system's background and processes. In the second, we discuss the operational results and present conditions of the system application.

Keywords: Housing defect, Housing dispute settlement, ADR, Legal & Technical advice, Consumer

1. Introduction

This report introduces the Japanese system for the settlement of housing disputes.

We mentioned Japan's housing situation and the need for a system for settling housing disputes. Next, we will outline the origins of the housing dispute settlement system Japan. Finally, we provide an overview of the system for settlement of the housing disputes in Japan.

We will also mention two related services that contribute to housing dispute resolution – telephone consultation and face to face expert advice that lawyers and registered architects attend.

2. Japan's housing situation and the need for a system for settling housing disputes

2.1 Japan's housing situation

From the viewpoint of the housing stock, the total number of housing units in Japan is 61 million units according to the results of 2013 survey[1] by the Ministry of Internal Affairs and Communications, Bureau of Statistics. This includes 52 million residential units, which consists of 29 million detached houses and 23 million apartments. Many detached houses and low-rise apartments, totalling more than half of Japan's housing units are wooden structures.

From the viewpoint of newly supplied houses, approximately half of the dwelling units in Japan are built by big housing companies, with the remainder built by small and medium-sized housing companies. In terms of the number of housing companies, 99% of the whole housing companies are small and medium-sized companies and 1% are big housing companies in the market.

Figure 1 shows the number of houses built in Japan[2] every year since 2000. In the 5 years after the 2007-2009 slump, which was due to the subprime mortgage crisis, 800 to 900 thousand newly units have been built. The ratio of apartments is approximately half of the total houses.

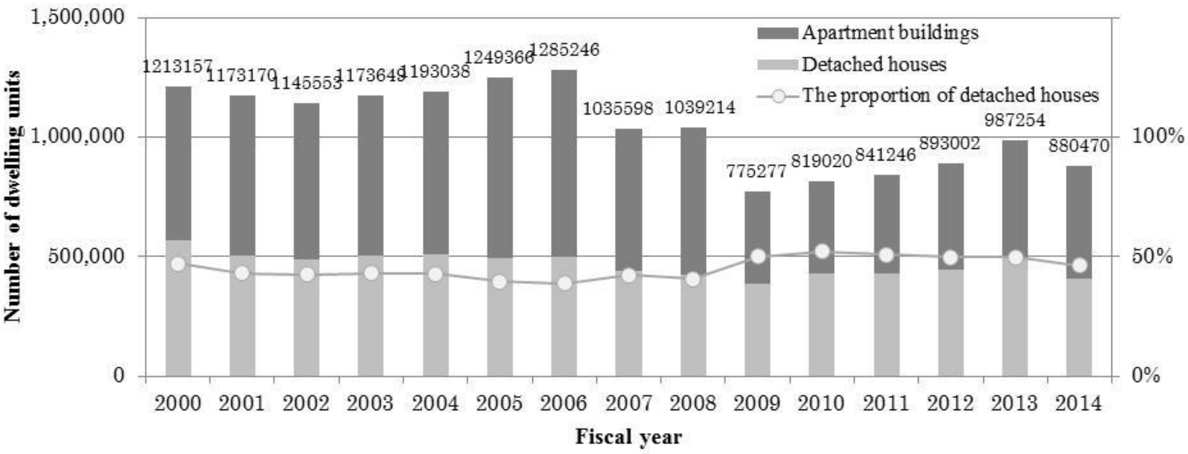


Figure 1: An annual number of newly built houses in Japan 2000-2014

There are various trial estimations[4] of the service life of houses. Figure 2 shows the data estimated by the Ministry of Land, Infrastructure, Transport and Tourism as an example of the service life of houses in Japan[3]. The average service life of houses in Japan is shorter than that in the US and the UK. This means new family builds new house and their children's generation don't succeed to stay nor doesn't another family stay at the house. The following reasons may be significant.

- Japanese people strongly prefer new houses to existing ones. (e.g. in 2008 fiscal year 13.5% of the housing transactions was for existing houses.)

- There is a tendency to treat that the value is lost for existing houses over a certain age in Japan

- Implementation of future renovation is not considered in the initial design concept of houses

- During the high economic growth period, people paid much attention to the quantity than the quality. The renovation of less performance houses needs much more cost.

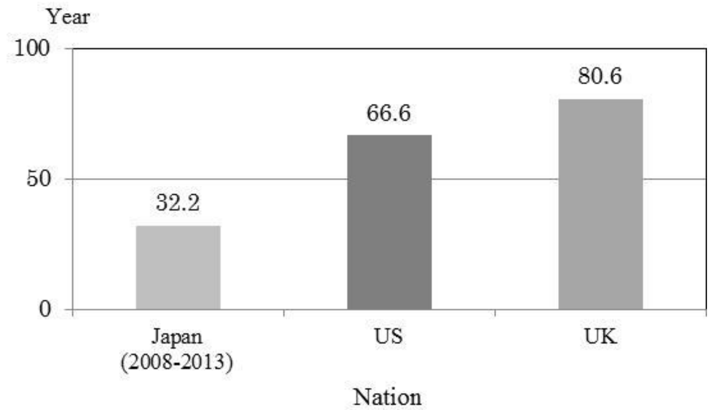


Figure 2: The average service life of houses

2.2 The need for the system for settlement of the housing disputes in Japan

The following three features are key differences between houses and other goods and services.

1. Houses are very expensive. For many people it is the most expensive purchase in their life. Usually they will buy their own house with the help of a long-term mortgage of 25 or 35 years. If the purchased house had the defects, the purchasers feel the great disappointment and would like to know how to handle.

2. Despite the largest purchase of their life, the homebuyer usually has less knowledge or information about the construction quality of the house.

3. Houses are built by combining a variety of materials and construction methods. Because technologies and terminology related to architecture are relatively complex, the consumers do not generally understand them. The purchaser is trying to verify the construction

quality, but because the construction work is carried out over a long period, and because access to some areas (such as sub-basements and roof spaces) is difficult it is not feasible for the consumer to check all of the components and processes. Additionally, there are a number of elements that cannot be tested in a non-destructive way. Verification that design specifications have been met in the actual building is very difficult.

In Japan, because the service life of houses is short, residential new construction opportunities are greater than the other countries. For the above reasons, to resolve disputes related to housing, a neutral expert is desirable.

Dispute resolution has traditionally meant a court trial. In general, court proceedings are slow and expensive. Litigation related to architecture has a strong tendency to take longer than the normal civil litigation. The reasons for prolonged proceedings are in part due to the time it takes time to verify the professional knowledge and to separate objective evidence from emotional conflict (such as the owner's feelings for their own house).

There are alternative dispute resolution ADR procedures that seek to solve conflict outside the court system. ADR is the dispute resolution process that experts such as lawyers encourage, where resolution is achieved by agreement between the parties by involved.

Conflict resolution in housing requires the participation of both lawyers (as legal experts) and technical experts such as architects – who provide knowledge of the technical aspects related to the building. ADR is a simple procedure and can provide a rapid resolution when compared to a trial. We can say that the advantage of the ADR is it allows for agreement between the parties without disclosing that disputes have occurred.

3. The background of Institutional establishment and legal basis

3.1 The background of Institutional establishment

The housing dispute settlement system in Japan is supported by "The Housing Quality Assurance Act HQAA" and "The Act for Secure Execution of Defects Warranty Liability under HQAA".

Prior to enactment of "The Housing Quality Assurance Act HQAA", housing defects have been considered under the provisions of the Civil Code[5)]. The provisions of the warranty for the building construction contracts are stipulated in the Civil Code Article 634 and 638. The article 638 defines the warranty period for new houses. The defined period is five years for buildings of light structure (e.g. wooden buildings), and ten years for building constructed of reinforced concrete or similar materials. The provisions of the warranty for the sale contracts are Civil Code Article 570 and 566.

Contracts with different warranty periods were also allowed by the freedom of contract principle. This act has since been defined as invalid as it could adversely affect a purchaser.

Around the end of the 20th century, many poorly-performing houses were sold. It became the social problem. As a result "The Housing Quality Assurance Act HQAA" was passed, calling for the establishment of a House Performance Indication System, Housing Dispute Resolution System, and Special Case for Defects Warranty Liability.

Several years later, the seismic building code scandal happened. It was discovered that the structural capacity of some multiple - dwelling complexes had been deliberately lowered. According to the ruling of HQAA, repair expenses should be demanded by the house owner and met by the vendor. But some house vendors went bankrupt before being able to meet these demands. As the result, many consumers could not receive compensation for housing defects, and some people were not only obliged to continue to pay the remaining mortgage, but also lost their houses in the multiple-dwelling. Following this social problem, a policy to secure the compensation was introduced.

3.2 "The Housing Quality Assurance Act HQAA" and assessed houses

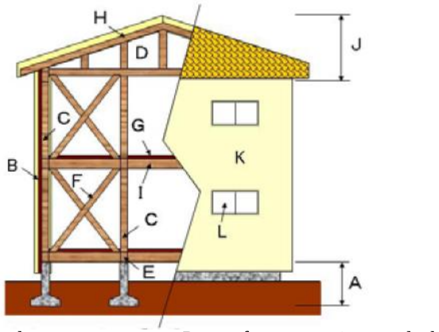
"The Housing Quality Assurance Act HQAA" was enforced in April 2000. The main details of this act are outlined below

1. 10-year warranties for principal structural parts and parts used to prevent rainwater leakage became mandatory in new housing sales and constructions contracts

2. Common rules for housing performance indications were established by the government

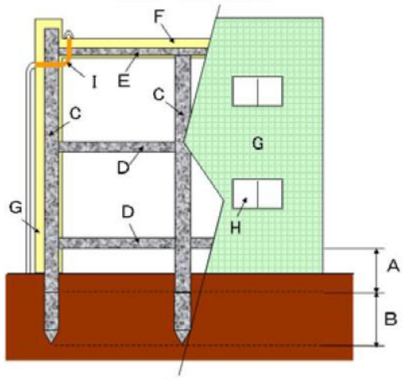
3. A housing dispute settlement system was introduced

The house vendors and contractors of new houses had to bear the warranty responsibility of 10 years for the elements necessary for structural resistance and the elements used to prevent rainwater leakage. The Act is limited to the important parts required to maintain structural rather than targeting all parts of the house. Figure 3 shows an image of the applicability of defect liability under the Act. The left and right figures[6)] show applicability for a detached house and co-housing, respectively.



Principal structure parts		Parts of prevent rainwater leak	
A	Foundations	J	Roofs
B	Walls	K	Exterior Walls
C	Columns	L	Openings
D	Roof trusses		
E	Sills		
F	Diagonal Members		
G	Floor Slabs		
H	Roof Slabs		
I	Horizontal framing Members		

Case of a detached house of wooden structure (post & beam traditional structure)



Principal structure parts		Parts of prevent rainwater leak	
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B	Foundation Piles	G	Exterior Walls
C	Walls	H	Openings
D	Floor Slabs	I	Drainage Pipes
E	Roof Slabs		

Case of an apartment house of reinforced concrete structure (wall type structure)

Figure 3: Part of the house that is the subject of the Act

The mandatory 10-year guarantee determined was accompanied by the concept of optional labelling. A new house which has been evaluated for performance is called an "Assessed House". Figure 4 shows the number of households receiving residential delivery of a construction housing performance evaluation report[7]. The number of assessed houses increased steadily from establishment of the evaluation system in 2000 until 2007. Since then a relatively constant 20% percent have received a construction house performance evaluation. Under the HQAA, disputes related to the contract should be solved by alternative dispute resolution (ADR) where possible. Approximately 20% of new houses apply the labelling, which has the benefit that both the house vendor and the purchaser are guaranteed the option of using ADR as a dispute settlement system.

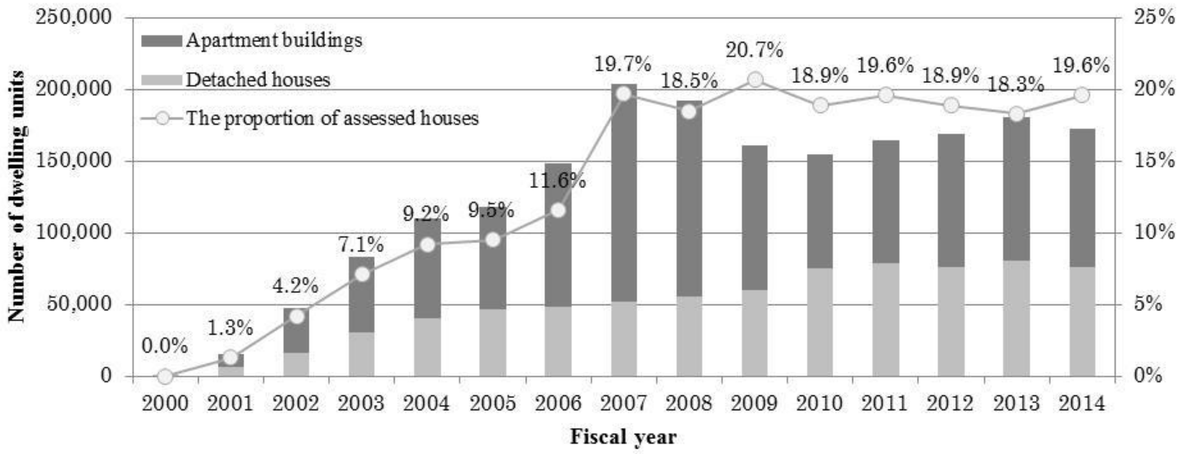

Figure 4: An annual number of newly built assessed houses in Japan 2000-2014

3.3 "The Act for Secure Execution of Defects Warranty Liability under HQAA" and insured houses

In April 2008, "The Act for Secure Execution of Defects Warranty Liability under HQAA" was enforced. A housing defect liability insurance scheme and an associated dispute resolution system were introduced. Eighteen months later, in October 2009, mandatory measures were enacted to ensure that new house suppliers have adequate financial resources. The Act demands that suppliers either participate in deposit schemes or purchase defect warranty insurance. New houses are covered by housing defect liability insurance called an “Insured house”.

Figure 5 indicates the annual number of dwelling units and the percentage of insured houses[7]. The number of insured houses has increased sequentially from 2008 to ensure measures are mandatory of resources. By 2010 (the third year after the introduction of the system) approximately half of new houses were covered by housing defect liability insurance.

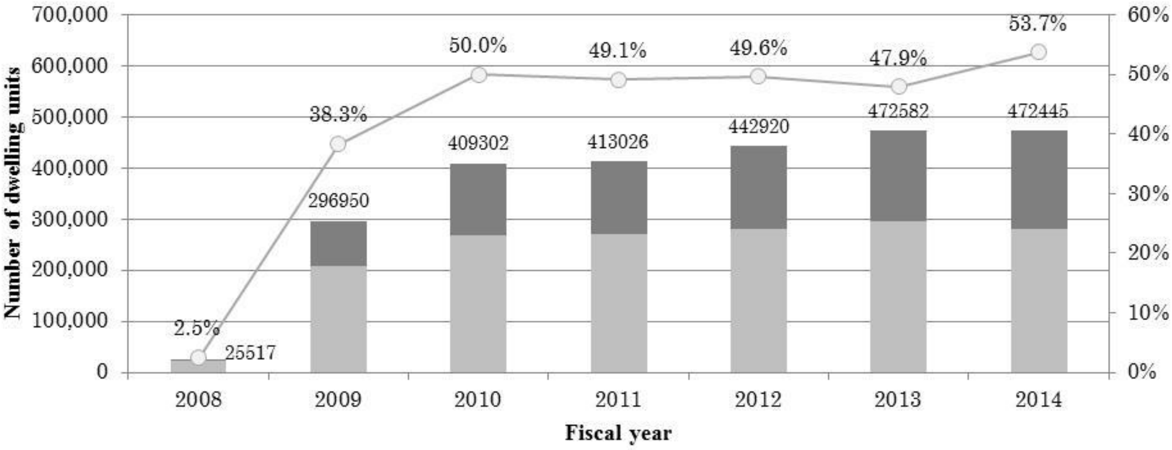

Figure 5: An annual number of newly built insured houses in Japan 2008-2014

The Ministry of Land, Infrastructure, Transport and Tourism reported the share of types of financial resources that housing suppliers have selected to use. Figure 6 shows the results[3]. More than 99% of housing companies have chosen insurance. The deposit schemes are used by less than 1% of housing companies. Taken together with the fact that the ratio in the number of units is roughly 50:50, the deposit scheme means that there is a strong tendency for many leading companies use deposit scheme.

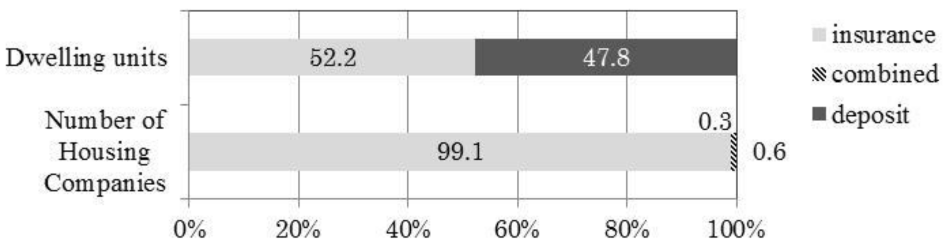

Figure 6: Resources secure method for repair

The new ADR scheme is also applied to "insured houses". Ignoring overlaps, the proportion of insured houses is 2.5 times greater than that of assessed houses, and housing defect warranty insurance will cover more than 99% of the companies. So, one of the notable point of this act is the expansion of the ADR scheme has included many small and medium-sized enterprises that have a relatively weak financial base.

3.4 The system for settlement of the housing disputes in Japan

The dispute resolution scheme that is applied by the two laws is the same. The overall flow for the system for settlement of the housing disputes in Japan[8] is shown in Figure 7. This scheme is private type ADR which does not receive the financial support from the government.

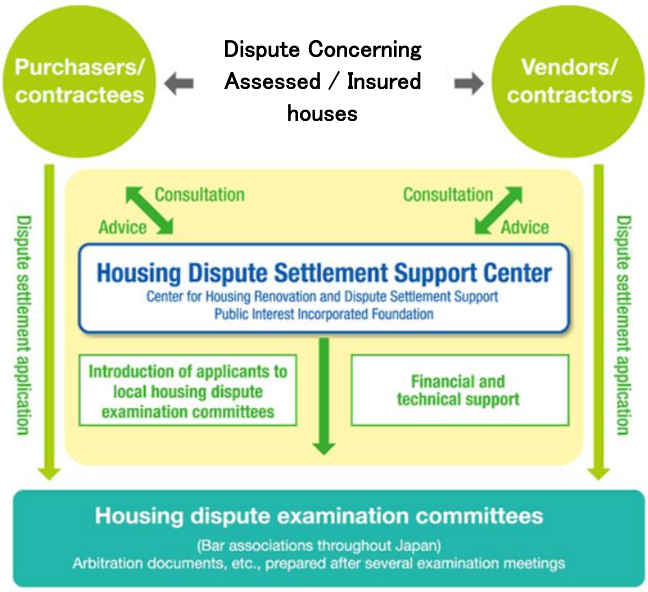

Figure 7: Dispute settlement flowchart

Based on the HQAA, the 52 bar associations in Japan are designated as housing dispute settlement bodies. Housing dispute settlement (for assessed houses and insured houses), disputes concerning sales and constructions contracts are available when they occurred. This housing dispute settlement treats the very broad issue, such as agreement, payment and delivery, post-purchase incidents and so on.

If the dispute about the contract between the vendors-purchasers and the contractees-contractors relating to assessed or insured houses has occurred, the parties will be able to apply for the dispute settlement to the housing dispute settlement bodies. On acceptance of the application, housing dispute settlement begins.

Lawyers and registered architects who are neutral fair third parties participate in housing dispute settlement as committee members. The committee promotes solution by mutual agreement. In the process of dispute resolution, a hearing will take place or the parties' documents will be examined. If necessary a site survey and appraisal will be performed.

The housing dispute settlement support center (the support center) is the only institution has been specified in Japan by the provisions of the Act. The support center will introduce a housing dispute settlement system to the questioners when the support center has received a consultation on assessed and insured houses. Also the support center introduces a nearby Bar Association to the parties as required.

The support center provides a number of services including the subsidy required for dispute settlement cost, advice based on similar previous cases and judgements, provision of building technology information.

4. Related services that contribute to the housing dispute settlement

This chapter introduces the two services to support the housing dispute settlement.

4.1 Telephone consultation

A telephone consultation service is provided for consumers who suffer from anxiety or trouble related to the acquisition or renovation of houses. It covers both technical and legal issues, Telephone counsellors are registered architects. Answers to legal issues are provided by a resident lawyer. Telephone consultation is available on weekdays except for the year-end and New Year holidays. Consultation will have been carried out in a manner to reduce the burden of telephone charges. Figure 8 shows the flow of telephone consultation[8].

Figure 8: Housing consultation flowchart of telephone consultation

4.2 Expert advice

Services of the face-to-face consultation in cooperation with 52 bar associations across Japan are provided to the people who would like to further help with problems related to the assessed houses, insured houses or housing renovation. This service is free; lawyers and registered architects have attended, and give advice from both the legal and technical sides. This consultation is called expert advice. In the face-to-face consultation, participants can bring the relevant documents such as the contracts, the drawings and the photographs, and advice is provided on the basis of those materials. Figure 9 shows the flow of expert advice[8)].

Figure 9: Expert advice flowchart

5. Conclusions

Part 1 was an overview of the system of private type of housing dispute settlement in Japan. We described the condition of Japanese houses as a background to institutional establishment and related services that contribute to the housing dispute resolution. We illustrate the application performance of the system in Part 2.

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Housing Dispute Settlement System in Japan; Part 2 - The results and present conditions of the housing dispute resolution

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Abstract

In this report, we summarize the Japanese system for settlement of housing disputes.

We will detail the background of the legislation and the establishment of the system, along with the current state of the system and operational results.

We posted two related papers to WBC16. In this second paper, we discuss the operational results and present conditions of the system application.

Keywords: Housing defect, Housing dispute settlement, ADR, Legal & Technical advice, Consumer

1. Introduction

This report introduces the Japanese system for settlement of housing disputes.

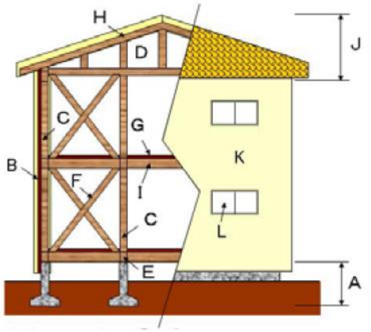
We previously mentioned Japan's housing situation, the need for the system for settlement of the housing disputes and the background of the housing dispute settlement to the legislation in part 1.

In this paper we show the results of an analysis of data that collected in the process of providing the housing dispute settlement service, the telephone consultation service and expert advice.

2. Assessed houses and Insured houses can use the housing dispute settlement

2.1 Assessed houses

“The Housing Quality Assurance Act HQAA” was enforced in April 2000. Under the act vendors and constructors of new houses have to bear responsibility for the elements necessary for structural resistance and the elements used to prevent rainwater leakage via a 10-year warranty. Figure 1 shows an image of the applicability of defect liability under the Act. The left and right figures show applicability for a detached house and an apartment house, respectively.



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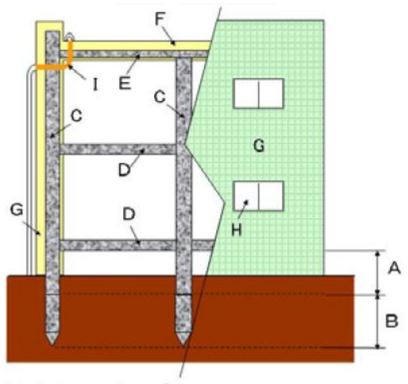
Case of a detached house of wooden structure (post & beam traditional structure)



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C	Walls	H	Openings
D	Floor Slabs	I	Drainage Pipes
E	Roof Slabs		

Case of an apartment house of reinforced concrete structure (wall type structure)

Figure 1: Part of the house that is the subject of the Act

New houses utilising Housing Performance Indication System are called an “Assessed House”. Figure 2 shows the number of the houses receiving the evaluation reports. The number of assessed houses increased steadily from the establishment of the evaluation system in 2000 to 2007. After that a relatively constant 20% percent have received the evaluation reports. The HQAA enables both vendor and the purchaser of an “assessed house” to utilise newly introduced ADR as a dispute settlement system.

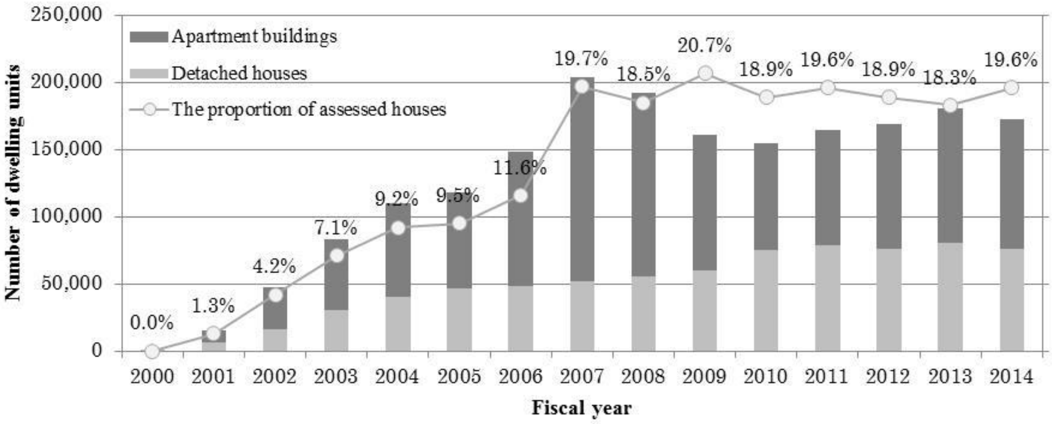


Figure 2: An annual number of newly built assessed houses in Japan 2000-2014

2.2 Insured houses

New houses are covered by housing defect liability insurance called an "Insured house".

Figure 3 indicates an annual number of insured houses and the percentage against newly built houses. The number of insured houses has increased sequentially from 2008 to ensure measures are mandatory of resources. By 2010 (the third year after the introduction of the system) approximately half of new houses were covered by housing defect liability insurance.

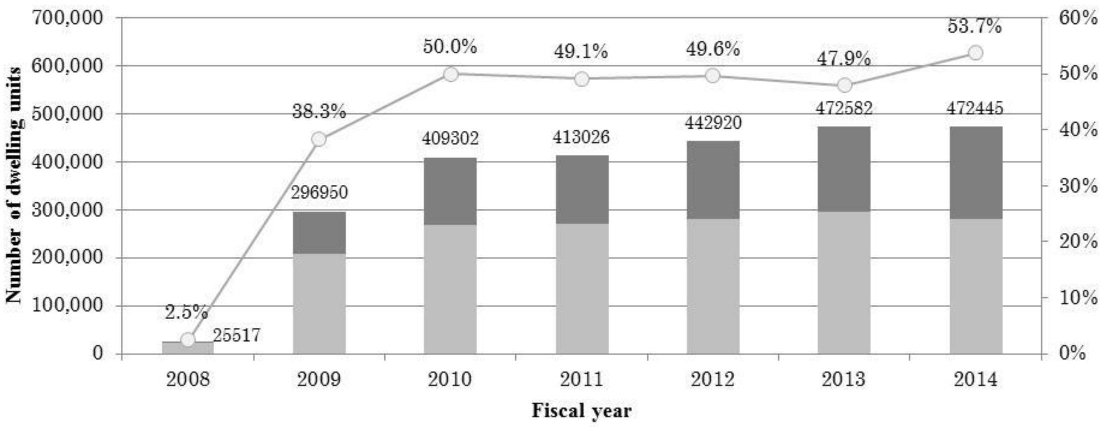


Figure 3: An annual number of newly built insured houses in Japan 2008-2014

3. The application results of the system for settlement of the housing disputes in Japan

The overall flow for the system for settlement of the housing disputes in Japan is shown in Figure 4.

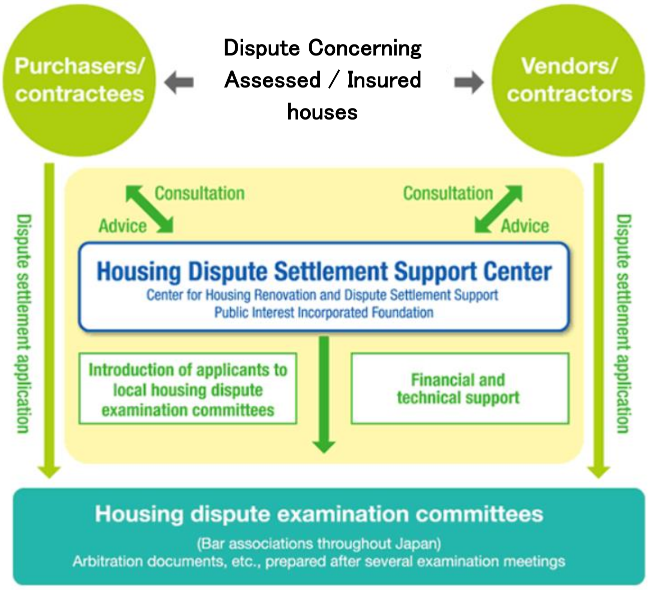


Figure 4: Dispute settlement flowchart

Figure 5 shows the dispute settlement filings after the system started. The first dispute application for an assessed house was processed the fiscal 2001, and number of applications has then gradually increased. Between 2005 and 2009, there were 20-30 requests per year.

"The Act for Secure Execution of Defects Warranty Liability under HQAA" was enacted in 2008, and as a result insured houses became subject to the same dispute settlement scheme as assessed houses. This has led to a significant increase in dispute settlement filings from fiscal 2010. In future, continuous increase in the number of applications predominantly from insured houses will be expected.

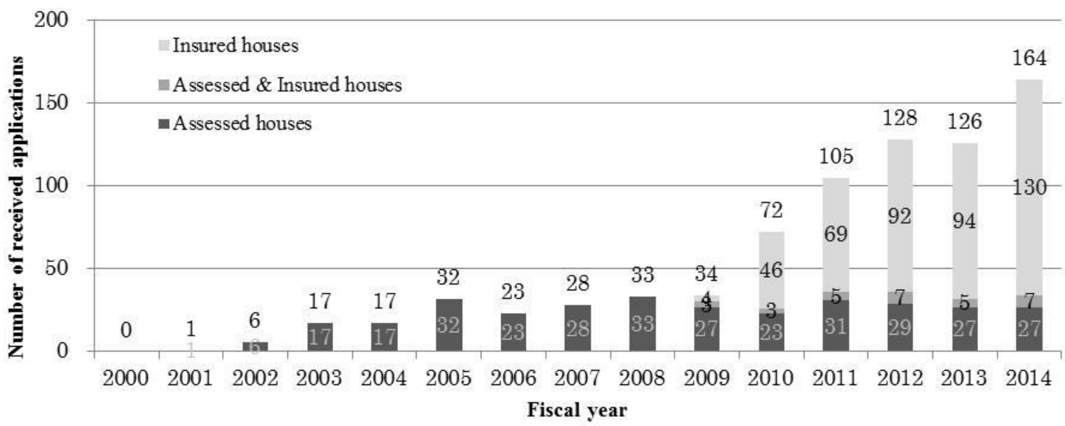


Figure 5: Dispute settlement applications received 2000-2014

Figure 6 shows the number of the dispute settlement applications after the process of the expert advice and the proportion against all dispute settlement applications. The proportion indicates an increasing trend.

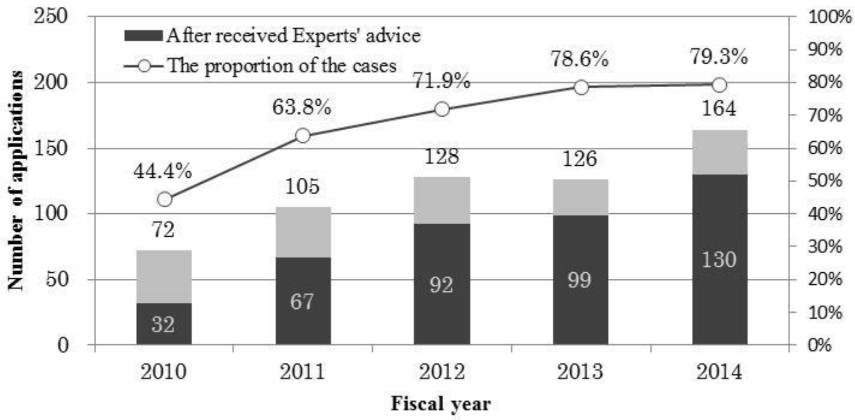


Figure 6: Number of the dispute settlement applications after expert advice 2010-2014

Figure 7 shows the results of the dispute settlement process for a total of 684 cases processed by 2014. 53.5% (366 cases) have been resolved by mutual agreement.

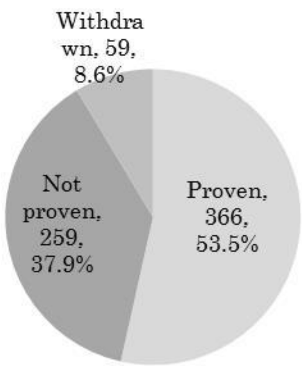
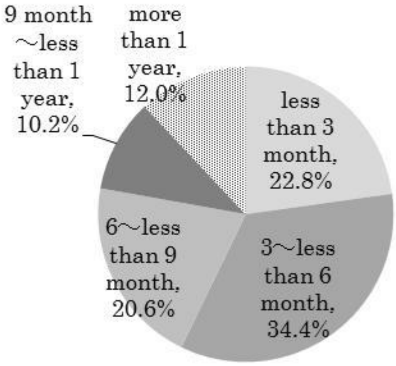


Figure 7: Results of dispute settlement (n=684)

Figure 8 shows a length of the conflict resolution process. The greatest proportion of cases took between three and six months, although the average case took 6.6 months (close to our target 6 month timescale). The number of consultations for each case is shown in figure 9. Around two-thirds of cases (66.5 percent) required less than 5 times consultations. The average was 4.7 times.



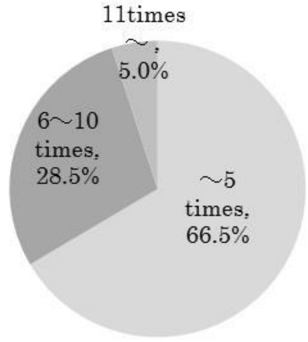
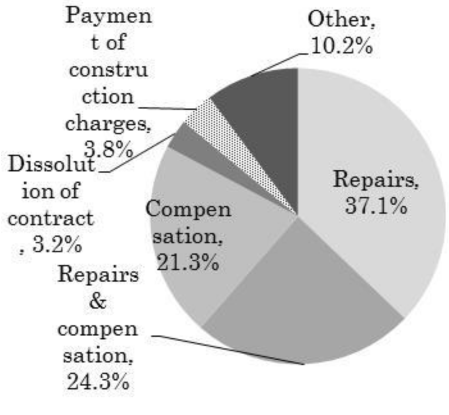


Figure 8: Trial period (n=684)   *Figure 9: Trial number of times (n=684)*

Figure 10 shows the desired resolution when the application filed. The Resolution in the resolved cases (n=366) are shown in Figure 11.

The most common outcome desired was “repair”, followed by “repair plus compensation” and “compensation only”. The most common outcome was “repair” followed by “compensation” and “repair plus compensation”



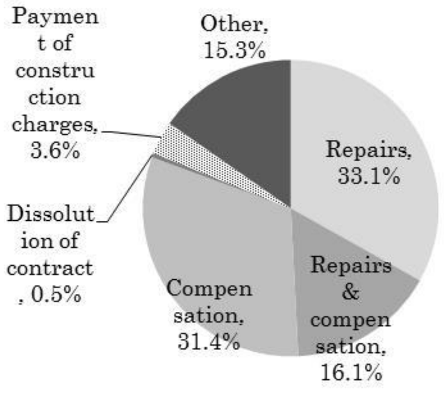
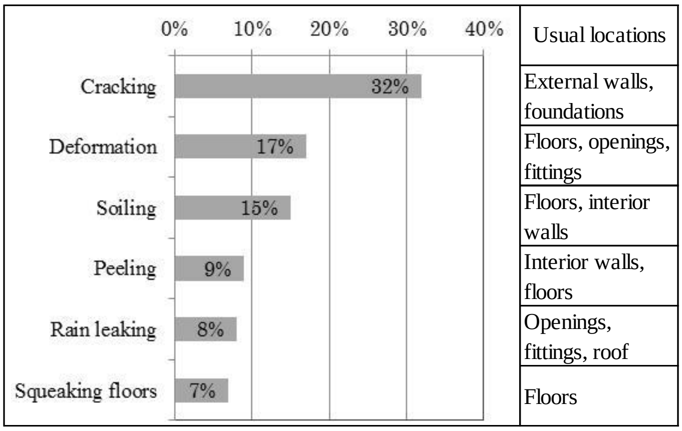


Figure 10: Initial hope (n=684)   *Figure 11: Agreed solution (n=366)*

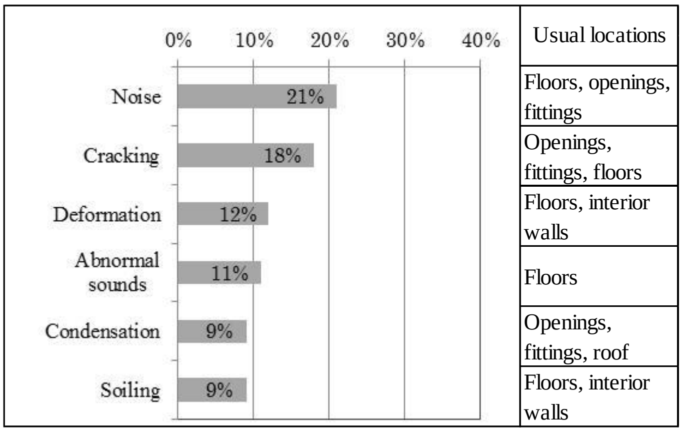
The issues in dispute are listed in Table 1 & 2. The most common problem in detached houses is “Cracking” whilst “Noise” issues are most common in apartments.

Table 1: The main trouble events that became issue of dispute settlement on detached houses n=406 (multiple counts)



problem counted multiple times (n=406)

Table 2: The main trouble events that became issue of dispute settlement on apartment building n=151 (multiple counts)



problem counted multiple times (n=151)

4. The application results of the related services that contribute to the housing dispute settlement

This chapter introduces the two services that support housing dispute settlement.

4.1 Telephone consultation

The telephone consultation service, covering both technical problems and legal issues, is provided for consumers who suffer from anxiety or trouble related to the acquisition or renovation of housing. Figure 12 shows the flow of telephone consultation.

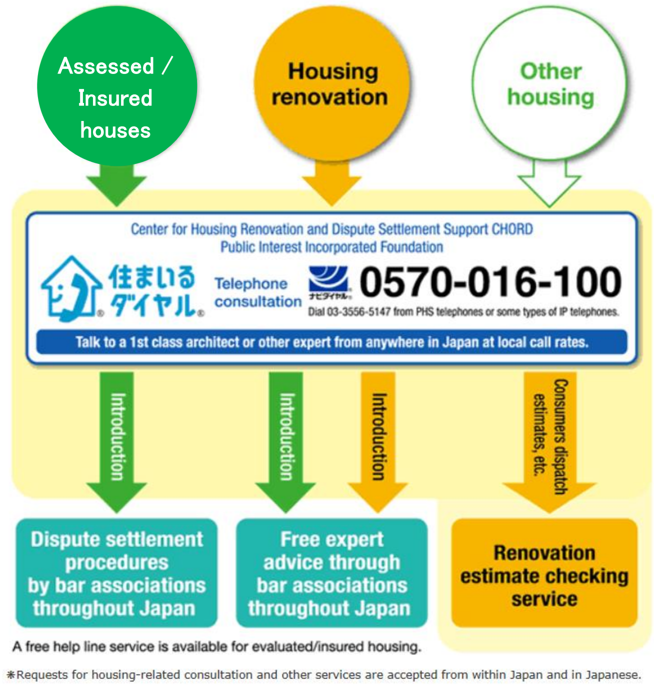


Figure 12: Housing consultation flowchart of telephone consultation

Figure 13 shows the corresponding record of telephone consultation. In the first year (fiscal year 2000) of the service, about 4000 calls were handled. The number of consultations increased after the enforcement of "The Act for Secure Execution of Defects Warranty Liability under HQAA" in 2008 and exceeded 26,000 in the fiscal 2014. In recent years the support center has been receiving telephone consultations for over 100 new cases per day. Approximately 60% of consultations relate to new houses, with the remaining 40% being consultation about renovation.

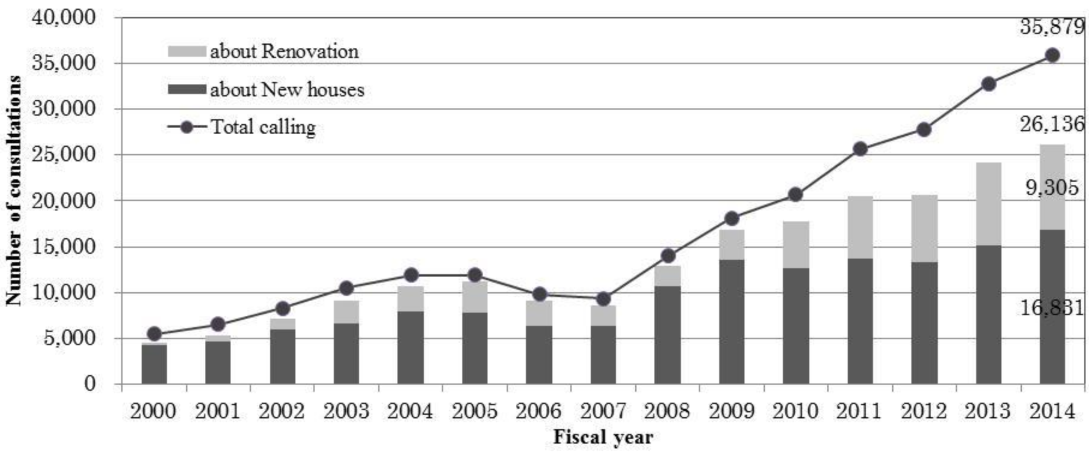


Figure 13: An annual number of telephone consultations 2000-2014

Figure 14 shows a breakdown of the consultations about housing issues for 2014. The pie chart on the left shows the reasons for the consultation across 16,831 incidents. The pie chart on the right shows the percentages for assessed and insured houses. The group on the right shows a 10% greater proportion of consultations relating to troubles. This trend was similar in the fiscal 2012 and 2013.

Figure 14: The proportion of telephone consultations about trouble on 2014

4.2 Expert advice

Face-to-face consultation services are provided in cooperation with 52 bar associations across Japan. Figure 15 shows the flow of expert advice.

Figure 15: Experts advice flowchart

Figure 16 shows the number of the expert advice consultations since they were introduced in April, 2010. The number of consultations has increased every year to more than 1,800 in the fiscal 2014. The expert advices concerning the renovation accounted for 50% of the cases.

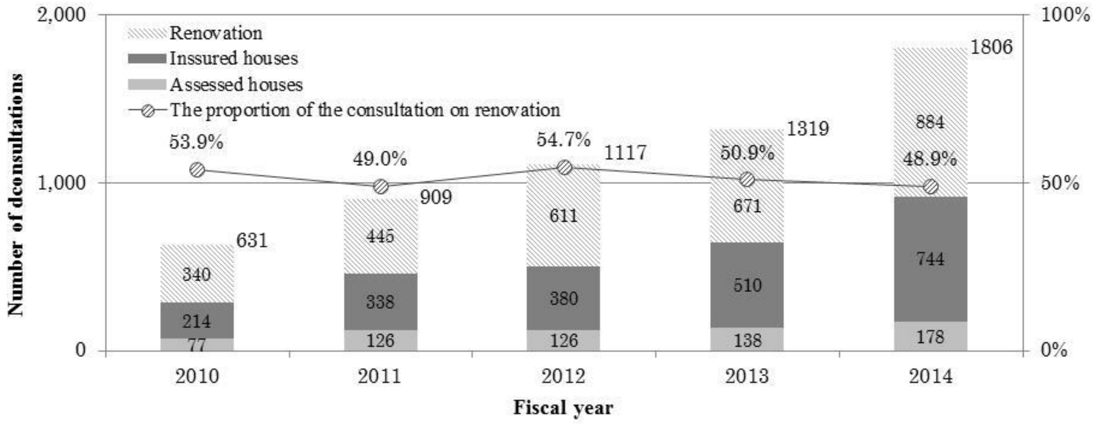
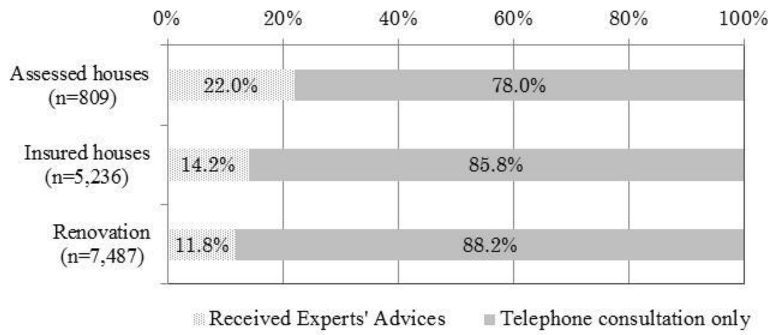


Figure 16: An annual number of expert advice 2010-2014

Figure 17 indicates the number and the percentage of people using expert advice that had previously received a telephone consultation. Of the 178 cases relating to assessed housing, just 22% had previously had a telephone consultation; even fewer of the 744 insured housing cases (just 14.2%) used telephone consultancy first. Cases to proceed to expert advice through the telephone consultation are a minority. There is a possibility that telephone consultations are to contribute to the prevention of housing dispute.



Received Experts' Advices	Telephone consultation only
178	631
744	4,492
884	6,603

Figure 17: The number and proportion of the expert advices after telephone consultations

Figure 18 shows the reason for the use of the expert advice. The total is greater than 100 percent, as multiple reasons can be given. Nearly 90% of users chose the reason that lawyers and architects have attended, giving the user expert advice from both legal and technical perspectives.

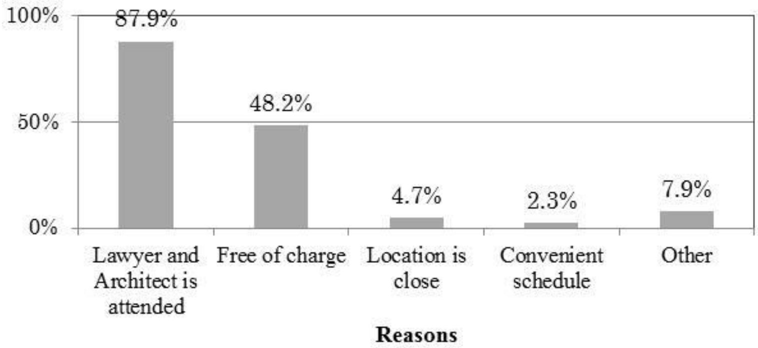


Figure 18: Why the expert advices used (multiple choices)

Figure 19 shows how satisfied users are with expert advice consultations. User satisfaction is considered high based on the fact that 90% were "Highly satisfied" or "Satisfied" with the service.

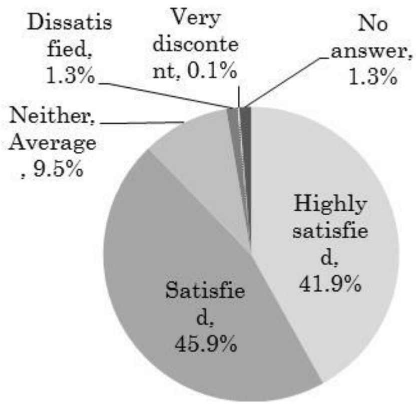


Figure 19: User satisfaction of expert advice (n=1345)

In the case of consultation on assessed or insured houses, the support center will introduce a housing dispute settlement of the Bar Associations in response to the consultation.

5. Conclusions

Part 2 has shown the results of the housing dispute settlement, the face-to-face expert consultation and the telephone consultation as well as the cause of the housing dispute and the satisfaction of the users. The users of all three services have been increasing year by year. This means that the Center For Housing Renovation and Dispute Settlement Support CHORD has accumulated the data of those three services. Under the condition that the secret of these data should be kept, the accumulated huge data should be analysed and utilised for the housing consumers and suppliers to prevent housing disputes and to do the prompt and effective dispute settlements.

References

Center for Housing Renovation and Dispute Settlement Support CHORD web site (Available online http://www.chord.or.jp/tokei/pdf/soudan_web2015.pdf [accessed on 30/11/2015] and http://www.chord.or.jp/english/support.html [accessed on 30/11/2015]).

The Building Center of Japan BCJ "A Quick Look at Housing in Japan June, 2015", pp49-50, BCJ. Available online http: https://e2102.secure.jp/~e2102002/form/mail.cgi?id=quicklook02 [accessed on 30/11/2015].

SECTION

2

Stakeholder involvement and satisfaction

Housing association objectives and the results of indices in the Netherlands

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Abstract

Housing associations make too little a contribution to Society, the government has to step in too frequently because of maladministration, and the associations' executives are often unaware of the far-reaching impact of their decisions. These are the conclusions of new academic research conducted by Jan Veuger of Rotterdam School of Management, Erasmus University (RSM). In his dissertation, he asserts that in numerous cases there is no correlation between social and financial objectives. The Dutch House of Representatives debated the results of the report 'Ver van huis' from the Parliamentary Committee of Inquiry on Housing Associations in early December 2014. After extensive exploration of the literature and PhD studies on the period from 2005-2009, the research design inspired based on the grounded theory, which has a certain bias as a result of the extensive literature study. In the line of thinking of the grounded theory, interviews with directors contacted more or less uninhibited according to a narrative method. Afterwards these interviews, independent of the researcher, thematic and labeled by a single Delphi method have been submitted to an expert group which created a storyline. The results of this Delphi method were submitted to a peer group of directors. The conclusions were presented in a survey to 60 selected directors and the subsequent conclusions. There has thus been more than a triangulation of research than just interviews, Delphi method and survey. Hypotheses are thereby omitted because of the difficulty of fitting in within the chosen research design inspired by grounded theory. At his request Stef Blok, Minister for Housing and Kingdom Relations, has received the thesis Material Immaterial (Veuger 2014) on December 4, 2014. On December 11, 2014, the Minister decided to change its proposed policy through the establishment of an inspection model in which the financial and social objectives of the corporations are tested and assured, with the Minister as the final responsible. The parliament has unanimously agreed.

Keywords Control – housing associations – social values – board – MSCI IPD index

1. Introduction: in the eye of the hurricane

Before starting the study of control and appreciation of housing associations there was in my opinion a real chance that housing corporations might actually end up in a danger zone of legitimacy and the right to exist. The question I then asked about the contradictions there are in the social values of housing associations that affect the way they are governed, is still relevant. The reputation and trust in housing corporations has also decreased dramatically in recent years. The question is what is really going on at housing associations about control and appreciation.

An extensive study of literature and (PhD) studies on the period from 2005 until 2009, with a present potential of 720 professional magazines in the field of housing and real estate, 149 articles were found to be relevant with the inclusion criteria: values, control and corporations. Therefore are these 149 articles all included in the bibliography. From these articles emerges a picture about values and control of housing associations which are mostly financially oriented and much less socially. Reason to start a PhD research to get a grip on societal values and control of housing associations. After the extensive exploration of the literature and (PhD) studies on the period from 2005 until 2009, the research design was inspired on the basis of the grounded theory, which has a certain bias due to the extensive literature study. Following the line of thinking of the grounded theory, interviews with directors, have started, more or less unprejudiced, according to a narrative method. Afterwards these interviews were, independent of the investigator, thematically labelled by a single Delphi method - appropriate in the line of grounded theory - and submitted to an expert group creating a narrative. The results of this simple Delphi method have been submitted to a peer group of directors. Afterwards these conclusions were presented in a survey to 60 selected directors to raise the subsequent conclusions. So there has been more than a triangulation of research by interviews, Delphi method and survey.

After this introduction, this article is based upon the methodology of the survey, the results of research on control of housing associations in the Netherlands, the European context of housing associations and final justification of the IPD Netherlands Housing Property Index over the policy of housing associations about a certain period of time in terms of returns.

2. Methodology

The *grounded theory* is a method developed in the 1960s by Glaser and Strauss (1967). The emphasis of the method is to generate a theory based on data. Because not expressly in advance is to determine what the missing operating and monitoring questions are, it is of interest to collect data to a saturation point because it may be assumed that there is no more new information to generate on this topic. The grounded theory is flexible and is able to highlight questions that have not been previously asked. Fed by the pragmatic legal theories, ethnographic research – bringing information about dividing lines between different communities – and explicitation of qualitative methods, Glaser and Strauss intended to codify procedures. They can be summarized by reasoning, to handle more deliberate on the one hand and, on the other hand, they become to theory. Glaser and Strauss's approach indicates that the quality of a theory can be evaluated by the process by which a theory is constructed.

Methodical over a period of five years of literature, ten years of stakeholders, instruments and behaviour and a hundred years of housing corporation history, the developments in the field of value thinking and the governance of housing corporations have been studied. This qualitative study with a positivistic approach of values and governance of housing corporations has answered the research question What social values underlie social housing and are there contradictions that affect the control of a social housing corporation? The grounded theory is the research method chosen as a line of thinking, because that method emphasises the generating of theory-based data. Because it is flexible, it enables us to highlight questions that have not been asked before. These questions have been evaluated by the process with which the theory of this study has been constructed.

The Process of this Research

This research inspired by the grounded theory follows an inductive method for development of that theory. This process of collection of data about thinking in terms of values and control begins with the open encoding – a combination of the concepts of values, control and corporations – data in the professional literature in the field of opinion and scientific research over the period of 2005-2009. The found fragments are reduced to a number of concepts such as those in the relevant chapters are examined. By the interaction of comparisons of terms a smaller number of concepts is created to which different dimensions can be awarded. This is leading to a certain saturation process. By the relating of concepts arises a theory that flows into a story line. This storyline is surrounded by tables and overviews for a rich presentation of evidence and a clear statement of arguments.

The final result of this research is a description of missing operating and monitoring questions, the collected and saturated core concepts that explain certain events. By this methodology an understanding of patterns and processes is revealed. 'This makes clear how a group of people, through their social interactions, their reality and defines acts' (VOC 2010:17). Not the theory is leading, but the practice on which research is being done. The choice for this theory formative research is has been made because the research question requires insight in missing operating and monitoring questions. The answer need not to be found in the existing practice or theory, but lies in not yet asked questions that can offer a solution in the area like Einstein this describes as 'the actual problems cannot be solved at the same level of thinking, in which we were when we created them'. The power of the grounded theory is that it is detailed in the descriptions of the method of data analysis and gives a possibility for the research draft anchoring and accountability. This allows that difficulty of validation and generalization can be parried. Later on additional literature research and findings in the study are faced with the insights from the theory. By this method of constant reflection additional insights in the analyses are created; the dialogue between theory and practice and enhances the consistency of the description of this research to understand. The process of this research is from step to step, where each step validity is ensured. The different phases, with underlying steps of this study are included in the following figure, inspired by Pandit (1996). The phases and steps are related to the chapters of this study.

3. Control of Housing Corporations in the Netherlands

Why this qualitative research into control of housing associations? To understand and to discover patterns about the how and why of the operation of housing associations in society as they do now. This qualitative research is about the search for ideas, backgrounds, motives, resistors and rationale and is therefore suitable for the following central question to answer: are there contradictions in the social values that underpin housing associations that have an impact on the way they are governed? Partial questions here are: (1) how can be arranged that the social objective behind the values becomes transparent?, (2) what is that social enterprise Housing Corporation, what is its role in society and what is social real estate?, (3) how can values and orientation of corporations on the basis of the criterion be of social relevance?, (4) how does the executive now operate in practice, does he usefully apply operating models and the theories about Corporate Real Estate Management (CREM), which are based on the commercial sector?, (5) how does innovative control of housing corporations look like? and (6) how to get an insight in operating questions about social real estate?

Methodical literature over a period of five to ten years, instruments and stakeholders behavior and hundred-year history of the housing corporations, the developments in the field of values in thinking and driving housing corporations are examined. This qualitative research into values and control of housing associations, the research question answered. The grounded theory is chosen as a line of thinking for the qualitative research method because the emphasis is on generating the data based on theory. By being flexible, being able to highlight questions that have not been previously asked. These questions are evaluated by the process by which the theory of this study is constructed.

In this review values are examined in relation to social real estate. The social real estate as an object is made up of material value. This material value is necessary for the commercial power of the Corporation, with which they control public real estate and the organic value. The social real estate is a prerequisite for the operation of the Corporation, the social value. Particularly in the relation of public real estate and the Corporation is that they can exist separately, but the Corporation is not able to operate without social real estate. The social real estate retains its values without the Corporation, but not the other way around. The combination in its entirety creates an intellectual value. Corporations are focused on creating social value by deliberately allocating resources for social objectives and want to preserve, restore and refresh this value. Social integration and planning of the sector are important in determining which behavior is preferred. The Corporation executive appears however to stick to its own accumulated power and can hardly be influenced. Looking inside the Organization, it is noticeable that the investment behavior within the Corporation is generally in line with the personal conduct of the executive. Performance indicators as power and money, in which the executives are neglecting the current financial crisis, are still leading.

It is also not about a new organizational infrastructure, but above all improving the effectiveness, efficiency and financial position fueled by the pneuma – in the spirit of the work – related to the statement of the Corporation. The interpretation of this and the raison d' être of the Corporation can be found in a more offensive cooperation, new forms of mutual solidarity and thriving on the added values of the Corporation. In improving the social objectives of corporations three partly domains are to be distinguished: (1) housing the primary target group, (2) investing in the living and housing environment and (3) contributing to the socio-economic developments of districts. In doing so, its financial position, efficiency, effectiveness, transparency and planning of value-drivers are of importance. The Corporation also has three balanced values: (1) the fixed value (continuity), (2) the direction value (initiator) and (3) the profitability value (the mutual influence of neighborhood quality and real estate value translated into social and financial value). In the task demarcation are thus the effectiveness and efficiency of importance. It comes to the maximization of the financial value, but on maintaining a minimum acceptable ability. A more conscious control on social returns is a prerequisite for effective and efficient work. The effectiveness of housing corporations can mainly be considered to be a responsibility of the State and the municipalities.

In practice the Board is not controlling in coherence between financial and social returns and trust. CREM as theory can play a role in conjunction of values. In contrast to criticism of corporations, it is professionalizing, but the question is whether they are sufficiently keeping the focus on the sustainability of professionalization. Otherwise chaos is organized. Why worrying about the instrumentation for comparisons and why is it not possible to have a quick fix arranged by the Corporation directors among themselves? The answer to this lies in three reasons: (1) the quality and reliability of the information flows is not on the desired level, (2) the Government is not steering and leaves it to the perfect free market operation and (3) the discipline of behavior of the Corporation which leaves much to be desired. Striking is that an explicit evaluation of the destination goal, related to previous objectives, is rarely measured. Could be assumed that this is not about rational led settings but to a controlled chaos. By Corporate Real Estate Management (CREM) the real estate portfolio can be in line with the needs of the core activity of the Corporation. The aim of this key action is not new. This creates an optimization of the added values of the result. A values-based real estate strategy not only enables a competitive Corporation, but also with a moral strategy.

The multidisciplinary nature of public real estate management is not a bottleneck as far as clear definitions and observations are available. If hard and soft skills are not related to each other they build a bottleneck in the total control of a corporation and its reporting on them. If a task and the measurement of it not defined and organized, controlling is of no use and correcting is not possible. The dimension time affects value concepts from a historical context. Changes of value definitions affect the rating and thinking in those concepts. In addition, rating is depending on the one that defines quality of life and how it should be appreciated. Real estate is a social challenge with varying meanings for people involved. The corporation is a method of financing and value in the sense of usefulness. The orientation on change has affected the innovation and agility of the Corporation and on different values. Orientation to change should be seen as proof that the Corporation is able to achieve real renewal of the built up achievements, to consolidate and enhance these. If she is able to do this, it will lead to a richer Corporation where everyone can support with new developments and ideas. The future leadership of a corporation in the Corporation world is not determined by the possession of assets, but how it can focus these funds on a particular purpose. But what would it bring us if the monopoly position of the Corporation sector is halted? In ethics, it is a question of values and value system within an enterprise. Rank, position and power are important criteria and generally more important than money. Money is the medium to rank, position and power. The financial and thus the real estate market, is a market that exaggerates by irrational behaviour. Fear of 'eat or be eaten' provides the mechanism of people. Financial and real estate markets are always so unstable and should always be regulated. The Corporation must above all have a serving and no prevailing role. Regulation is an attempt to bring together different images of reality. Anchor points for this are: private capital, manage transactions and regulation of major players, in which the State should create the counterbalance.

Part of the conclusions of this research are:

1. Improving the social objectives of the governance of corporations must be reflected in three domains: (1) housing as the primary target group, (2) investing in the living and housing environment and (3) contributing to the socio-economic developments of districts. Financial position, effectiveness and efficiency are important.

2. Existing legislation is in itself not blocking any task of the Corporation. The specific characteristic of the public real estate covers: (a) a building related to common social activity and (b) providing and facilitating stakeholders from a recognized societal interest.

3. Corporations are focused on creating social values by deliberately allocating resources for social objectives and want to preserve, restore and refresh these values. Social integration and planning of the sector are important whereas the behaviour of the executive is of importance.

4. The Executive Committee will control in practice with operating models, but does this not in coherence between financial and social returns, social confidence, effectiveness and efficiency. CREM as theory can bring a cohesion in social and financial values.

5. Stories and performance are not connected to each other by the executive. A possible solution for real innovation to the fourth age of housing corporations, is planning the cohesion of societal values that leads to its licence of existence to operate in the future.

6. The multidisciplinary nature of public real estate management is not a bottleneck if definitions and observation are clear. Not related to each other financial and non-financial assessment criteria create a bottleneck in the total control of a corporation and her reporting on them.

The summary conclusion as answer to the central question: 'are there contradictions in the social values that underpin housing associations that have an impact on the way they are governed?' is: *Yes. Executives who think at the highest level about how they should deal with values, ensure they control on their own, know what the consequences of their decisions are and take their responsibility.*

The research question has led to the conclusions and formed the basis for further research in the form of three follow-up propositions. These propositions deserve attention for further research on governance of corporations: the housing cooperative as a crowbar, the possible integration of Corporate Real Estate Management in between a Corporation and the Societal Autism of Corporation directors. The follow-up investigations are shown in the three propositions (a) a cooperative form – embodied by the Seven Cooperative Principles in 1844 – caused a bundle of values in socio-economic developments, (b) a non-monopolistic arrangement increases the future value of a corporation and (c) as long as social autism of Corporation directors continues, this blocks a change of Control. The Community would be leading about the objective of public housing if the inner striving for desire and power is controlled. The true value of a corporation is not organised by an executive in a controlled chaos on a sliding scale, but determined in the context of societal values that public housing can bring further. Substance is therefore immaterial: material immaterial. This science, built on facts, is like a house built of stones. And not an accumulation of facts as a pile of stones in the shape of a House.

The research is limited to the Netherlands in view of the complexity and topicality of the corporations in the Netherlands. But what makes the Dutch housing corporations now so unique in Europe? The next section places the Dutch Corporation also in the European perspective.

4. European context

Dutch politics has a general preference for a broad definition of the target group from the vision of the preventing of segregation and providing equal opportunities in the housing market, in comparison with a narrower definition in countries like Germany, Italy, Spain and Austria. Hieminga (2006) also distinguishes the social activities with support facilities – and in line with the service of general economic interest (sgei) definition – if (1) construction, rental, maintenance, renovation and possibly sales (whether or not under conditions) of rental properties in the regulated rent segment, namely the rental properties for the primary target group is clearly defined in terms of income limits, (2) the activities in the sense of promoting the quality of life and living quality as far as relating to regulated home ownership, (3) construction, rental and maintenance of social property meant for use by a social task, such as community schools, welfare buildings and such. Looking at the qualitative housing shortage and the influence of the tenants Gruis and Zijlstra (2006) conclude by means of a theoretical analysis that a client controlled stock has a very limited contribution to solve this need. European research of Gruis, Tsenkova and Nieboer (2009) shows that in addition to regulation or subsidies also working on culture change and professionalization of management organisations is of interest. Dreimüller (2008), Gruis (2009a) and Docters van Leeuwen (2009) already recalled that the definition of the ‘volkshuisvesting’ is not an easy task, which is strengthened by the call in the House of representatives in 2009 to Minister Van der Laan to get support within the European Union for the Dutch definition of housing. For European notions are the public-private characteristics and the quality of the housing stock in Netherlands considered as unique. The Dutch State ranks with the availability of social housing on the first place of the 27 Member States of Europe (35% of all houses carry the label social housing) and is at a great distance followed by England and Austria, each with 21 percent. In 18 European countries, the social rental sectorhas less than 8% of the total housing stock.

Cecodas Housing Europe shows in a review in 2012 again what is the balance of social, cooperative and public housing in 27 EU Member States. This is an update of the report Housing Europe (2007). The 2007 study is especially aimed at providing an overview of policy developments in the areas of housing and markets in the social, cooperative and public sector housing. The research Housing Europe Review 2012 (Pittini and Laino 2011) has focused on the way in which social housing systems are structured in the European Union and the developments in the sector. The research gives an answer to questions like, "what is social housing?, how much is the sector? Who are provided with social housing? How is social housing funded? Who has access to social housing? ' The 27 Member States were questioned about these items and are analysed by country. To compare all these countries with the Netherlands is a lot of work, but this is certainly a worthy research. On many points the Netherlands show an exceptional position. A striking example of this is that in the Netherlands social housing, as the highest in Europe, has 32% of the total housing stock. This compares to

Greece where this percentage is 0%. Cecodas Housing Europe is a European Federation of public, cooperative and social housing business, a network of 45 national and regional federations in 19 countries. In total she represents a control of 27 million households. This is about 12% of the existing housing in the European Union.

On the question of European colleagues how it can be that the Netherlands, as one of the richer EU countries, is in need of so much social housing, Netherlands still owes the answer. By defining an iron stock – the number of available homes for the primary target group – and the rest of the housing stock in a subsidiary, a commercial housing stock has appeared. By this model 'Servatius' – named after the Housing Corporation Servatius in Maastricht – (Aedes magazine 2007-4) by extrapolating to the Dutch social housing stock the Netherlands shares a similar place in the rankings as England, Austria, Denmark and the Czech Republic. This would be the solution for preventing the discussion in Europe about the social housing in the Netherlands and State aid, on which European Commissioner Kroes in 2005 from the European Union have previously complained.

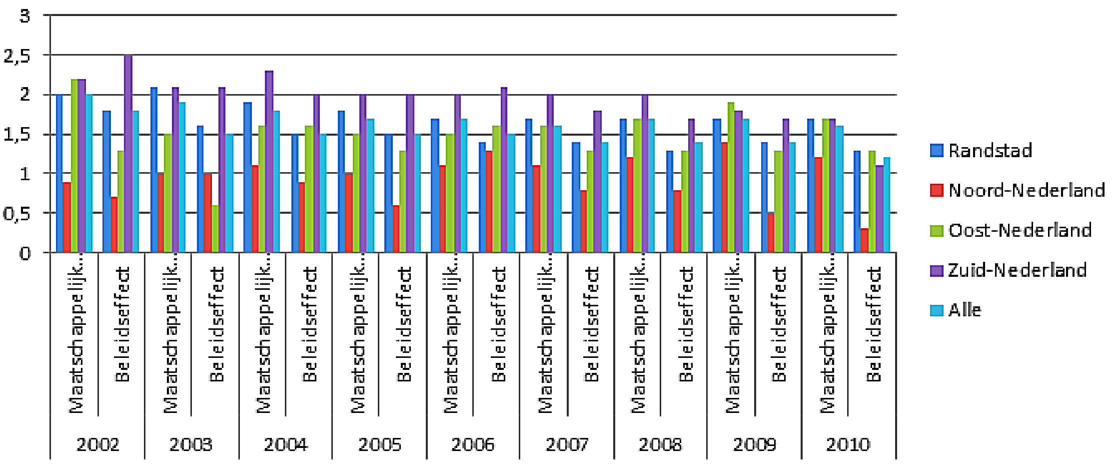
Now the unique position of social housing in the Netherlands is indicated in European perspective, it is important how the performance of housing associations in Netherlands can be indicated in financial and social returns, and what do these returns tell?

5. Accountability with the IPD Nederland Corporatie Vastgoedindex

IPD Netherlands (formerly aeDex) gives the performance of related corporations in returns and is a financial indicator for comparisons (Vlak 2006, 2007, 2009, Konings 2009, Vlak & Den Dekker 2008 en Vlak & Spelbos 2008). IPD is relevant because it aims to create transparency and contributes to further professionalisation of the real estate and investment market. IPD records the returns (Broek 2009) in terms of investment in direct property real estate, that were kept throughout the year. These are so-called standing investments. The independent investment efficiency concerns the so-called gross return on the basis of directly on the management and administration of the objects in the portfolio attributable gross revenue, market value and social management.

It can be concluded that 11% of the number of corporations, have a coverage ratio of 26% in 2009. This coverage ratio has dropped in 2009 compared to the increase in the previous eight years, while the number of properties within the corporations remains stable, according to the indication of IPD. The obvious rise of the size from 2004, which in 2007 and 2008 covered one third of the total home ownership of the corporations has got a relapse of a quarter in 2009, and is thus somewhat at the level of 2004 and 2005. This implies that the importance of the IPD is diminishing. The IPD Property index Corporation (2009) is a guide for the participating Corporation, and functions as a framework on (planned) results. The whole is part of a continuous process of benchmarking. The comparisons among themselves in a certain segment, as well as the analysis behind the numbers, limited to that examined market. The IPD indicates, that the index is just a means of getting information about the financial performance related to return on investment. For example, the policy impact on the primary social portfolio is only in financial and economic terms. The more qualitative choices made are not shown. The policy effect of the IPD also records the effects of the return, arising from the specific items of control. A distinction is made in that part of the portfolio, that is maintained primary with a view to achieving the social goals– the primary social portfolio – and that part for which this does not apply, not the primary social portfolio. The social return is made clear by the real return against what might have been achieved. This under the hypothesis of what could have been fully in line with the prevailing market rent of all properties. That are than the estimated social returns. There still remain two issues about it. First, the condition, that the size of the actual invested capital must be determined and what the minimum required rate of return on that equity should be. Secondly, the question has to be answered, whether the goals set by the company are realized on the basis of the benchmarking that is a reflection on what happened on the market for the participating parties. In Figure 18 the policy effects and the social dividend is shown for the years 2002 to 2010. The effect of the administrative anchoring that homes in the primary portfolio due to social reasons are rented below market rent, is called social dividend. About policy impact is spoken if it is transparent what the yield effects of the realized policy on the non primary social portfolio are. Providing insight into the efficiency effects of realized not primary policy portfolio is defined as policy impact. The policy effect over the period from 2002 to 2009 is measured constantly around the 1.5%. The social dividend for the same period is similar and not significantly different. When the framing-effect (Khaneman 2012:95) is applied it creates the image that 98.5% of the portfolio is not socially profitable.

Figure 2: Policy impact and social dividend 2002-2010 in % efficiency



But what do the comparisons of returns of the IPD tell and are they to be compared? For this research the Dutch IPD figures are put over the period 2000 to 2009 in cross tables with real estate index, efficiency, structure and policy impact. In some cases is chosen to omit certain figures from the cross tables to achieve correct connections. In the tables phases are introduced to indicate that classification and definition have changed over the years. The stages are 1, 2 and 3, respectively, 2001-2004, 2005-2006 and 2007, while the policy over the entire period from 2002 to 2009 has been measured. In and between the different phases are significant differences present caused by definition changes. The figures of the real estate index are processed from 2001 to 2007, over all the years the value over 3 years is annualized and therefore can be considered as a 'common denominator' so closing conclusions can be drawn. The figures for the year 2000 are no longer included in the cross table because the figures from this year are not annualized over 3 years and do therefore not fit in the system of the other years. Reason for this could be that the index in that year has started up and therefore a possible annualization was over more than 2 years. It is striking that in 2007 (phase 3) has been chosen to have only the figures for 2005, 2006 and 2007, and that while after 2001 just about 4 respective 5 years figures are given. A possible explanation is, that the figures were not favorable and therefore were not included in the index. In conclusion, to say that the universe of the IPD Property index Corporation is not frozen. This also means that if a participant or IPD points out inaccuracies in the (historical) data, these will be adjusted. Also are each year participants are added to the index or removed. This means that the IPD Index figures that publishes do not necessarily contain the most current data, although the differences on index level are never big. Remarkable is that data is not frozen. Even more interesting is that at inaccuracies data can be changed. In itself it is defendable that data can be changed due to an error, but the assessment lies with the Corporation that is providing them. And the question then is whether the assessment is correct, or if not (again) can be interpreted differently. But if margins are clear it has no significant impact on final conclusions. Also the actual content of the digits (Hordijk 2005a, Middelhoven 2008 and Hoogen 2010) fits within that framework, because mutations can occur afterwards. Of interest is the tendency of the last ten years and especially in terms of percentages, numbers and participant fluctuation. For the period under review can be concluded that the figures are not significantly different. The problem of constructed historical time series has been acknowledged earlier by Keeris (2005).

6. Conclusions

Findings I - Why this qualitative thesis 'Control of housing associations in consistency with social values'? To understand and to discover patterns about the how and why of the functioning of corporations in society as they do now. This qualitative study is about the search for ideas, backgrounds, motives, resistors and motives and is therefore suitable for the following question: which contradictions are there in the social values that underlie housing associations that affect the way they are governed? The overall summary conclusions to answer the central question is: *Directors, at the highest level thinking about how to deal with values ensure they drive on their own, monitor, know the consequences and take responsibility.*

Findings II - - On the question of European colleagues how it is possible that Netherlands, as one of the richer EU countries, needs so much social housing, the Netherlands still owes an answer. By defining an Iron Stock – the number of available homes for the primary target group – and the rest of the housing stock being put in a subsidiary, a commercial housing stock has appeared. By this model called 'Servatius' by extrapolation to the Dutch social housing stock the Netherlands has about the same level in the rankings as England, Austria, Denmark and the Czech Republic. This would be the solution for preventing the discussion in Europe about the social housing in the Netherlands and State aid, on which European Commissioner Kroes of the European Union has previously complained in 2005.

Findings III – The results of social housing index 2000-2014 MSCI-IPD. Corporations that want to better understand the returns of their portfolio and want to compare their figures to colleagues and competitors can participate in the aeDex / IPD property index corporation. This company comparison system offers corporations insight into their performance as an investor and manager of real estate. The aeDex / IPD property index corporation may make participants visible both their financial and economic and social performance. IPD Netherlands measures periodically the group of participating corporations and compares the results at the organizational level with the aeDex / IPD property index corporation. The aeDex / IPD analyzes the contribution of the various real estate objects to the result, the corporations compares results between themselves and makes comparison with other players in the property market as possible. The real estate index corporation aeDex Foundation aims to preserve the instrument for benchmarking and development through to its member participants.

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Serving Building End-Users: Network Positions, Knowledge and the Role of Various Professions

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Abstract

Built Environment research is beginning to pay more attention towards understanding facility end-user requirements. While this has been more of a focus within construction and architectural research, empirical investigations into how built environment professions serve facility end-user needs have been few and far between. This is due to the customary emphasis on the technical and technological aspects of built environment professions, as opposed to the managerial and social aspects of their work. The primary purpose of this paper is to identify and explore the networked relationships between various building professions during the design, delivery and early occupation of a facility. It reports the findings of an interpretive, inductive case study where network relationships were mapped with knowledge of user requirements being the key determinant of the binary relationships. The principal parties are the users themselves and the various professions serving them. Findings show that during facility design, delivery and early occupation, project sponsor and facilities manager roles remained central to this 'knowledge network'. Users and other professions relied heavily on the knowledge of these two roles. These findings add to current built environment theory by identifying facilities professionals and project sponsors as the two primary roles that can enable the built environment to support the activities of its users. The paper further proposes that only the aggregation of the 'operational' knowledge of building use (held by facilities professionals) and the' strategic' knowledge (held by project sponsors) can lead to a more robust theory of how the built environment can be developed around end-user needs.

Keywords: Built Environment, End-User Requirements, Network, Knowledge, Social Network Analysis

1. Introduction: A User-Centred Theory of the Built Environment

An understanding of building end user needs, whether defined through the customary triple constraint model of project management or through a much wider socio-political lens, is key to the life of successful construction projects. Research shows that an awareness of user needs leads not only to less critical, but also more satisfied clients (Kaya, 2004). It is therefore important that during construction projects, immediate and long term needs of the building users are identified and decisions built upon these throughout briefing, design and delivery of these projects (De wolf and Van Meel, 2002). This paper looks at a co-location (construction) project in the Scottish Borders to develop existing built environment theory on end users. Various built environment professions are mapped using Social Network Analysis with the exchange of building-related knowledge being the determinants of the actors' binary relationships. The theory developed provides new insights and understanding of user-centred theory as defined by Vischer (2008). The purpose is to deepen our sensitivity towards the 'theoretical' in a widely 'practical' field, and to especially develop a more tangible basis of incorporating knowledge of end-user expectations to make building projects more successful.

In the editorial to the special issue of *Building Research and Information* on 'Developing Theories of the Built Environment', Koskela (2008) points out that theory plays a central and crucial role in scholarly activities and also informs public policy concerning the built environment. Koskela notes that built environment theory been fragmented and under-resourced so far. Koskela further notes that built environment theory has also generally been providing the perspective of certain professions or groups, rather than a holistic, cohesive theory addressing the construction and use of the buildings. Koskela (2008) argues that a unified theory of the built environment be developed, especially since most problems associated with design and construction have been the outcome of inadequate theories underpinning the process.

Among theories of the built environment, those that approach users' experiences of built space are extremely important in that they provide a lens to view the creation and management of the built environment to serve the sole purpose of supporting the needs of its end-users. Such user-centred theories then, not only explain the complex relationships between buildings and occupants, but also allow for a more robust measurement of the degree to which built environment has been successful in fulfilling user expectations (Vischer, 2008).

These user-centred theories could generally be categorised on a spectrum of ranging from the macro to the micro. Theory of building use developed around research into the project stages of planning, building and delivery of the buildings, business processes (Cooper *et al*., 2004), building performance evaluation theory (Preiser and Vischer, 2004), building serviceability (Davis *et al*., 1993) and building information systems (e.g. Lutzkendorf and Speer, 2005) for example are theories that provide a larger, all-inclusive lens of building use. The other leg of theories including post-occupancy evaluation (Zeisel, 2006), evidence-based design (Healthcare Design 90, 2006) and the effect of physical features on neural processes (Eberhard, 2007) study the micro-level perspective of specific user needs. Kuhn (2012) notes that neither categories should be seen to be exclusive of each other, as both present different lenses to view the buildings as the means to satisfy users. Furthermore, Green and Schweber (2008) make a compelling case for the development of interdisciplinary middle-range theories that build on micro-phenomenon and connect these to grand theories. The primary purpose of such middle-range theories of the built environment, they pose, is to develop a theoretical response to specific issues: solutions that draw from a wide variety of disciplines and focus on specific, identifiable problems nonetheless.

The theory developed in this paper can perhaps best be categorised as a middle-range theory proposed by Green and Schweber (2008) that brings together a technical tool of representing social relations (Social Network Analysis) with the wider theory of knowledge ownership and sharing and the existing built environment theory on the building end-user. Using a specific context of a socially complex and strategically important co-location project, it links the findings of this one context to develop a better understanding of certain built environment professions in their inherent capacity to engage with and understand the specific (immediate and long term) needs of the people and organisations using buildings. This knowledge of user needs, the paper argues, makes these roles extremely important to the whole building development process.

This paper, which is based upon an inductive, interpretive case study of co-locating higher and further education institutions seeks to address the theoretical gap discussed above, simultaneously addressing the practitioner's need to know which building professions can best identify end-user requirements. This being a necessary step for developing successful buildings.

The structure of the paper is as follows. It begins with a brief review of the existing literature on the significance of knowledge as a means of creating value. This section discusses how knowledge of end-user expectations and needs constitutes a key components of what makes building projects 'successful'. Subsequently, the method of inquiry and the case study is presented. Then the network of key actors is reviewed. This leads to network data analysis and then onto the final section, where conclusions regarding significant built environment professions based on the network of project actors are reached.

2. Knowledge of User Requirements

The 'end users' can be defined as those who occupy or use the building. These persons may not be the experts at managing the buildings, but have knowledge and opinions about its performance in relation to their own objectives (Kaya, 2004; Lai and Yik (2007). A common characteristic of successful building projects is successfully meeting end-user requirements. This user satisfaction contributes to much wider benefits to the client organisation through sustained loyalty to the firm, repeat purchase, increased market share and profitability (Mbachu, 2003). The widely cited Latham Report (Latham, 1994) published by the UK government had reasoned that an important cause of built spaces falling short of client expectations was that construction professions usually designed and executed projects with environmental constraints, longevity and aesthetics in mind rather than the need of the user-clients. Such an observation either postulates that the construction professions involved either lacked clear knowledge of client's needs, or those professions which do have clear insights usually retained a less central role in the construction process. Either way, it is important to identify professions that hold the key to knowledge regarding built environment use.

The significance of knowledge as the means of creating value in the organisation has also increasingly come to the fore in management literature especially in the past fifteen years (Schreyogg and Geiger, 2007). Knowledge is now considered a significant resource (David and Foray, 2002) with knowledge work emerging as a dominant theme in the context of the knowledge economy (Robertson *et al*., 2003; Alvesson, 2004). Related concepts focus on the growing significance of social capital (Tsai and Ghoshal, 1998) the need to leverage knowledge assets (Newell *et al*., 2002) and improving the accessibility of knowledge (Rifkin, 2000). This literature establishes the significance of knowledge and knowledge sharing processes as the means of value creation.

Knowledge of end-user expectations and needs constitutes a key components of what makes building projects 'successful'. Hence its 'value' to the organisation undertaking the project, as well as the developer/ consultant is immense.

3. Case site and Research Methods

The AB co-location case study presented here is part of a much wider exploratory case study undertaken to assess a number of theoretical questions. The objective of this particular enquiry was to use Social Network Analysis in a mixed-method design to explore wider underpinnings of knowledge sharing within a project system. While the unit of analysis for the wider study was the project itself, the unit of analysis for the analysis presented in this paper is the 'core network' of also built environment professions and other managers which constituted of nine project actors identified by the 'ego' (the most central actor) in the wider network of the entire project, constituting of 52 project actors. The 'ego' was the individual with the most central location in the project network, with the widest number of ties with other actors and hence was in the best position to identify key project players.

The case site was a construction project of a co-locating campus undertaken by two established Scottish educational institutions: one Further Education (FE) institution and the other a Higher Education (HE) institution. Org-A is an FE institution while Org-B is an HE institution. The co-location project, now complete, was undertaken under the Scottish Executive's 'Shared Services Initiative', the purpose of which was providing better financial value FE/ HE through modern, shared, co-located facilities to replace outdated, dispersed campuses. Within the new campus, which jointly hosts both Org-A and Org-B, most of the physical infrastructure (services and spaces such as the libraries, catering, common areas and classrooms) was designed as shared areas for both Org-A and Org-B. However, within the campus, each institution continues to maintain its own autonomy as a separate entity with separate spaces for staff, research students, administration and specialist laboratories and teaching areas.

Apart from the advantage of providing a wider scope of academic collaboration across subject areas common to both institutions, both organisations saw this project as the means to offer far superior facilities and services to both students and staff, than what might have been possible for any single institution to provide on its own. As the new campus fulfilled the 'shared services' aims of the Scottish Executive's policy initiatives, this co-location was partly funded by the Scottish Funding Council (SFC), which remained an important stakeholder throughout the life of the project. For these reasons the project was perhaps the most important physical undertaking for both institutions quite possibly for the next decade.

Apart from the differing end-user they serviced (in terms of a different student and faculty body)- since Org-A was a further education body and Org-B a higher education institution- Org-A and Org-B were vastly different in terms of size and organisational structure as well. Org-B was physically dispersed over different campuses, and had an estates function with one senior management person was attached to each of its campus locations with responsibility for the estates, facilities, and services. Org-A, on the other hand, was a large organisation with a multi-tiered organisational structure. Although its presence in the region was small, it had a layered organisational structure with a high powered Director of Estates formally responsible for the management of all campuses and estates and a Director of Campus Services (who was supported by a formal in-house facilities services team) responsible for the campus in question.

The case site was studied during its final completion year and post-occupancy (Figure 1), however the data used in this paper was collected prior to full occupancy: hence capturing relational data during the development of the buildings, a requisite aim of the enquiry.

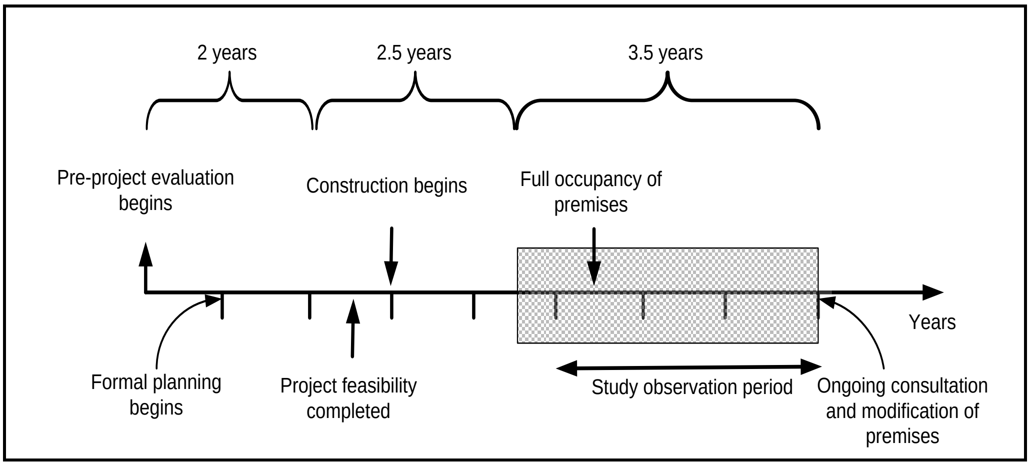

Figure 1: Timeline of the case

Key actors in the co-location project identified by the 'ego' in the wider project network were those with a high value as sources of knowledge. Together, these nine actors were identified as the 'core network' of the project. These actors were the Vice Principal (Org-B), Director Planning (Org-B), Director Campus Services (Org-B), Director Finance (Org-B), Building Surveyor, University Secretary (Org-B), Project Sponsor (Org-A), Project Manager and the Principal (Org-A). Questionnaires were then distributed among these primary actors and their responses solicited regarding their interdependencies and knowledge of:

- Real estate and strategic needs of organization (knowledge area 1)
- Operational requirements of the buildings (knowledge area 2)
- Human and environmental factors in buildings (knowledge area 3)
- Planning and project management involving built facilities (knowledge area 4)
- Facility and service delivery (knowledge area 5)
- Communication (knowledge area 6)

Knowledge area 6 was added as a particular knowledge area since practitioners find great difficulty in making end-users see a longer-term perspective as well as overcoming cultural barriers to understanding real end-user needs (Pemsel et al., 2010). Both these challenges can be overcome through effective communication and hence the profession with the superior knowledge of communication channels and structures was better equipped to be able to engage with the end-users.

4. Network Data and Analysis

Previous efforts on capturing relationships of built environment professions holding key knowledge of users has typically been limited to pre-identified professions in the project. Pemsel *et al*. (2010), for example, focuses on three players only: end users, end users project manager (EPM-which they define as a selected end user) and the facility planners (FP). This paper, however, uses a case study of a complex, phased co-location project of two Scottish educational institutions (one Further Education, the other Higher Education) and maps 52 key players and their dyadic knowledge-dependent relationships identified through interviews with stakeholders. The mapping is carried out using Social Network Analysis (SNA), which is a method of exploring social structures through the use of network and graph theories. SNA describes networked structures in terms of nodes (individual actors, people, or organisations within the network) and the ties (i.e. relationships or interactions) connecting these nodes or actors. A broad majority of social network studies either use the “whole network” or the “egocentric” design. The first: whole network studies, examine sets of interrelated actors that are related. Egocentric studies, on the other hand, focus on a focal person and the relationships in its locality (Marsden P., 2006). The matrix representation of this common form of network data is known as a “who to whom” matrix or a *sociomatrix*. The results presented in this paper follow the whole network design where the ‘core network’ is identified from a wider network of the entire project. Data regarding knowledge sharing (the relationship) between and primary actors is developed. The data obtained was directional and valued (i.e. the flow of knowledge had a direction and the collaborative tie had an intensity assigned by the recipient actor), and the analysis was carried out using the Ucinet 6 software (Borgatti *et al*., 2002).

The data on the level of collaboration and knowledge sharing (collaborative relationships) between the key actors was collected using a questionnaire. The other eight key actors comprising the core network were the other eight ‘alters’ identified by the ‘ego’ of the wider network of 52 actors. By ‘collaborative ties’ the research means the existence and strength of knowledge-sharing between the key actors on issues related to the six knowledge areas identified. Each questionnaire respondent was asked to identify the other ‘alters’ in the core network with whom they discussed, shared or developed knowledge relating to any of these FM competencies. The responses were not dichotomous (dichotomous responses are binary, with a value of 0 or 1, showing only the existence or non-existence of a tie) but valued (where respondents placed a value between 0 and 5 on their knowledge sharing ties with the other ‘alters’) and directional (where knowledge sharing relation had an origin and a destination). This ego-centric core network had nine actors, i.e. N=9, where N was the total number of nodes in the network.

$$N = \{n_1, n_2, n_3, n_4, n_5, n_6, n_7, n_8, n_9\}$$

The lines between the actors (for example line $l_{1,2}$ between n_1 and n_2) as shown in figure 3 and 4 depict the degree of reliance of n_1 on n_2 for building-related knowledge. Line $l_{1,2}$ depicts the degree of reliance of n_2 on n_1's expertise. Figure 3 shows only the ties, while Figure 4 shows the ties and the *strength* of the tie i.e. the intensity of knowledge dependency on a certain actor, for knowledge area 3: Human and Environmental Factor.

The sociomatrices for each of the knowledge areas were valued and non-symmetric and took the following form shown in Figure 2 below:

		1	2	3	4	5	6	7	8	9
		1	2	3	4	5	6	7	8	9
1	1	0	4	5	0	0	3	0	0	0
2	2	4	0	5	4	1	3	4	1	3
3	3	4	4	0	3	4	4	4	2	4
4	4	3	2	5	0	2	4	5	2	5
5	5	0	1	5	2	0	0	3	2	2
6	6	0	1	5	1	3	0	1	0	2
7	7	0	3	4	2	1	1	0	3	5
8	8	0	0	0	0	1	0	1	0	0
9	9	0	4	5	3	0	0	4	0	0

Figure 2: Sociomatrix for Knowledge Area 3-Human and Environmental Factors

Similar sociomatrices were developed for each knowledge area. Two digraphs (the graphical representation of the relational data) for the above adjacency matrix of knowledge sharing of human and environmental factors are shown below. The first diagraph (Figure 3) shows only the direction of the knowledge sharing without tie strength (i.e. the intensity of the relationship). The second diagraph (Figure 4) is a valued graph, with the thickness of the lines depicting the tie strength between the actors. Figure 4 is obtained by adding the tie strength data to the diagraph in Figure 3. The arrows (in Figure 3) depict the flow of knowledge and line thickness (in 4) depicts the tie strength of the collaborative relationship. Similar digraphs were created for all knowledge areas.

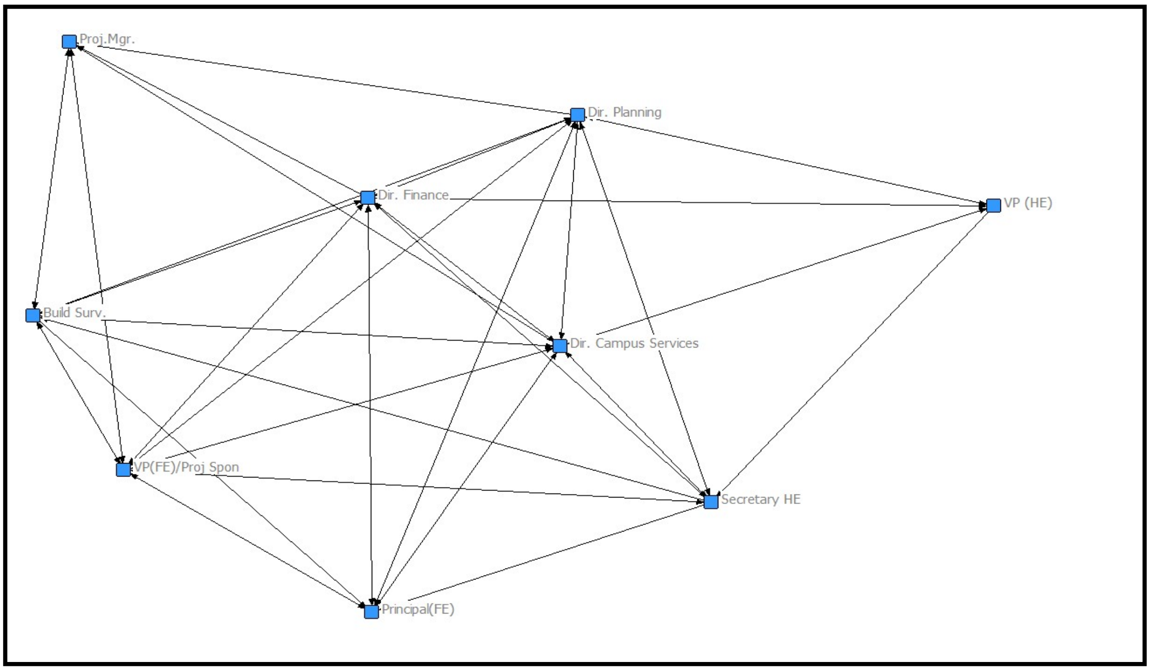

Figure 3: Diagraph of Knowledge Area 3 (Human and Environmental factors)

The analysis of the 'human and environmental factors' knowledge area is discussed here in detail. What is immediately evident from Figure 3 is the fact that despite the core network being a closely knit unit, not all actors were approached by others as sources of knowledge. Human and environmental concerns are a vital component of any workplace and the individuals that contribute to decisions relating to it, inevitably affect workplace usage, social interactions and overall user experience. In the core network, certain actors for example the vice principal of Org-B and the construction project manager were not sources of knowledge for this particular competency. At least five or more other actors said they had never approached these actors for human and environmental issues. They were, nevertheless, important for the knowledge sharing process supporting the overall decision-making process during design and construction. On the other hand, the network analysis shows that there were certain individuals who were repeatedly approached for expertise related to knowledge of human and environmental factors and were approached by almost all actors in the core network. These were the Project Sponsor (Org-A) and the Director of Campus Services (Org-B). The degree of reliance on these individuals for human and environment-related knowledge was consistently given a very high value by other actors. Two other actors, the Director of Finance (Org-B) and Principal (Org-A) were also approached by six other actors. However the degree of reliance on them for expert knowledge was considerably lower.

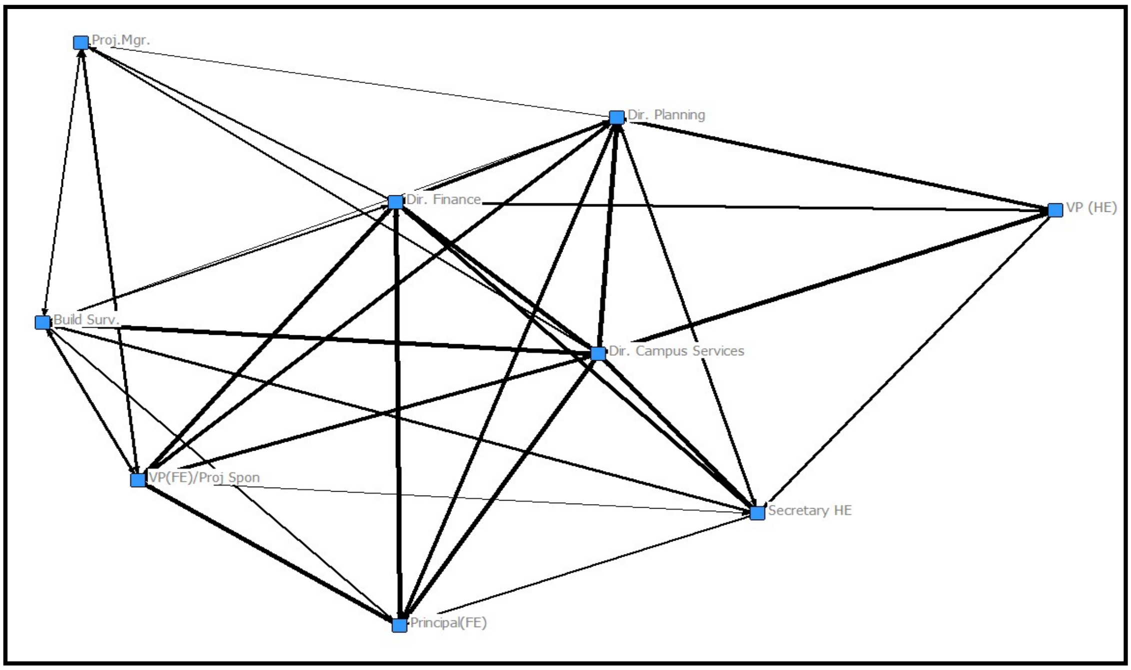

Figure 4: Diagraph of Knowledge Area 3 (Human and Environmental factors) with tie strength

Figure 4, which shows the tie strengths, provides a visual picture of the intensity of collaborative ties between the members of the core network for this competency. Interestingly, the ties are also strongest for the four individuals noted above, who were the primary sources of human and environment-related knowledge during the co-location project. This finding shows that together not only were these individuals a source of expertise to others, but that they remained close to each other for collaboration and to complement each other's knowledge relating to this competency.

Similar findings, with varying degrees of tie strengths were found for the other five knowledge areas. Table 1 below gives a synopsis of the findings from the sociomatrices and diagraphs of all the six knowledge areas, including competency 3 discussed above. In the table, a single 'X' denotes a low status as source of knowledge for each of the FM competency areas, while an 'XX' denotes a high status as a source of knowledge for each of the FM competency areas for an actor.

Table 1: Individuals with high value as sources of knowledge

	Vice Principal (Org-B)	*Director Planning (Org-B)*	*Director Campus Services (Org-B)*	*Director Finance (Org-B)*	*Buildin g Survey or*	*Universit y Secretary (Org-B)*	*Project Sponsor (Org-A)*	*Project Manag er*	*Principal (Org-A)*
K 1	*X*	*XX*	*XX*	*X*			*XX*		*X*
K 2			*XX*				*XX*	*X*	*X*
K 3			*XX*	*X*			*XX*		*X*
K 4		*X*	*XX*	*XX*	*XX*		*XX*	*XX*	*XX*
K 5			*XX*	*X*	*X*		*XX*		*XX*
K 6		*X*	*XX*	*XX*			*XX*	*X*	*XX*

A comparison of the various digraphs (not shown here) demonstrates that while differences existed across different knowledge areas, overall the core network had close knowledge sharing and collaborative ties. Nevertheless two individuals, the Director of Campus Services (the top facilities manager) and the Project Sponsor (senior manager responsible for the overall success of the project) remained central as sources of vital knowledge for all competencies. These two actors were also the individuals with the strongest ties with other actors in the core network. The analysis of the wider whole network (not shown here) also showed that these two individuals were strong ‘connectors’ between the other actors in the whole network as well (i.e. some actors would have been totally disconnected from the rest of the network were it not for these individuals). The analysis of the core network’s relationships primarily showed the emergence of two individuals as critical disseminators of building -related knowledge and a clear indication by other actors that not only were the top facilities manager and project sponsor the source of expertise for real estate strategic planning, but also operations, communication, the management of the entire project, facility service delivery and environmental factors.

In order to investigate the direction of knowledge sharing, the research also computed the nodal degrees of the knowledge sharing phenomenon within the core network (see table 2). The ‘degree’ for a node, defined as the total number of relationships involving that node and it permits comparisons between network participants. Individuals with higher degree values are more active than those with lower values. The ‘indegree’ for a node is the number of relationships in which a particular node is the target (in this case, approached for certain building-related knowledge). Both nodal degrees are measures of a node’s connectivity with other nodes: the higher the node degree, the higher its connectivity. Again, the two actors: the facilities head (Director of Campus Services) and the project sponsor (Vice Principal, Org-A) came out as the leaders when it came to being the source of building-related knowledge for all core network actors. The implications of these findings are discussed in the conclusions section.

Table 2: Nodal Indegree of actors in the network

	Vice Principal (Org-B)	Director Planning (Org-B)	Director Campus Services (Org-B)	Director Finance (Org-B)	Building Surveyor	University Secretary (Org-B)	Project Sponsor (Org-A)	Project Manager	Principal (Org-A)
K 1	15	29	36	20	17	15	35	24	24
K 2	8	14	33	13	17	11	29	18	20
K 3	11	19	34	15	12	15	22	10	21
K 4	9	16	35	24	22	7	28	23	22
K 5	7	11	29	14	16	8	22	11	19
K 6	16	19	30	21	14	15	24	19	21
Σ Nodal Indegrees	**66**	**108**	**197**	**107**	**98**	**71**	**160**	**105**	**127**

5. Discussion and Conclusions

As discussed earlier, established theories of the built environment tend to be either product-oriented (how the building and its associated services function post-completion) or process oriented (how buildings are procured and produced). In neither set of theories do end-users play a pivotal role. A likely gap in built environment theory, therefor, exists around the nexus of end-users, perhaps due to the 'technical' focus of built environment research that does not capture softer, human aspects of the context. It is therefore important that built environment theorists make a conceded effort to capture the perceptions, needs and expectations of facility end-users in order to develop a coherent, integrated theory that assimilates end-users into previously developed theory. The widely cited Latham Report (Latham, 1994) has also reasoned that an important cause of built spaces falling short of client expectations was that construction professions usually designed and executed projects with environmental constraints, longevity and aesthetics in mind rather than the need of the user-clients. Such an observation either postulates that the construction professions involved either lacked clear knowledge of client's needs, or those professions which do have clear insights usually retained a less central role in the construction process. Either way, it is important to identify professions that hold the key to knowledge regarding built environment use.

This paper therefor asserts that one way is to identify built environment professions/ roles that best capture end-user requirements- be they related to strategic real estate needs of the organisation, operational requirements of the buildings, human factors affecting building design and use, the planning and execution of building projects, or the facility and service delivery during the operational life of these built assets. The analysis of network data presented in the previous section helps built environment theory by identifying certain professions and roles that remained pivotal in knowledge dissemination (leading to policy and strategy development as well as project execution) related to several aspects of end-user needs within the core project network. The findings from the network analysis show that during facility design, delivery and early occupation, project sponsor and facilities manager roles remained central to this ‘knowledge network’. Users and other professions relied heavily on the knowledge of these two roles. These findings add to current built environment theory by identifying facilities professionals and project sponsors as the two primary roles that can enable the built environment to support the activities of its users. The paper further proposes that only the aggregation of the ‘operational’ knowledge of building use (held by facilities professionals) and the’ strategic’ knowledge (held by project sponsors) can lead to a more robust theory of how the built environment can be developed around end-user needs.

The findings help develop an understanding that certain built environment professions (the project sponsor and the facilities head) in their inherent capacity to engage with and understand the specific (immediate and long term) needs of the people and organisations using buildings, can be pivotal in developing a closer understanding of end-user needs throughout the life of the construction and occupancy of built assets.. This inherent knowledge of user needs makes these two roles extremely important to the whole building development process.

These findings support earlier theory developed within facilities management domain such as McLennan’s (2000) work which argues that building (or facilities) knowledge that has strategic value is that which pertains to its understanding of the relationship between the performance of physical resources and the customer/ end user being served. Pathirage *et al*. (2008) view such knowledge to be vastly tacit in nature and assert that it is necessary for facility managers to realise that they hold the unique information on the physical resources and their use over time. In their proposed Intellectual Capital Framework for FM, FM’s knowledge capital is the outcome of the knowledge it derived from strategy, systems and assets (‘structural capital’); customer’s orientation and market positioning (‘customer capital’); and the knowledge and capabilities of individuals to provide solutions to facility customers (‘human capital’). Together this knowledge base, they argue, can be used to create value for the organisation. The findings from practice, presented in the paper augments this key role of facilities managers. The role of project sponsors as carriers of important tacit knowledge regarding end-users has been less explored in theory and this research must be taken forward to explore this aspect further.

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Emerging Issues of Stakeholder Management in PPP Projects and Improvement Measures: An Australian Study

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Abstract

Many countries around the world are in search of new means to engage the private sector in managing and financing infrastructure through Public Private Partnerships (PPPs). However, most of the PPPs have faced issues during design and concession period. When considering Australian context Stakeholder Management (SM) related issues have been reported as one of the main reasons for failure in several instances. PPPs involve many stakeholders whose interests might not be in agreement leading to conflicting objectives. In such situations SM has a high level of importance to avoid the conflicts and to achieve the success of projects. Therefore, this research aims to determine the current emerging issues related to SM in Australian PPPs and to investigate the strategies to cope with those issues. Mixed methods of research were adopted in this research. Initially critical review of literature was undertaken followed by 19 semi structured interviews and a questionnaire survey. The findings revealed twelve critical issues related to SM. A variety of SM strategies to cope with the critical issues were also established. The proposition that the Government sector is better equipped to manage the general public involving in economic decision making was further confirmed via the findings. Also the findings insisted the necessity of a strong Government in managing the stakeholders of a PPP project. Nonetheless in reality the Government tries to transfer the entire SM risk to the private sector.

Keywords: Public-Private Partnerships, Stakeholder Management, Issues, Government

1. Introduction

PPPs are a popular form of major project procurement for the delivery of building and infrastructure facilities. Service contracts, management contracts, lease contracts, build operate transfer and similar arrangements, concessions and joint ventures are some different formats of PPPs (Felsinger, 2008). According to Grimsey and Lewis (2002), achieving value for money in the services delivered and allowing the private sector entities to meet their contractual obligations are the primary objectives of using PPPs in delivering public infrastructure. PPPs have become a popular method to procure infrastructure projects in Australia. The PPPs in connection with building and infrastructure procurement constituted around 5% of the new investments in Australia in 2009 (Chan et al., 2009).

However, Johnston (2010) highlighted many implementation issues in Australian PPPs. The Sydney Cross City Tunnel, the Southern Cross Station in Melbourne and the Southbank Technical College and School are some examples where the public has been disappointed which leaded to adverse publicity for the Government and commercial losses for the private sector (Wilson et al., 2010). Johnston (2010), Hodge (2004), Siddiquee (2011), Johnston and Kouzmin (2010) and Regan et al. (2011) pointed out many issues in Australian PPPs. Some of these issues in border context can be viewed as: lack of transparency of the PPP arrangements, lack of monitoring during the operations, lack of collaboration between the public and private parties, lack of trust towards PPPs, political agenda towards PPP projects and lack in addressing the interests of the general public. These issues can be directly associated with ineffective SM practices. Similarly stakeholder opposition towards the PPPs has been reported as one of the main reasons for the failed PPP projects globally (El-Gohary et al., 2006, Siemiatycki, 2009, De Schepper et al., 2014, Smyth and Edkins, 2007). As such the issues related to SM should be further explored to investigate the strategies to cope with those issues. Chinyio and Akintoye (2008) confirmed the importance of SM in the modern forms of construction procurement such as partnering and private finance initiative. Accordingly many stakeholders are involved in this process whose interests are not always likely to be in agreement. According to a report published by World Bank, the first factor out of seven major points that are holding up private investment in infrastructure is the wider gap between the Government and the private sector interests (De Schepper et al., 2014). However, according to De Schepper et al. (2014) these stakeholder issues do not merely emerge because of this gap but due to the concerns related to ineffective SM approaches. Despite the literature have suggested proper SM a systematic SM framework for PPPs is yet to be developed in addressing the current emerging issues in PPPs.

The objective of this paper is to address the aforementioned gap and contribute to the knowledge base of SM in PPP projects by presenting findings regarding the current emerging issues in the Australian PPP market. Also to propose a list of SM strategies in addressing the current emerging issues. This study is part of a larger research project which aimed at developing a SM framework for PPP projects in Australia. The next section will discuss SM implications in PPP environment highlighted by previous studies. Then it will explain the research methodology of the study followed by research findings and the discussion of the findings. Finally some conclusions were drawn.

2. Stakeholder Management Implications in PPP Environment

2.1 SM in PPPs

SM concepts continued to evolve from general management to construction project management literature. Many authors have highlighted the importance of stakeholder consideration in construction projects. Assudani and Kloppenborg (2010) and Cleland (1998) suggested that success in construction projects significantly depends on meeting the needs of stakeholders. Bourne and Walker (2005) and El-Gohary et al. (2006) highlighted that stakeholders play a decisive role in construction projects which can make or break a project. Before discussing the SM in PPP project environment it is worthwhile in defining SM in a project. Rowlinson and Cheung (2008) provided a definition for SM by using the studies undertaken by Brammer and Millington (2004) and Pajunen (2006). Turner (2003) and Yang and Shen (2014) also provided definitions for SM. According to these scholars this research defines SM as “A process of identifying, negotiating, engaging stakeholders and developing relationships among stakeholders to achieve minimum project risks and facilitating projects to deliver the project timely and effectively.”

El-Gohary et al. (2006) initiated the development of a SM model for PPP projects. This semantic model was developed to capture and incorporate stakeholder input in the design. But according to Henjewele et al. (2013), the proposed semantic model is too complex to adopt in real projects and has only focused on the design stage. Also this model has only concentrated on the public involvement process of PPPs. Henjewele et al. (2013) developed a SM model for the whole life of a PPP project which insisted the importance of incorporating the ideas of the general public. However this model is too generic and has not considered the actual level of complexities associated with the PPP procurement structure. Ng et al. (2013) and Ahmed and Ali (2006) also highlighted the importance of considering the people as partners. Ng et al. (2013) developed a framework for the successful public engagement. Majamaa et al. (2008) also did a study on how to build the fourth P into the PPP process using some case studies in Finland. However no study has focused on exploring SM related issues and the strategies to cope with those issues. These SM strategies will help to develop a proper SM framework for PPPs. To achieve the main aim of this study it is worth to investigate the issues highlighted by the previous studies that are directly related to SM practices.

2.2 Lessons from Recent Experience in PPPs in Australia

Political agenda towards these infrastructure project decisions have created many issues from the start of several PPP projects in Australia. According to Siddiquee (2011), the Sydney Cross City Tunnel project was politically advantageous in a PPP structure and in reality the way it was structured didn’t produce the best outcomes. Lack of information dissemination to the public is another critical issue identified in the wider PPP literature (Linder, 1999). While general public tend to ask for more information of PPP projects, the Government had to maintain a balance of what information to be disclosed and what are commercially sensitive. This has become problematic in many cases and led to citizens’ distrust towards these infrastructure developments. Serving the wider community is one of the main objectives of using PPPs in infrastructure development. However, Wilson et al. (2010) highlighted that the Sydney Cross City Tunnel, the Southern Cross Station in Melbourne and the Southbank Technical College and School are the examples where the interests of the general public are not well addressed. Johnston (2010) highlighted another critical issue as longer-term performance monitoring is lacking in the Australian PPPs which is often need to sustain the defence of the long-term operational viability or success of a PPP versus traditional procurement. Further Siddiquee

(2011) pointed out that there is no sufficient staff capability for the PPP delivery. According to Kwak et al. (2009) this can lead to tensions between public and private partners and, if not remedied, it could lead to project failure. Another critical issue is the conflicts between the public and the private partners are not well managed. According to Johnston (2010), this may affect the core value of PPPs and potentially represent a major, but usually silent, pitfall within the model.

Table 1 summarises the above issues in PPPs explored by the previous studies. Most of the issues in Australia have been echoed by the authors in global context demanding urgent research efforts. All the above issues can be directly related to SM practices of a project. For example political agenda deals with stakeholder interests and effective stakeholder analysis might help to solve those issues to a greater extent (De Schepper et al., 2014). The issues related to the general public interest also can be directly related to SM as public engagement is one of its major components (Leung, 2010). Performance monitoring issues also can be directly associated with SM practices as it involves following-up the strategies and actions that have been implemented (Karlsen, 2002). Staff training aspect and conflict resolutions are two of the major components of SM framework of a project (Yuan et al., 2009).

Table 1: Summary of the issues in PPPs

Issue	*Johnston and Kouzmin (2010)*	*Siddiquee (2011)*	*Regan et al. (2011)*	*Johnston (2010)*	*Wilson et al. (2010)*	*De Schepper et al. (2014)*	*Kwak et al. (2009)*	*Henjewele et al. (2014)*	*(Jepsen and Eskerod, 2009)*	*(Koppenjan, 2005)*	*(Saengsupavanich et al., 2012)*
Political agenda towards PPP project decisions	*x*	*x*		*x*		*x*	*x*				
Lack of information dissemination to the public	*x*		*x*	*x*		*x*		*x*			
Interests of the general public are not addressed				*x*	*x*	*x*		*x*			*x*
Lack of longer-term performance monitoring				*x*	*x*						
Lack of staff capability in the PPP project delivery		*x*	*x*			*x*	*x*				
Conflicts are not well managed	*x*	*x*	*x*			*x*					
Difficulty in assessing the expectations of each stakeholder						*x*			*x*		
Lack of interaction with the stakeholders						*x*				*x*	

3. Research Methods

3.1 Data Collection & Analysis

The eight SM related issues explored by the literature review were discussed in the previous section. Subsequently semi structured in-depth interviews were adopted as means of further investigating the SM related issues in the Australian context. Also to explore the strategies to cope with the SM related issues. At present nineteen semi-structured interviews were conducted. Due to the involvement of multiple numbers of stakeholders in a PPP project, we stratified the sample into two professional groups to obtain the public and private professional insights into the research questions. Respondents were selected randomly by contacting the Government Departments and the private companies that have dealt with a variety of Australian PPPs. Successively a questionnaire survey was conducted to further evaluate the criticality of the identified issues from the literature review and the interviews. The online survey tool ‘Qualtrics’ was used to distribute the survey. Stratified and random sampling was again used. The survey was distributed to the contact lists in public and private company websites which have dealt with PPP projects in Australia. Additionally, many respondents were found from the LinkedIn social network where pools of professionals get in to contact. In order to identify the relative significance of SM related issues for different stakeholders, Likert-style rating questions, using a five-point scale. The scale intervals in this research can be interpreted as follows: (1) not critical at all; (2) not critical; (3) Neutral; (4) critical; (5) extremely critical. Overall, 357 responses were received of which 341 were valid and used for further analysis.

The interview results were analysed using the content analysis via NVIVO software. The questionnaire data were analysed using the IBM statistical package SPSS22 soft-ware. Initially descriptive statistics such as mean and standard deviation were used. The responses given by the respondents were tested for the null hypothesis (i.e. that means between groups do not differ significantly) using non-parametric tests suitable for small and unequal sample group sizes. As such the Mann–Whitney U-test can examine the level of agreement. The null hypothesis is that the mean significance of each factor is equal between any two groups. If the value of U exceeds its critical value at some significance level (0.05), there is evidence to reject the null hypothesis.

3.2 Analysis of the background of respondents

The interview participants were all senior managers involved in the bidding, construction and operational phases of PPP projects. All of the interviewees had more than five years’ experience in any type of PPP project with some SM experiences. 10 Panel members represented the private sector, 5 the public sector where as 4 have involved in both the sectors. Considering the questionnaire survey 37% of the respondents had more than ten years of professional experience and 32% had more than 5 years of experience. Also nearly 50% of the respondents had the exposure for 2-5 number of PPP projects. Therefore, the respondents can be considered as well experienced in this field. There were representations covering both the private and public sector views. Figure 1 shows the sample structure for the interviews and the questionnaire survey respectively.

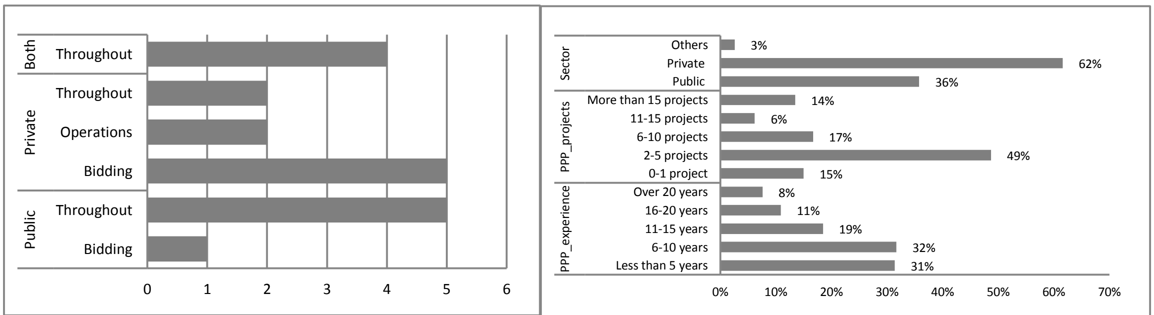

Figure 1a: Sample structure (interviews) *Figure 1b: Sample structure (survey)*

Figure 1: Sample structure

4. Research Findings

4.1 SM related issues in PPPs

Table 2 summarises the interview and the questionnaire survey results. It shows the number of interviewees agreed for each of the issues. Also it reports the mean response rating values for the questionnaire survey results. After the interviews four new issues (Issue_3, Issue_4, Issue_5 and Issue_7) were added into the SM related issues identified from the literature review. Interview respondents agreed that all these issues are critical in PPP environment. One interviewee highlighted that it is essential to identify the issues in the past projects and implement corrective actions from a SM point view. Considering the questionnaire survey results no mean value scores fell into the 'extremely critical' (4.50) and 'not critical at all' (1.5) categories, which indicates that all of these 12 issue are critical for each group.

Both the interview and survey results have confirmed the Issues_4 is critical in Australian PPP environment. This was captured from one of the interviewee representing the private consortium. Accordingly they are interacting with multiple Departments when working on a PPP. However, these departments provide contradicting information which has leaded to many conflicts within the partnership. The Issue_6 is a well-recognised issue in the wide PPP literature. Interviewees highlighted that most of these PPPs are in existence due to a political party pushing through for its political gain. And they stressed that in reality this decision should be longer term economic and social decision rather than political. The representatives from the private consortium explained the Issue_5 as, the project brief and the reference design prepared by the Government is not sufficiently comprehensive leading to many issues during the operations. Regarding the Issue_12 the interviewees highlighted that there are many loopholes in the PPP contracts which have leaded many conflicts. Therefore, they underscored the importance of the relationships between the parties to the contract demanding urgent research effort for proper strategies to improve the strength of relationships. Private sector consortium members were desperate about the Issue_2 and they urged the need for more stakeholder engagement by the Government. Issue_7 was recognised from the interviewees representing the private sector. Accordingly there is a lot of nervousness around the financiers due to the current conditions in Victoria (the fact that the Government could change at any point in time). This has leaded to less financial support for the PPP development process. Interviewees from both the sector highlighted that as the PPP concept is fairly new to Australia there is a lack of sufficient resources to manage these projects (Issue_11). Also the interviewees highlighted that some of the managers consider moving on to the operations as the focal point of these projects. However they stressed that it should not be the case. Therefore they stressed the issue of lack of monitoring during the operations (Issue_10). Further the interviewees from both the sector highlighted the difficulty in forecasting the stakeholders and their interests throughout the project life cycle especially due the long term nature of these projects (Issue_1). The Issue_3 and Issue_9 have reported low mean values as opposed to the literature review and the interview results. For example the Issue_9 was a well-recognised issue in literature and also the interviewees confirmed it. One of the interviewees highlighted that there are many PPP projects that have pushed into the industry without considering the needs of the general public. Although the questionnaire survey reported low mean values for these issues they are in acceptable level with a mean value above 3.0 and therefore considered as critical.

Table 2: The SM related issues in PPP projects and their scores and rankings in different groups

Code	Issue	Interview results	Questionnaire Survey Results						
			Overall		Public		Private		P-value
		No of agreed interviewee	Mean	Rank	Mean	Rank	Mean	Rank	
Issue_4	Responsibilities overlap between different Government agencies	15 out of 19	3.70	1	3.63	2	3.75	1	0.343
Issue_6	Political interests push PPP project decisions rather than social and economic	19 out of 19	3.66	2	3.65	1	3.67	2	0.723
Issue_5	Incomprehensible project brief and reference design leads to uncertainties	16 out of 19	3.44	3	3.27	4	3.56	3	0.044
Issue_12	Not efficiently managing conflicts between the private and Government	17 out of 19	3.44	4	3.25	6	3.56	4	0.011
Issue_2	Lack of early stakeholder engagement	13 out of 19	3.43	5	3.25	5	3.52	5	0.049
Issue_7	Financier's nervousness due to changes in the Government	14 out of 19	3.40	6	3.29	3	3.46	6	0.190
Issue_11	Lack of staff capability in the PPP project delivery	15 out of 19	3.23	7	3.16	7	3.26	8	0.516
Issue_10	Lack of monitoring in stakeholder needs and issues during operations	18 out of 19	3.18	8	3.09	8	3.25	9	0.236
Issue_1	Difficulty in identifying stakeholders and their interests throughout the PPP life cycle	15 out of 19	3.15	9	2.94	11	3.27	7	0.004
Issue_8	Lack of information dissemination to public	17 out of 19	3.09	10	3.02	10	3.14	10	0.233
Issue_3	Not disclosing the history behind PPP project to the private consortium	16 out of 19	3.02	11	2.80	12	3.14	11	0.004
Issue_9	Interest of the general public is not well addressed	15 out of 19	3.01	12	3.11	9	2.96	12	0.645

Reliability analysis is conducted to test the internal consistency of the survey variable data. Cronbach's alphas are 0.853. It is much higher than the 0.70 of Nunnally's guideline (1978). The results of reliability tests show that the stakeholders agreed on most of the SM related issues. However, there are some disagreements reflected by the scores and rankings in different stakeholder groups. For example, the mean and the ranking of the issue "Issue 12" is higher for the private sector when compared with the public sector. However it is important to investigate whether these differences are statistically significant. Therefore, Mann–Whitney U-test was used to explain these disagreements between stakeholder groups. The test results of pairwise comparisons between public and the private sectors are summarized in Table 2, which indicates that there are significant differences in the opinions between groups for the issues "Issue 6", "Issue 7", "Issue 8", "Issue 9" and "Issue 11". All these issues have become critical for the private sector side of the partnership.

4.2 SM strategies for PPP project success

Interviewees were asked to propose some improvement measures to cope with the above identified SM related issues. The following section will discuss the strategies proposed by the interviewees for each of the issue.

The interviewees emphasized the importance of having a good understanding on each others objectives in a team. Appointing an independent party to monitor the stakeholder matters during initial stages was another recommendation. Representatives from the private sector proposed that extensive initial consultation by the Government will help to understand the stakeholders and their needs more sensibly. These were proposed to address the Issue_1. The following were proposed to address the Issue_2. Both the sectors highlighted the need for extensive stakeholder engagement during the initial stages by the Government. Also the private sector representatives highlighted the necessity of participating in the very early information sessions conducted by the Government. The interviewees from the private sector proposed to maintain a register of all commitments made to stakeholders before bidding by the Government sector to address the Issue_3. Accordingly that register should be shared with the project company within the tender. Also the private consortium members proposed to have a process to streamline the overlaps between different Government agencies (Issue_4).

As the project brief and the reference design prepared by the Government is not sufficiently comprehensive (Issue_5) the representatives from the private sector urged the need to have more certainty within the Government's tender document. Most of the interviewees couldn't give a solution to cope of the Issue_6. They highlighted that the political forces are a pain for them. The interviewees from the private sector highlighted that the Government should approach PPPs with honesty. Further they proposed that the Government can follow a by-partisan approach to the stakeholders through engaging with all political parties during bidding. The private sector representatives proposed to provide regular updates to the financiers to cope with the Issue_7. Also more engagement with the state before approaching the financiers is also recommended.

The private sector participates proposed to improve the websites allowing people to access the information easily, to communicate clear information to general community at the correct time and to make the independent reviewer's opinion available to the general community to improve the transparency of the project (Issue_8). Interviewees highlighted the importance of the Government's role in protecting public interest (Issue_9). The interviewees urged the necessity of engaging with the general public during the initial stages. The interviewees highlighted many improvements to cope with the Issue_10. The representatives from both the sectors proposed to develop more KPIs related to SM and to measure the KPIs via stakeholder surveys. Also they proposed to monitor the stakeholder relationships during operations. And they advocated the importance of proper issue escalation process to efficiently address the stakeholder issues. Regular strategic stakeholder meetings and on site engagement meetings were suggested. The interviewees from the Government proposed to appoint an independent party to monitor the stakeholder matters during operations. They highlighted the need to embed the SM into business case and contract manuals.

The representatives from both the sectors proposed to create a system which accumulates the lessons learnt via regular stakeholder workshops to cope with the Issue_11. Also providing training for the people who are working around PPPs is also important. SM experts highlighted that the project directors do not see the clear advantages of SM to a project. As such they advised to expose project managers into real cold phased stakeholder issues. The representatives from the private sector highlighted the importance of developing comprehensive reference designs in dealing with Issue_12. This will lead to fewer conflicts during the construction and operations. Also the interviewees highlighted the need for more stakeholder engagement by the Government sector at the very initial stages. Moreover they proposed appointing an independent party to monitor the stakeholder matters during the initial stages.

5. Discussion

The issues identified from the literature review and the interview results were further validated via a questionnaire survey. “Responsibilities overlap between different Government agencies” and “political interests push PPP project decisions rather than social and economic” have become the most critical issues based on the mean score ranking. Interview results also confirmed that “political interests push PPP project decisions rather than social and economic” is the most critical issue related to PPP projects. Further according to the interview results “lack of monitoring in stakeholder needs and issues during operations” and “not efficiently managing conflicts between the private and Government sectors” are the second most critical issues. Questionnaire survey also confirmed that these issues are critical with a mean score value of 3.18 and 3.44 respectively. Surprisingly although the literature review and the interview results confirmed that all the issues are very critical to PPP project success, questionnaire survey have reported few low mean values for some of the issues. However all the mean values were above 3.0 and considered that all these issues are critical.

The Government and the private sector parties had common opinions on the criticality of some of the SM related issues in PPP projects. However there are evident differences as well. As shown in Table 2 most of the issues have become critical for the private sector when compared with the public sector. “Difficulty in identifying stakeholders and their interests throughout the PPP life cycle at the bidding stage”, “non-disclosure of the history behind PPP project to the private consortium”, “incomprehensible project brief and reference design leads to uncertainties”, “lack of early stakeholder engagement” and “not efficiently managing conflicts between the private and Government sectors” have become critical for the private sector. “Non-disclosure of the history behind PPP project to the private consortium”, “incomprehensible project brief and reference design leads to uncertainties” and “lack of early stakeholder engagement” are directly associated with the activities related to the Government sector side of the partnership. As “not efficiently managing conflicts between the private and Government sectors” has become a critical issues to private sector it can be viewed that the Government should become the main driving party in managing the conflicts of a PPP project. As such these results highlighted the importance of the Government sector role in SM for PPPs. One interviewee from the private consortium also confirmed this point in relation to public engagement as *“… then the Government has someone to blame if the community is not happy with the outcome. But we have no control over the public benefit of the project as we are not the once who created those projects.”* Further it was noted that in reality the Government is trying to transfer the total SM related risk to the private consortium. Chung et al. (2010) confirmed this point in relation to risk management in PPP projects in Australia. As such the findings insisted the importance a strong Government with robust SM practices for successful PPP projects.

The identified issues and strategies proposed were summarized and assigned into the sector that is mostly relevant. The following Figure 2 summarizes the findings. Accordingly most of the issues and the strategies identified are related to the government sector side of the partnership. This finding also confirmed the importance of the Government sector role in managing stakeholders.

	Issues	Reccomendations
Government	• Lack of early consultation with all stakeholders (by the Government agency) • Political interests push PPP project decisions rather than social and economic • Lack of information dissemination to the public • Not disclosing the history behind PPP project to the private consortium • Incomprehensible project brief and reference design leads to uncertainties • Responsibilities overlap between different Govt. agencies	• Maintain a register of all commitments made to stakeholders before bidding • Share the register of all commitments with the private consortium • Communicate clear information to general community at the correct time • Allow private consortium to participate in information sessions conducted by Govt. • Improve Govt. websites allowing people to access the information easily • Govt. agency engages with general community to develop tender doc • Govt. makes the independent reviewer’s opinion available to Public • Allow private consortium To engage with all political parties during bidding • Ensure the responsibilities do not overlap among different Govt. agencies
Both	• Difficulty in identifying stakeholders and their interests throughout the PPP life cycle at the bidding stage • Lack of monitoring in stakeholder needs and issues during operations • Not efficiently managing conflicts between the private and Government sectors • Lack of staff capability in the PPP project delivery • Interest of the general public is not well addressed	• Be honest with general community • Develop more Key Performance Indicators (KPIs) related to stakeholder management • Measure possible KPIs via stakeholder surveys • Appoint an independent party to monitor the stakeholder matters during initial and operations • Monitor relationships of stakeholders during operations • Create a system which accumulates the lessons learnt via regular stakeholder forums • Embed stakeholder management into business case, procurement and contract manuals • Establish issue escalation process to efficiently address stakeholder issues • Regular stakeholder meetings and on site engagement meetings during operations
Private	• Financier's nervousness due to changes in the Government	• Early involvement of the financial institutions

Figure 2: Overview of the issues and the strategies proposed by the interviewees

6. Conclusions

Both the interview and the questionnaire survey results investigated 12 critical issues related to SM in PPPs. It is necessary to address the current emerging issues related to SM in the research agenda. The comparative study between the private and the Government sector highlighted some differences in the views on the criticality for some of the issues. And it was noted that most of the issues have become critical for the private sector side of the partnership enquiring improvements in the Government sector. As such, the findings insisted the importance of a strong Government sector in dealing with SM for PPPs. However in reality the Government is trying to transfer the total SM risk to the project company leading to many confusions and issues in the later stages. This study emphasised an urgent research interest to develop a set of strategies to improve the SM related to the Government sector side of the partnership. Interview results identified a variety of strategies to cope with the SM related issues in PPPs. These strategies should be further validated from a questionnaire survey which is currently in progress. This study is part a larger research project which aimed at developing a systematic framework for SM in PPPs.

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Uncovering the Real Needs of Customers

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Abstract

In this paper an inventory will be given of methods and tools currently available in the construction industry and other sectors to make the needs and wishes of clients explicit, in order to incorporate them into the design, engineering and building process. In order to be able to create value from a client's point of perspective, it is necessary to find out what really matters to clients and what their real needs are. However, professionals in the construction sector with a genuine interest in making needs and wishes from clients and customer organisations explicit, know this is not an easy task. In contrast with the field of construction, it is more common practice in most industries to involve all different stakeholders in order to make requirements explicit. There are also different methods and tools available, which leads to the question what tools are most effective and reliable to discover requirements? Research in the domains of marketing, cognitive linguistics and psychology shows that customer needs can't be clarified by expression in words alone. A lot of choices are made unconsciously, without the use of language. Important associations people have can be made visible by using metaphors or pictures. These insights from other sectors can be of advantage to professionals in the construction industry. Based on this insight evaluation criteria are formulated to assess the available methods to uncover requirements. Based on the outcomes of this evaluation an improved tool is proposed, in which pictures are used to unravel customer needs.

Keywords: requirement engineering, MCDM+, stakeholder requirements, photo elicitation

1. Introduction

It seems an easy job; to collect the requirements for a new building. Just ask the stakeholders what they want, write it down in a programme of requirements and translate it into a design. But even when we spent a lot of time talking to stakeholders[1] , about their needs and wishes, it is still a difficult job to develop something that will meet all the requirements. On the one hand this happens of course because there are a lot of different stakeholders with often conflicting requirements and it is impossible to develop something that will meet all demands. But on the other hand are we able to uncover the necessary requirements with the methods we use in construction today? Looking at research into current failure costs it becomes visible that a large part of these costs is caused by bad or a lack of information. Recent research in the Dutch building sector shows that sloppy information exchange and a lack of communication are the most important causes of high failure costs (almost 11% from the total returns) (USP Marketing Consultancy BV, 2010). Getting the right information and sufficient data will help to decrease these failure costs. This starts with clear information on what it is end-users, clients and other stakeholders want. How can we make sure we get the right information on stakeholder requirements? What are the questions behind the questions when clients demand a specific building? What are the underlying motives? And which tools are the most effective and reliable to discover the requirements? To answer these questions additional research is needed, therefore the following research question was formulated: What are efficient ways to discover the real requirements and needs of stakeholders, based on what we know on the functioning of customers (unconscious) minds from marketing research, cognitive linguistics and psychology? In order to be able to make a proper inventory of stakeholder requirements in an efficient manner, research was conducted into what is known about the functioning of customer's minds. This knowledge was used to formulate criteria to evaluate the different methods[2] used in construction and in other sectors on this aspect. This evaluation is presented in section 3.4.

2. Inside the customer's mind

According to marketing expert Zaltman (2003), most marketing managers operate from a paradigm – a set of assumptions about how the world works – which prevents them from understanding and serving customers effectively. In the construction sector we seem to have the same problem. Professional clients think to know what the requirements of the users are, but quite often when the building is realised, it appears that it does not meet the users' needs in the

[1]When the term "stakeholders" is used in this paper, the different users of the building (employees, visitors, cleaners, etc.) are meant, as well as the parties involved in het development process of a building (e.g. architect, municipality, fire department, contractor, electrician).

[2]Tools used to visualize the requirements found are beyond the scope of this paper and are not discussed.

way it was intended. One of the reasons this happens is that people don't understand how their own and their customers minds interacts. We can explain this by taking a look at figure 1 (Jastrow, 1900). At first you'll see a rabbit or a duck. What you will see the first is different from person to person. This demonstrates a very important point; two people can look at the very same information and have two totally different interpretations (Jastrow, 1900). Miscommunication can come into existence quite easily. This is one of the reasons new

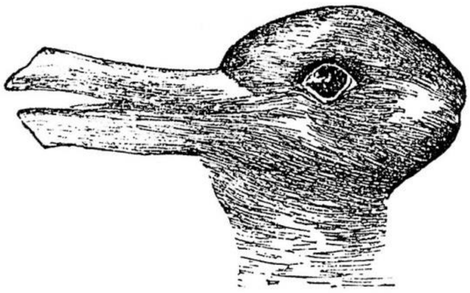

Figure 1: Duck-Rabbit (Joseph Jastrow, 1900)

buildings do not always fit the needs of the users of the building. It occurs even when developing parties can and do involve the users and other stakeholders. In a lot of cases however, they are not even invited to participate, or are not involved on a regular basis, so their needs are not even heard. Jerome Kagan, a professor of psychology at Harvard University, is regarded as a key pioneer in the field of developmental psychology. According to him ninety-five percent of our thinking takes place in our unconscious mind. Therefore the selection process is relatively automatic and is influenced by social and physical context (Kagan, 2002).

Most people also think that people's thoughts occur in terms of words. They think they can find out how people think by using standard interviews or questionnaires. Of course, words do play an important role in expressing our thoughts, but they don't outline the whole picture. This leads to the question, if the methods currently used to uncover needs are the right ones and the most effective ones. It seems smart to make more use of people's unconscious thinking and decision making. This means that we shouldn't use 'words' alone to find out what the real needs are, but also use pictures to tap into emotions and to discover needs. On top of that, decisions in construction are often quite complex and not transparent. Usually the client does not know what exactly they will get from the contractor or architect. "Human thought arises from what neuroscientist call images. Words can trigger our thoughts and enable us to express them. That's why people believe that thought occurs largely as words" (Zaltman, 2003). Metaphors often help us express the way we feel about important aspects in life (Zaltman, 2003; Johnson & Lakoff, 1980). "We have found, on the contrary, that metaphor is pervasive in everyday life, not just in language but in thought and action. Our ordinary conceptual system, in terms of which we both think and act, is fundamentally metaphorical in nature." (Johnson & Lakoff, 1980). Researchers who make use of photo elicitation (PEI), which is mostly used in social and anthropology studies, also support this view. Therefore Marisol Clark-Ibáñez concludes in her paper "Framing the Social World with Photo-Elicitation Interviews" that using the PEI alone or in combination with other methods such as interviews or observations can discover insights that wouldn't be found when using other approaches.

Based on this information on the functioning of our brains, we formulated the following criteria to evaluate existing methods to reveal stakeholder requirements:

1. *Taps into emotions*; are the instruments fit to pinpoint the emotions that drive the stakeholders involved?
2. *Closes the content gap*; can part of the method close the interpretation gap that exists between stakeholder and the person who is conducting the workshop/interview/discussion (caused by different experience, backgrounds, education)?
3. *Uncovers the underlying motivation*; is the method able to reveal the underlying motivation of the needs of the participant/stakeholder?
4. *Gives depth and detailed information*; can the method provide detailed information about the requirements of the participant/stakeholder?
5. *Breaks into the unconscious part of our brain*

3. Existing methods to explore customer needs

Different methods are used in various sectors to uncover the needs and requirements of users when developing products or services. Basically the questions that developers have and the information they need are the same, only the approach to gather this information sometimes differs.

3.1. Popular methods in the construction sector

When new buildings are developed, requirements of end-users are often filled in by the client. Although sometimes methods from other industries are used to explicitly investigate those, the methods most commonly used in the construction sector are described below. The advantages and disadvantages of the methods are listed in table 1.

Surveys

Surveys are also regarded as an easy way to discover needs and requirements. It’s a frequently used method in many different industries. With the use of surveys a lot of people can be reached to gather a substantial amount of information, that enables researchers to extract general conclusions valid for a large part of the population.

Interviews

Interviews are frequently used as a user requirement gathering method. This method is also used to discover the requirements of other stakeholders. Interviews can provide a lot of important information. Aspects that can cause problems or result in wrong conclusions when conducting interviews are that stakeholders and engineers usually have different backgrounds, experiences, and expectations from the system-to-be (Burnay et al, 2014).

Focus groups

A focus group is a special group of people in terms of purpose, size, composition and procedures. The purpose of a focus group is to get more insights in how people think and feel about a certain subject, idea or service. The group discussion is repeated several times with similar types of people. The aim is to find trends and patterns in the perceptions from the different participants (Krueger & Casey, 2015).

Multi Criteria Decision Method (MCDM)

The MCDM is a new tool in the construction sector, initially introduced to come to an Integrated Building Design (IBD) for new construction projects in which the environmental issues are addressed properly. The selection and prioritisation of design criteria among stakeholders at the beginning of the project is considered crucial (Balcomb et al, 2002). Additionally alternative design solutions should be evaluated in the process in relation to these criteria. The MCDM method is developed to assist in both. With this method it becomes possible to make the requirements of the different stakeholders explicit by discovering what is important to the different departments of the client organisation. It starts with a discussion to formulate priorities for the organisation as a whole, thereby transferring detailed information on what has value to the parties that will design, engineer and construct the building. Since the introduction in 2002 this method is also used for refurbishment projects (Alanne & Klobut, 2003; Hofman et al, 2012) . The MCDM is therefore an instrument that is developed to clarify and prioritize the different aspects that are important to clients and end-users. The MCDM-discussions starts with a list of major aspects (Hofman et al, 2012). Valuable aspects are divided in sub-themes in order to make the different facets from a specific aspect explicit for the client. Subsequently the importance of the aspects are indicated by marks. The higher the mark, the more important the aspect is in the eyes of the entire client organisation. Finally the outcome will be a map of the most important aspects and their priorities (Hofman et al, 2012).

3.2. Methods from other sectors

In other industries they use different methods whereby also visualisation is used. These methods are described below. In table 1 an overview can be found of the strengths and weaknesses of each method.

Photo elicitation

Photo elicitation is used in anthropology and sociology. Basically photo elicitation is the introduction of photographs into an interview. Compared to standard interviews, it can be noticed that people respond differently when photos are shown. Interviews whereby photos are used not only produce more information, but also different kinds of information, because images evoke deeper elements of human consciousness than words are capable of (Harper, 2002).

Metaphors

In the IT sector the requirements elicitation process is quite difficult, because it’s often about a new sort of system and specifications hereof that has not been built before, as is also the case in construction. In this sector metaphors are often used to find out what the real users' needs are. A metaphor is an imagery and suggests a similarity between two things or ideas that are not equal in reality. Metaphors therefore help to better understand unknown abstractions (Visscher et al, 2005).

Personas

What working with personas is, can best be described with a citation from Sim and Brouse (2014): "The concept of persona is an emerging new paradigm in user requirements modelling. Personas are fictitious and concrete representations of a specific group of target users. Personas are constructed to resemble real people. Personas contain information about the users' names, ages, occupations, educational backgrounds, knowledge, abilities, interests, goals, concerns, usage patterns, environment the users engage in, and so forth."

Some might expect Systems Engineering (SE)to be included in this overview. SE is a method that is commonly used in Civil Engineering and is used more and more in the development process of buildings. With Systems Engineering more time is required in an early stage of a project. First all the stakeholders will have to be identified and the project team will determine if and how the stakeholders should participate in the project. This creates support for the project and it helps to clarify all requirements. An important aspect of Systems Engineering is the requirement analysis for which usually standard methods are used such as interviews, surveys and focus groups. This means that all the information is gathered by verbal methods. It is therefor not a method in itself that is used to determine the requirements in the initial phase only, but more like an overall approach that is used throughout the development process as a whole. This is the reason SE is not included as requirement gathering method in this paper.

3.3 Evaluation of the methods

To determine the value and appropriateness of the different methods, the strengths and weaknesses are listed in table 1.

Table 1: Strengths and weaknesses of requirement gathering methods

Instrument	***Strengths***	***Weaknesses***
Survey	- *Delivers a lot of data* - *Fit for questioning large groups of people* - *Fit to derive conclusions valid for a large group of people* - *Less social desirable answers* - *Cheap*	- *The results are incomplete and not always correct, because 95% of our decision-making is unconscious* - *Not able to uncover the underlying motivation of people* - *No in depth information* - *No influence on the response* - *Often a low response* - *Additional questions for clarification are not possible* - *Most of the time answers are predefined*

Interview	- *Provides detailed information* - *You can ask additional questions to get more information*	- *The results are incomplete and not always correct, because 95% of our decision-making is unconscious* - *Not appropriate if you are looking for information from a large sample of the population* - *Can take significant time to conduct* - *Interviewer and stakeholder will probably have different backgrounds, experiences and expectations (Burnay et al, 2014)*
Focus groups	- *Will gain insights in how people think and feel* - *Provides information quickly with low costs* - *Researcher can interact directly with the participants* - *Possible to obtain rich and large amounts of information* - *People can react and build on responses by others* - *Flexible (Krueger & Casey, 2015)*	- *The results are incomplete and not always correct, because 95% of our decision-making is unconscious* - *Participants in a group are inclined to give socially appropriated answers* - *Will not tap into emotions, while emotions are the key drivers of behaviour* - *Participants can feel forced to make up answers when they don't know the answer* - *Results can be trivial* - *Dominant participants can influence the outcomes (Krueger & Casey, 2015)*
MCDM	- *Contradicting needs and interests will become transparent* - *Provides insight in what is most important to clients and why* - *Gives insight in what the client really wants* - *Leads to better communication and understanding between the different departments in an organisation* - *Helps to structure the requirements within user organisations* - *Helps to prioritise the different requirements (Hofman et al, 2012)*	- *Costs more time in the initial phase of the project* - *Can be difficult to keep the main question in focus therefore experienced moderation is important* - *Can be difficult to clarify all the different aspects that are important to the client* - *Providers think in technical specifications and solutions (can lead to misunderstanding or miscommunication)* - *It is really hard for the representatives of client organisations to represent the organisation as a whole (Hofman et al, 2012)*
Photo elicitation	- *Images evoke deeper elements of human consciousness that words do* - *With photos the unconscious part of our thinking is stimulated* - *Better and more reliable information* - *Provides more detailed information (Pommeranz et al, 2011)*	- *Finding useful photos can be difficult* - *Using unsuitable photos can be harmful* - *More time consuming then standard interviews (Pommeranz et al, 2011)*
Metaphors	- *Helps to understand unknown abstractions* - *Are dynamic* - *Deliver a collective conceptual reference model* - *Suggest features and sometimes relations*	- *The client can interpret the metaphor in a way that is not anticipated* - *Problems can occur due to cultural differences.* - *The search for the right metaphor can be a difficult process (Visscher et al, 2005)*

	- *Clients and developers are talking on the same level* - *Metaphors can break through existing thinking patterns* - *Metaphors makes us use multiple parts of our brain (Visscher et al, 2005)*	
Personas	- *More focus on the end-user, their tasks, goals and motivation* - *Leads to better design solutions* - *Make the needs of the end-user more explicit* - *Strengthen the focus on the end-user, their tasks, goals and motivation* - *Can improve communication* - *Facilitates more constructive and user-focused design discussion (Long, 2009)*	- *Considerable resources are required* - *Developing personas costs a lot of time and effort* - *A scaled-back or low-budget version of personas can be harmful* - *If details and goals of the persona are not correct then the alignment of the design can be inappropriate* - *Requires training at an organisational level (Long, 2009)*

If we compare different requirement gathering methods, it can be concluded that surveys and interviews aren't the most useful methods to discover the real in depth requirements. Surveys will only help to get a general view of needs. Interviews can be used to get more detailed information, but both methods give only insight in the conscious thoughts of people, while actually information about the unconscious motives of people can be much more valuable. Burnay et al (2014) also conclude that a standard interview doesn't provide all the necessary information to develop an optimal system (in this case a building). Although focus groups will gain more insights in how people think and feel by participating in a group discussion, it still doesn't tap into their emotions. People are inclined to give socially appropriate answers. Often people are unaware what really drives their behaviour. Many decisions are non-rational and often emotional responses to circumstances. According to Barry Feig (as cited in Krueger & Casey, 2015) emotions are the key drivers of behaviour. Most people are not aware of the emotions that influence their behaviour. In a focus groups it is hard for the moderator to get to relevant insights. The MCDM method seems therefore a better method to make the requirements of the client organisation explicit. It also leads to better communication and understanding between the different departments in an organisation and between the organisation and the suppliers. Another strong aspect compared to some other methods is that this method helps to prioritise and structure the requirements. This will finally result in a building that meets the needs and requirements better than it would be when the building was developed in a traditional way. Despite the fact that it makes requirements more clear and transparent, it still is a method that makes use of words only. This means that there is still hidden information that will not come to the surface. Pommeranz et al (2011) concluded in their paper "Elicitation of situated values: need for tools to help stakeholders and designers to reflect and communicate" that standard methods (for example interviews and surveys) don't provide the real life context needed for people to understand and express their values. They have compared different methods and concluded that photo elicitation seems well suited to uncover real values. They tested the method by using a normal questionnaire and a photo elicitation interview. The most detailed information came out of the photo elicitation interview (Pommeranz et al, 2011). With photos or images you can stimulate the more unconscious part of our thinking, which leads to more accurate and more reliable information. While most projects in construction are rather complex and meant for a long lifespan, we should not exclusively use linguistic methods to uncover needs. Making use of pictures or photos can help to get more insights into the real needs, and it provides more detailed information, which will automatically lead to a better understanding. During requirements elicitation clients and developers often have the problem that they don't understand each other. The client thinks in organisational and business terms, while the engineer thinks in technical terms. To close this gap metaphors can be an appropriate tool (Visscher et al , 2005). This communication gap, as it is referred to in the IT sector, also exists when developing buildings. Yet metaphors are not or rarely used in the construction sector. They are used in the design, but not in the initial phase of a project where the first requirements are gathered. The construction parties speak a more technical language and think mostly in technical solutions, while the client and other stakeholders think and communicate in other terms (organisational or financial). Besides, another related problem is that clients generally do not really know the requirements of their end users. The client also speaks another language than the different user groups, so there's another gap. Metaphors can help to break through existing thinking patterns and can also help to talk on the same level. Because of that metaphors stimulate us to use multiple parts of our brain, there for more detailed and reliable information can be gathered. Sim and Brouse (2014) claim that by empowering the concept of personas into requirement engineering activities, a greater comprehensive understanding of the users' needs and behaviours can be realized early in the requirements engineering process, thus allowing engineers to identify missing demands. According to Long (2009) there is more focus on the end-user, on their tasks, goals and motivation. It makes the needs and requirements of the end-user more explicit. Using personas therefore could be helpful for the requirement analysis when developing buildings.

3.4 Evaluation of existing methods

In the multi criteria analysis in table 2 the different methods and the five criteria are listed as introduced in chapter 2. For every criteria a method can score on a scale from 0 – 5. 0 means that it doesn't apply at all and 5 means that it strongly applies.

Table 2: Multi criteria analysis existing methods

	Tap into emotions	*Closes the content gap*	*Uncovers the underlying motivation*	*Gives depth & detailed information*	*Breaks into the unconscious*	***Total score***
Survey	*0*	*0*	*0*	*0*	*0*	***0***
Interview	*2*	*0*	*3*	*3*	*0*	***8***
Focus groups	*1*	*0*	*4*	*4*	*0*	***9***
MCDM	*2*	*3*	*4*	*4*	*0*	***13***
PEI	*4*	*2*	*5*	*4*	*5*	***20***
Metaphors	*4*	*4*	*3*	*4*	*5*	***20***
Personas	*2*	*4*	*3*	*3*	*2*	***14***

When looking at the mca, it can be concluded that the survey is the most ineffective method to discover customer needs. It will not provide detailed information and is thus not useful in finding out the underlying motivation. Utilizing interviews is a bit better, but also with this method it is hard to tap into emotions and it still doesn't trigger the unconscious part of our brain. The methods that really do break into the unconscious part of our brain are the photo elicitation and the metaphors. Since these methods break into the unconsciousness part of the brain, these two methods also have a high score in 'tapping into emotions'. These two criteria make them score a lot better than the other methods to reveal customer needs. Because most of what we do or decide occurs unconscious, an effective method should tap into this decision process.

A lot of stakeholders are involved when developing buildings. Not only the requirements of individuals are important, also the requirements of different departments or user groups is needed. Therefore not only individual information should be collected, but also information from groups. Photo elicitation or the use of metaphors are worthwhile methods to get the needed information from the individuals, but a different method is needed to disclose information of groups. Looking at the strengths and weaknesses of all the methods evaluated in this paper we see that especially the 'visual' methods (using metaphors and photo elicitation) have a lot of important advantages that really contribute to better end results. Besides that, there are not a lot of weaknesses known from these methods. The weaknesses that are mentioned can be prevented. Personas also have a lot of strengths that could contribute to better results, however, attention should be given to known weaknesses. Developing personas is already a project in itself and cost a lot of time and effort. Using photos or metaphors is therefore to be preferred. This is also proven in other sectors e.g. the IT sector, anthropology and sociology.

3.5 MCDM+

Based on the conditions described above a new tool is evolving. The general aim is to develop a tool that triggers the unconscious parts of the users minds to get better and more valuable information about the real needs and requirements from different users. At first the focus is on professional end-users of a building. The tool should also help to articulate the needs of specific client groups consisting of the different departments of an organisation by making use of photos and pictures, since needs and requirements within an organisation depend partly on the activities, working methods and subcultures within the different departments. Because the MCDM method does this, it makes requirements more explicit and helps to prioritize them, it is chosen as a basis. When this method is combined with a tool that addresses the unconscious part of peoples thinking, a more complete and wider supported set of requirements can be made. This new method is called MCDM+. A first concept is ready and has been tested in two workshops during the 2015 edition of the LEAN Construction Symposium in the Netherlands with sustainability & lean as central theme.

Aim

The main aim is finally to give insight into the needs of different organisation departments to arrive at a shared view of the needs of an organisation as a whole, including the most relevant priorities therein. An important part is to give insight into the differences and provide understanding of each other's motives and point of views. To get a total list of all the requirements, the tool should be used in several rounds to discuss different topics. In the tests of the concept method the topic 'sustainability' was addressed.

How the tool is used

(1) For each subject there is a large amount of pictures related to the subject (at least 30). Every individual collects a maximum of five pictures that symbolises the main aspects concerning this topic from his or her point of view. When choosing the pictures the person should reflect from his or her function and department, but personal preferences should also be ventilated. (2) People from the same department show each other the pictures chosen and explain to each other why they have chosen these and what it is they think matters. (3) When every member of the group has done this, they discuss were the similarities and differences appear. (4) The group put the pictures that symbolises the most relevant aspects for them as a group on a large piece of paper and clarify (e.g. with different colours, text, drawings and clustering of pictures) their motivation. (5) In the next step each group presents what the topic, in this case 'sustainability', means for them as a department. The most important differences between the departments will start to emerge in this stage. (6) Finally, when all groups have presented, the moderator will try to reach consensus about the most important priorities of the organisation as a whole on this specific topic.

4. Summary

An evaluation was made in this paper of the methods that can be used to make an inventory of stakeholder requirements. Considering the methods that are used to discover stakeholder needs in the construction sector, we can conclude that methods commonly used in construction only make use of words and verbal communication. Using these methods leaves a lot of important information undiscovered. This clarifies for an important part the inability to meet the needs of the users and other important stakeholders. Construction parties and clients are not able to tap into the unconscious level of stakeholders' minds, even when they are focused on involving important stakeholders and put a lot of time and effort in the start-up phase and the requirement analysis with Systems Engineering. While the final outcome of this process may have less shortcomings, usually only linguistic methods are used, thereby missing important information which results in an incomplete listing of requirements. Knowing that most information rests in the unconscious parts of our mind, unable to come out with verbal research methods, this isn't really surprising. Looking at the evaluation of seven existing methods, four from construction and three from other sectors, the construction industry could benefit from the use of photo elicitation and/or metaphors to discover requirements. Using photos and metaphors seem to be a welcome addition to the existing methods in construction, because they can gather more specific and reliable information and help different parties to communicate on the same level. This is really an important issue, because a lot of problems and failure costs are caused by miscommunication and a lack of information exchange between the different parties. In order to improve this a new method was developed: MCDM+. The MCDM was used as a basis, combined with the use of pictures, thereby ameliorating the requirement gathering process to reveal in a more complete and supported set of requirements.

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Toward an Occupant Satisfaction Measure for Office Building Retrofits

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Abstract

It has been widely acknowledged that failing to address occupant needs and expectations has severe negative effects on the outcomes of building retrofitting efforts, resulting in a performance gap in energy saving as well as occupant satisfaction and productivity. When evaluating performance metrics such as occupants' thermal comfort, indoor air quality, space use and control by occupants, literature indicates a particular success of occupant feedback in comparison to the code defined standards and physical measurements since no assumptions is made and all contextual influences are taken into account. Analysis of the existing post occupancy evaluation tools, however, reveals the lack of an empirically validated and structured framework to measure occupant satisfaction with a holistic approach embracing different aspects of occupant comfort. In this paper, as a first step in developing the occupant satisfaction measure, occupant satisfaction dimensions and indicators in the literature have been reviewed systematically and organized in a hierarchical structure to ensure content validity of the model. Occupant satisfaction was configured under eight dimensions and under each dimension, the related indicators were identified. In addition, possible sources of dissatisfaction for each indicator were determined from the literature, which are intended to be used for determining the needs of the occupants and priority areas to focus on in the pre-retrofit phase.

Keywords: Retrofit, occupant satisfaction, post occupancy evaluation, office, workplace satisfaction.

1. Introduction

The commercial building sector is widely accepted as the sector with highest potential for energy savings (Tobias and Vavaroutsos, 2009; DOE, 2012; Ma et al. 2012; Jazizadeh et al., 2014; Azar and Menassa, 2015). The energy demand of commercial buildings is growing faster than any other economy (Azar and Menassa, 2015) and is expected to grow by more than 20% by 2035 (EIA, 2003). To reduce the environmental impacts of buildings, the construction industry is undergoing a transition toward the development of a more sustainable built environment, often called as green buildings (World Green Building Council (WGBC), 2009). Riley et al. (2004) defined a green building as ‘the one that minimizes resource consumption during design, construction, and over its life, and provides healthy and productive environments for occupants through the application of sustainable principles’.

The green movement initially focused on the design and construction of new buildings and importance of energy efficiency improvements in existing building stock (retrofitting) have been underemphasized (Tobias and Vavaroutsos, 2009). During the last decade, however, it’s been realized that retrofitting existing buildings have even more significant effect on the total energy demand since many of the buildings in 2050 are the ones that exist today (McGraw-Hill, 2009; Ma et al. 2012; Asadi et al, 2013). Today, retrofitting is considered as the key approach to realistically achieving substantial energy saving in building sector and many governments and international organisations have put significant effort towards energy efficiency in existing buildings (Ma et al. 2012). Research has shown, however, that especially commercial and office buildings may show higher-than-expected energy consumption levels, even when energy-efficient building systems are installed in the retrofit process (Azar and Menassa, 2015). This ‘performance gap’ or ‘energy efficiency gap’, as commonly referred in the literature (Brown and Gorgolewski 2014), is mostly around 30% and can reach up to 100% for more energy intensive buildings (Turner and Frankel 2008; Yudelson 2010). Apart from estimation errors, a major driver of the gap is diagnosed as people (i.e., occupants and building management) in the recent studies (Azar and Menassa, 2015). Studies show that energy consumption is significantly correlated with the occupant behaviour (Shrestha and Kulkarni, 2013) and if occupants understand the building and environment control systems, provided that the systems are designed to meet their requirements, they may contribute to lower building energy use (Day and Gunderson, 2015).

In office buildings, retrofitting do not only save energy and reduce operating costs but also contribute to the occupant’s health and comfort, resulting in decreased absenteeism and increased productivity (Ardente et al., 2011; Chidiac et al., 2011), and therefore increased return on investment (Korkmaz et al., 2010). Aktas and Ozorhon (2015) reports employee satisfaction is one of the prominent drivers why private companies choose to green their existing buildings. Similar to the energy efficiency gap, green office buildings may underperform in terms of occupant satisfaction and comfort. In the current practice retrofit design is generally based on code defined occupant comfort standards, however studies have shown weak and context-dependent correlations between standard-defined comfort ranges and occupant-reported comfort ranges (Wagner et al. 2007). Observations showed that a significant portion of the occupants remain dissatisfied with environmental conditions in offices after retrofits and dissatisfaction with physical conditions may lead to misuse of building systems, which worsen the overall occupant satisfaction and increase energy consumption (Jazizadeh et al., 2014).

To minimize the performance gap, in terms of both energy consumption and occupant satisfaction, occupant needs and expectations should be determined in detail before a retrofit process in an office building. There has been a vast amount of research on post occupancy evaluations to understand how actions performed by building occupants and facility managers affect energy consumption, and to what degree occupants are satisfied with specific physical conditions. However an empirically validated measure to determine the occupant satisfaction and requirements before an office building retrofit is missing in the literature. Therefore, significant potential for energy savings, occupant satisfaction and productivity gains, which could be realized through a more appropriate retrofit design, remains untapped.

The aim of this research is to develop an empirically validated and structured framework to measure occupant satisfaction and determine the needs and expectations of occupants in the pre-retrofit phase in office buildings. This paper explains the first phase of the research, which is the identification of the occupant satisfaction dimensions and indicators through a detailed literature survey. This research is expected to be a timely contribution to the green retrofit movement, which is expected to intensify even more in the coming years due to national and international legislations imposing more stringent standards and wide-spreading voluntary certification schemes embracing the green transformation of the existing building stock.

2. Previous Work on Occupant Satisfaction Measurement

Occupant satisfaction measurement is most widely adopted in Post Occupancy Evaluation (POE), which typically focuses on assessment of client satisfaction and functional fit with a specific space after occupation (Turpin-Brooks and Viccars, 2006). Presier (1995) defines POE as ‘a diagnostic tool and system which allows facility managers to identify and evaluate critical aspects of building performance systematically’. In comparison to the code defined standards and physical measurements, literature indicates a particular success of occupant feedback when evaluating performance metrics such as occupants’ thermal comfort, indoor air quality, space use and control by occupants, as no assumptions is made and all contextual influences are taken into account (Jazizadeh et al., 2014; Azar and Menassa, 2015). So, despite its general use in the facility management phase, it is beyond any doubt that occupant feedback can and should be used to complement physical measurements and code defined standards for the goal of identification of retrofit actions in office buildings.

Occupant satisfaction measurement tools may also be named as Indoor Environmental Surveys or Building Performance Evaluation Surveys in the literature. Table 1 presents an overview of the most widely used occupant satisfaction measurement tools and their comparative metrics. These tools may be classified into two sub-categories as (1) mostly academic in-depth studies that embrace a limited number of parameters to investigate a particular occupant satisfaction dimension, and (2) more comprehensive but unstructured surveys mostly used in the industry where dependencies among the constructs are not described.

*Table 1: Occupant satisfaction measurement tools**

	POE Surveys																
	Indoor Environmental Surveys									*Occupant Satisfaction Mesurement Tools/Models*							
												Building Performance Evaluation Surveys					
	(Leaman, 2010)	*(Carlopio, 1996)*	*McCartney and Nicol, 2002)*	*(Veitch et al.,2007)*	*(Zagreus et al.,2004)*	*(Bluyssen et al.,2011*	*(Toftum et al.,2005)*	*(de Dear et al., 1998)*		*(Stokols and charf, 1990)*	*Candido et al. (2006)*	*Choi et al. (2013)*	*Preiser and Vischer (2005)*	*Preiser and Vischer (2005)*	*Preiser and Vischer (2005)*	*Preiser and Vischer (2005)*	*Azar and Menassa (2015)*
Survey	*BUS Methodology*	*HFSQ*	*SCATS (Smart Controls and Thermal Comfort)*	*COPE (Costeffective OpenPlan Environments)*	*CBE - UCB) Survey*	*HOPE Project*	*Remote Performance Measurement, ICIEE-DTU*	*ASHRAE*	*NABERS*	*REF (The Ratings of Environmental*	*BOSSA*	*IEQ Satisfaction*	*BIU (Building-In-Use, Canada)*	*NUTAU, USP, Brazil*	*Building User Questionnaire (Netherlands*	*Walden (1999, 2003)*	
Dimensions / Criterias / Measures / Metrics	thermal comfort IAQ noise lighting personal control occupant health perceived comfort productivity (self estimated space design image needs	thermal comfort IAQ acoustic quality structure health and security of occupants Satisfaction with environmental factors organization and quality	thermal comfort IAQ acoustic quality visual quality general comfort occupant productivity	thermal comfort IAQ acoustic quality visual quality lighting window access office layout work satisfaction general satisfaction of workstation privacy	thermal comfort IAQ acoustics quality visual quality lighting office layout office furnishings building cleanliness and maintenance general satisfaction (building) general satisfaction (workspace)	thermal comfort IAQ acoustic quality occupant health	thermal comfort IAQ acoustics quality visual quality personal control opportunities occupant productivity and health (SBS) general comfort and satisfaction	thermal sensation air speed preference acceptability and preference	thermal services IAQ acoustics lighting Office layout	thermal comfort IAQ acoustic quality visual quality structure layout quality	thermal comfort indoor air quality noise distraction and privacy connection to the outdoor environm ent visual comfort personal control spatial comfort individual space building image and maintenance	thermal conditions indoor air quality acoustic conditions lighting conditions furnishings asthetics technology view conditions vibration condit ions	temperature comfort ventilation comfort air fressness air movement Noise distractions lighting comfort office layout furniture comfort privacy	temperature comfort air quality ventilation humidity Odours Noise lighting quality environmental control layout(furniture) Spatial satisfaction(hallways, stairways etc) parking accesibility cleanliness and maintenance water quality safety and security privacy image (Floor/Building) neighbourhood	functonality noise daylight office layout layout (furniture) flexibility privacy productivity image	functonality (usefullness time/energy saving factors) environmental quality sound insulation relationship of space /Layout stylistic/asthetic Social/Phsical (value for communication) adaptability accesibility ecological value (value of health) security work ecciency aesthetic quality interior/exterior quality of materials organizational(planning, construction, administration)overall quality of building site	interior floor area functional area task lighting use installed lighting use HVAC heating energy use HVAC cooling energy use HVAC ventilation energy use plug loads total space energy use energy use intensity occupancy presence/absence

*For references used in Table 1, please see Appendix 1.

A deeper analysis on the occupant satisfaction measurement tools reveals that most of these surveys and studies do not involve any information on the selection of indicators, or validation of the indicator constructs used. A few studies that present some form of validation of the constructs are limited to a particular occupant satisfaction dimension such as thermal comfort or lighting. Thus, analysis of the existing tools reveals the lack of an empirically validated and structured framework to measure occupant satisfaction with a holistic approach embracing different aspects of occupant comfort.

Developing a measurement framework requires a systematic approach to the identification of the dimensions and indicators of the phenomenon to be measured. Normative refinement analysis of occupant measurement tools listed in Table 1 revealed that dimensions and measures used in these tools are different but mostly complementary. Presented in the next section, as a first step in developing the occupant satisfaction measure, occupant satisfaction dimensions and indicators in the literature have been reviewed systematically and organized in a hierarchical structure to ensure content validity of the model.

The existing tools investigated also present important limitations making them ineffective in identifying the real causes of inefficient building operation since they do not aim to investigate the dissatisfaction sources, which would enable to determine the needs and expectations of occupants in the early stages of a new retrofit project. So, in addition to dimensions and indicators of occupant satisfaction, possible sources of dissatisfaction for each indicator were also determined from the literature and presented in the next section.

3. Occupant Satisfaction Dimensions and Indicators

In the quest to find the relevant dimensions and indicators of occupant satisfaction, a literature search was performed using the key terms ‘occupant satisfaction’, ‘post-occupancy evaluation’ and ‘workplace satisfaction’ in four major research databases, namely, Science Direct, Taylor and Francis, Emerald and ASCE. A total of 317 articles published between 2000-2015 were analysed with regards to indicators proposed to measure occupant satisfaction or sub-dimensions of occupant satisfaction such as thermal comfort, indoor air quality, spatial comfort. Post-occupancy evaluation tools and standards presented in the previous section were also used to identify dimensions and indicators of occupant satisfaction.

Frequency analysis and normative refinement methodology were adopted in merging indicators found. The detailed literature review procedure adopted ensures the content validity of the occupant satisfaction measurement model to be developed in the following stages of the research. As a first step in the development of the model, the dimensions and indicators identified from the literature were organized in a hierarchical structure. Table 2 presents these dimensions and indicators along with their sources.

*Table 2: Occupant satisfaction dimensions and indicators**

Dimension	*References of Dimension*	*Indicator*	*References of Indicator*	*Dissatisfac-tion Source*
Thermal comfort	Meir et al (2009), Kavgic et al (2008), Agnieszka (2014), Brown et al (2014), Ali et al (2015), Driza and Park (2015), Brown and Cole (2009), Candido et al (2015), Leaman, A. and Bordass, B. (2001), Goins and Moezzi (2013), Newsham et al (2013), Leder et al (2015), Garreton et al (2015), Healey et al (2012),Gou et al (2014), Wright et al (2014),Voelker et al (2013), Hitchings, R. (2009),Menadue et al (2014), Afacan and Demirkan (2015), Ackerly and Brager (2013), Brager and Baker (2009), Paul and Taylor (2008), Lee et al (2015), Preiser and Vischer (2005), Brown and Gorgolewski (2014), Azar et al (2015), Brooks and Viccars(2006), Gultekin et al (2015), Jazizadeh et al (2014), Arif et al (2015), Hauge et al (2010), Calis et al (2015), Heerwagen and Zagreus (2005), Ann and Pearce (2013), Wong et.al. (2014), Hajdukiewicz et al (2013), L. Yang et al(2014),Khalil and Husin (2009), Emuze et al (2013), ASHRE S-55 2004, Leephakpreeda, T., (2008)	temperature	Kavgic et al (2008), Wagner (2007), Singh et al (2011), Jazizadeh et al (2014), Nahmens et al (2015), Laquatra et al (2008), Langston et al (2008), Rashid et al (2012), Kato et al (2008), Atkins and Emmanuel (2014), Sawyer et al (2008), Brown and Gorgolewski (2010), Ali et al (2015), Meir et al (2009), Goins and Moezzi (2013), Candido et al (2015), Moezzi (2009), Marie et al (2015), Garreton et al (2015), Healey et al (2012), Gou et al (2014), Brown and Cole (2009), Wright et al (2014), Brager and Baker (2009),Hitchings, R. (2009), Afacan and Demirkan (2015), Ackerly and Brager (2013), Paul and Taylor (2008), Lee et al (2015), Preiser and Vischer (2005), Brown and Gorgolewski (2014), Chen and Ahn (2014), Hopper et al (2012), Azar et al (2015), Brooks and Viccars(2006), Gultekin et al (2015), Low et al (2014), Jazizadeh et al (2014), Hauge et al (2010), Calis et al (2015), Heerwagen and Zagreus (2005), Ann and Pearce (2013)	too cold / too hot / unstable
		radiant temperature	Brager and Baker (2009), Hopper et al (2012), Choi et al (2012)	heating / cooling devices, facade
		relative humidity/draught/dry air	Kavgic et al (2008), Singh et al (2011), Jazizadeh et al (2014), Laquatra et al (2008), Kato et al (2008), Rashid et al (2012), Driza and Park (2015), Atkins and Emmanuel (2014), Agnieszka (2014), Meir et al (2009), Candido et al (2015), Healey et al (2012), Menadue et al (2014), Ackerly and Brager (2013), Preiser and Vischer (2005), Paul and Taylor (2008), Azar et al (2015), Gultekin et al (2015), Hopper et al (2012), Hauge et al (2010), , Heerwagen and Zagreus (2005), Calis et al (2015) , Voelker et al (2013), Hitchings, R. (2009)	too dry, too humid
		temperature shift	Brown and Gorgolewski (2014),	too fast / too slow
Indoor air quality	Nahmens et al (2015), Laquatra et al (2008), Seshadri and Topkar (2014), Langston et al (2008), Brown and Gorgolewski (2010), Rashid et al (2012), Agnieszka (2014), Atkins and Emmanuel (2014), Brown et al (2014), Driza and Park (2015) , Meir et al (2009), Kavgic et al (2008), Goins and Moezzi (2013), Candido et al (2015), Marie et al (2015), Newsham et al (2013), Leder et al (2015), Gou et al (2014), Brown and Cole (2009), Wright et al (2014), Voelker et al (2013), Brager and Baker (2009), Ackerly and Brager (2013), Paul and Taylor (2008), Lee	freshness of air / air quality	Singh et al (2011), Seshadri and Topkar (2014), Kato et al (2008), Rashid et al (2012), Brown et al (2014)/ Langston et al (2008), Agnieszka (2014), Atkins and Emmanuel (2014), Driza and Park (2015), Ackerly and Brager (2013), Meir et al (2009), Kavgic et al (2008), Goins and Moezzi (2013), Candido et al (2015), Leaman and Bordass (2001), Marie et al (2015), Newsham et al (2013), Leder et al (2015), Gou et al (2014), Brown and Cole (2009), Voelker et al (2013), Paul and Taylor (2008), Preiser and Vischer (2005), Lee et al (2015), Brown and Gorgolewski (2014), Hopper et al (2012), Azar et al (2015), Gultekin et al (2015), Low et al (2014), Jazizadeh et al (2014), Hauge et al (2010), Calis et al (2015), Heerwagen and Zagreus (2005), Ann and Pearce (2013), Salleh et.al. (2015), CBE Berkeley IEQ Survey	

	et al (2015), Preiser and Vischer (2005), Hopper et al (2012), Azar et al (2015), Brooks and Viccars(2006),Gultekin et al (2015), Jazizadeh et al (2014), Hauge et al (2010),Calis et al (2015) , Heerwagen and Zagreus (2005), Ann and Pearce (2013), Brager and Baker (2009)	natural ventilation	Mishra and Ramgopal (2015), Singh et al (2011), Laquatra et al (2008), Meir et al (2009), Kavgic et al (2008), Healey et al (2012), Gou et al (2014), Brager and Baker (2009), Afacan and Demirkan (2015), Paul and Taylor (2008), , Brown and Gorgolewski (2014),Calis et al (2015) , , Heerwagen and Zagreus (2005), Leaman and Bordass (2001), Voelker et al (2013), Menadue et al (2014), Afacan and Demirkan (2015), Lee et al (2015), Gultekin et al (2015), Wilkinson (2012), Preiser and Vischer (2005), Chen and Ahn (2014), Azar et al (2015), Hauge et al (2010), Ann and Pearce (2013), Hajdukiewicz et al (2013)	
		air speed /flow/velocity /movement	Singh et al (2011), Kavgic et al (2008), Jazizadeh et al (2014), Nahmens et al (2015), Meir et al (2009), Kavgic et al (2008), Preiser and Vischer (2005), Brown and Gorgolewski (2014), Low et al (2014), Jazizadeh et al (2014), Calis et al (2015), , Heerwagen and Zagreus (2005), Choi et al (2012), Khalil and Husin (2009)	HVAC devices, natural ventilation
		odour	Nahmens et al (2015), Brown et al (2014), Agnieszka (2014), Meir et al (2009), Kavgic et al (2008), Voelker et al (2013), CBE Berkeley IEQ Survey	outdoors, air pollution, materials, cooking, WC, mold
Audial / acoustical / sound comfort	Sawyer et al (2008), Agnieszka (2014), Driza and Park (2015), Jailani (2015), Ackerly And Brager (2013), Meir et al (2009), Goins and Moezzi (2013), Leaman and Bordass (2001), Marie et al (2008), Newsham et al (2013), Leder et al (2015), Voelker et al (2013), Menadue et al (2014), Goins et al (2013), Paul and Taylor (2008), Preiser and Vischer (2005), Brown and Gorgolewski (2014), Brooks and Viccars(2006), Hauge et al (2010), Brager and Baker (2009), Navai and Veitch (2003)	noise levels	Singh et al (2011), Nahmens et al (2015), Laquatra et al (2008), Seshadri and Topkar (2014), Kato et al (2008), Langston et al (2008), Brown and Gorgolewski (2010), Parkin et al (2011), Brown et al (2014), Atkins and Emmanuel (2014), Agnieszka (2014), Meir et al (2009), Moezzi (2009), Leaman and Bordass (2001), Newsham et al (2013), Gou et al (2014), Brown and Cole (2009),Voelker et al (2013),Menadue et al (2014), Goins et al (2013), Paul and Taylor (2008), Preiser and Vischer (2005), Brown and Gorgolewski (2014),Wang et al (2015), Brooks and Viccars(2006), Hauge et al (2010), Wagner (2007), Khalil and Husin (2009), Emuze et al (2013)	conversation, footsteps, outdoors, HVAC, lighting equipment, office devices
		echo	Meir et al (2009)	workspace, meeting rooms, conference halls, other
Visual comfort	Seshadri and Topkar (2014), Brown et al (2014), Driza and Park (2015), Langston et al (2008), Kato et al (2008), Sawyer et al (2008), Brown and Gorgolewski (2010), Meir et al (2009), Candido et al (2015), Garreton et al (2015), Healey et al (2012), Wright et al (2014), Voelker et al (2013), Afacan and Demirkan (2015), Preiser and Vischer (2005), Khalil and Husin (2009)	daylighting	Galasiu and Veitch (2006), Singh et al (2011), Menadue et al (2014), Afacan and Demirkan (2015), Healey et al (2012), Gou et al (2014), Paul and Taylor (2008), Preiser and Vischer (2005), Brown and Gorgolewski (2014), Brooks and Viccars(2006), Gultekin et al (2015), Low et al (2014), Hauge et al (2010), , Heerwagen and Zagreus (2005), Ann and Pearce (2013), Wagner (2007), Alzoubi et al (2010)	amount, duration
		artificial lighting	Cao et al (2012), Singh et al (2011), Jazizadeh et al (2014), Nahmens et al (2015), Laquatra et al (2008), Seshadri and Topkar (2014), Vos and van der Voordt (2002), Kato et al (2008), Rashid et al (2012), Atkins and Emmanuel (2014), Brown et al (2014), Agnieszka (2014),Afacan and Demirkan (2015), Marie et al (2015),Gou et al (2014), Preiser and Vischer (2005), Brown and	workplace level of light, work surface level of light, warmth, shadow, flicker (frequency)

			Gorgolewski (2014), Brooks and Viccars(2006), Gultekin et al (2015), Hauge et al (2010), Ann and Pearce (2013), Knez and Enmarker (1998), Wagner (2007), Nicol et al (2006),	
		glare	Singh et al (2011), Laquatra et al (2008), Galasiu and Veitch (2006), Seshadri and Topkar (2014), Kato et al (2008), Gou et al (2014), Brown and Cole (2009), Voelker et al (2013), Menadue et al (2014), Leder et al (2015), Afacan and Demirkan (2015),Meir et al (2009), Garreton et al (2015), Healey et al (2012), Paul and Taylor (2008), Preiser and Vischer (2005), Brown and Gorgolewski (2014), , Heerwagen and Zagreus (2005), Bakker et al (2014)	lights, windows
		reflection	Garreton et al (2015) CBE Berkeley IEQ Survey	monitors, other
Spatial comfort	Sawyer et al (2008), Brown and Gorgolewski (2010), Meir et al (2009), Candido et al (2015), Leaman and Bordass (2001), Marie et al (2015), Newsham et al (2013), Gou et al (2014), Preiser and Vischer (2005), Brooks and Viccars(2006), Hauge et al (2010)	amount of space	Seshadri and Topkar (2014), Kato et al (2008), Langston et al (2008), Schwede et al (2008), Brown and Gorgolewski (2010), Parkin et al (2011), Rashid et al (2012), Marie et al (2015),Meir et al (2009), Newsham et al (2013), Paul and Taylor (2008), Wilkinson (2012), Preiser and Vischer (2005), Chen and Ahn (2014), Azar et al (2015), Brooks and Viccars(2006)	workspace, work surface, social space, meeting / collaboration space, parking space, storage space, WC, restaurants / canteen, ceiling height
		audial privacy	Vos and van der Voordt (2002), Parkin et al (2011), Rashid et al (2012), Gou et al (2014), Afacan and Demirkan (2015), Meir et al (2009), Candido et al (2015), Newsham et al (2013) , Goins et al (2013), Preiser and Vischer (2005), Heerwagen and Zagreus (2005), Kim and Dear (2013), CBE Berkeley IEQ Survey	workspace, meeting rooms
		visual privacy	Singh et al (2011), Vos and van der Voordt (2002), Parkin et al (2011), Gou et al (2014), Meir et al (2009), Preiser and Vischer (2005), Heerwagen and Zagreus (2005)	workspace, monitor, meeting rooms
		visual disturbance	Seshadri and Topkar (2014), Langston et al (2008), Schwede et al (2008), Parkin et al (2011)	colleagues, monitors, other
		layout	Kato et al (2008), Langston et al (2008), Schwede et al (2008), Brown and Gorgolewski (2010), Riley et al (2010), Parkin et al (2011), Rashid et al (2012), Driza and Park (2015), Jailani (2015), Meir et al (2009), Healey et al (2012),Newsham et al (2013), Voelker et al (2013), Ackerly and Brager (2013), Goins and Moezzi (2013), Paul and Taylor (2008), Preiser and Vischer (2005), Wang et al (2015), Brooks and Viccars(2006), Jazizadeh et al (2014), , Heerwagen and Zagreus (2005), Ann and Pearce (2013), Kim and Dear (2013)	workspace layout, office layout, wayfinding, ease of / facilitating interaction, access to equipment
User control	Rashid et al (2012), Kato et al (2008), Meir et al (2009), Ackerly and Brager (2013), Healey et al (2012), Candido et al (2015), Paul and Taylor (2008), Preiser and Vischer (2005), Brown and Gorgolewski (2014), Chen and Ahn (2014), Azar et al	controllability of the environment	Galasiu and Veitch (2006), Seshadri and Topkar (2014), Vos and van der Voordt (2002), Kato et al (2008), Riley et al (2010), Rashid et al (2012), Brown et al (2014), Agnieszka (2014), Ali et al (2015), Driza and Park (2015), Brown and Cole (2009), Afacan and Demirkan (2015), Marie et al (2015),Stevens, S. (2001), Voelker et al (2013), Menadue et al (2014), Ackerly and	heating, cooling, humidity, air movement, lighting, shading, natural ventilation

	(2015), Brooks and Viccars(2006), Gultekin et al (2015), Jazizadeh et al (2014)		Brager (2013), Paul and Taylor (2008), Wilkinson (2012), Brown and Gorgolewski (2014), Chen and Ahn (2014), Hopper et al (2012), Brooks and Viccars(2006), Gultekin et al (2015), Jazizadeh et al (2014), Menzies and Wherrett (2005)	(windows), noise
		usability of control devices	Brown et al (2014), Meir et al (2009), Marie et al (2015), Brown and Cole (2009), Brown and Gorgolewski (2014), Chen and Ahn (2014), Azar et al (2015), Brooks and Viccars(2006), Gultekin et al (2015), , Heerwagen and Zagreus (2005)	user friendly manual description, difficulty of fine tuning
Building design	Atkins and Emmanuel (2014), Brown and Gorgolewski (2010), Meir et al (2009), Leaman and Bordass (2001), Leder et al (2015), Healey et al (2012), Paul and Taylor (2008), Lee et al (2015), Preiser and Vischer (2005), Brown and Gorgolewski (2014), Hopper et al (2012), Brooks and Viccars(2006)	exterior design	Lai (2011), Seshadri and Topkar (2014), Vos and van der Voordt (2002), Meir et al (2009), Menadue et al (2014), Stevens, S. (2001), Preiser and Vischer (2005),Brown and Gorgolewski (2014), Hopper et al (2012) , Wang et al (2015), Gultekin et al (2015), Hauge et al (2010), , Heerwagen and Zagreus (2005)	facade, landscape
		interior design	Laquatra et al (2008), Seshadri and Topkar (2014), Vos and van der Voordt (2002), Kato et al (2008), Brown and Gorgolewski (2010), Riley et al (2010), Rashid et al (2012), Atkins and Emmanuel (2014), Jailani (2015), Meir et al (2009), Leaman and Bordass (2001), Leder et al (2015), Healey et al (2012), Marie et al (2015), Newsham et al (2013), Menadue et al (2014), Paul and Taylor (2008), Wilkinson (2012), Preiser and Vischer (2005), Azar et al (2015), Gultekin et al (2015), Hauge et al (2010), , Heerwagen and Zagreus (2005), Cao et al (2015),), Au-Yong et al (2014)	aesthetics / attractiveness, level of contrast, personalizatio n of workspace, colors and textures, image value, functionality, durable & maintainable finishes
		furniture	Singh et al (2011), Kato et al (2008), Langston et al (2008), Schwede et al (2008), Brown and Gorgolewski (2010), Rashid et al (2012), Driza and Park (2015), Brown and Cole (2009), Ackerly and Brager (2013), Meir et al (2009), Goins and Moezzi (2013), Gou et al (2014), Preiser and Vischer (2005), Brooks and Viccars(2006), , Heerwagen and Zagreus (2005), Ann and Pearce (2013), Kim and Dear (2013), CBE Berkeley IEQ Survey, Brager and Baker (2009)	comfort / ergonomics, adjustability / flexibility
		accessibility	Seshadri and Topkar (2014), Riley et al (2010), Brown and Cole (2009), Newsham et al (2013), Leder et al (2015), Healey et al (2012), Wilkinson (2012), Preiser and Vischer (2005), Brown and Gorgolewski (2014), Chen and Ahn (2014), Brooks and Viccars(2006), Gultekin et al (2015), Jazizadeh et al (2014), Hauge et al (2010), Heerwagen and Zagreus (2005), Hashim et al (2002)	connectivity, internal roads, staircases, lifts, and escalators
		connection to outdoor environment	Singh et al (2011), Seshadri and Topkar (2014), Candido et al (2015),Healey et al (2012), Newsham et al (2013), Leder et al (2015), Paul and Taylor (2008), Wilkinson (2012), Preiser and Vischer (2005), Hauge et al (2010), Heerwagen and Zagreus (2005)	view out, access to daylight, connection to outdoors
		vibration	Voelker et al. (2013)	wind, vehicles, users

Building services	Lai (2011), Meir et al (2009), Marie et al (2015), Brown and Cole (2009), Lee et al (2015), Wilkinson (2012), Preiser and Vischer (2005), Brooks and Viccars(2006), Gultekin et al (2015), Jazizadeh et al (2014), Brager and Baker (2009)	service quality	Cao et al (2012), Au-Yong et al (2014), Shaw and Haynes (2004), Siu et al (2001), Lai (2011), Seshadri and Topkar (2014), Riley et al (2010), Driza and Park (2015), Jailani -2015, Lai (2011), Marie et al (2015), Brooks and Viccars(2006), Kim and Dear (2013), CBE Berkeley IEQ Survey, Khalil and Husin (2009))	(HVAC operation, waste management, security, cleaning, general management
		maintenance	Cao et al (2012), Lai (2011), Laquatra et al (2008), Seshadri and Topkar (2014), Riley et al (2010), Driza and Park (2015), Lai (2011), Marie et al (2015), Ackerly and Brager (2013), Goins and Moezzi (2013), Candido et al (2015),Leaman and Bordass (2001),Wilkinson (2012), Preiser and Vischer (2005), Brown and Gorgolewski (2014),Hopper et al (2012), Azar et al (2015), Brooks and Viccars (2006),Cao et al (2012), Au-Yong et al (2014)	maintenance scheduling, renewals of equipment and installations, durable and maintainable materials, repairs, insects and rodent, leakage, cracks, seepage, dampness

*For references used in Table 2, please see: Appendix2.

Occupant satisfaction was configured under eight dimensions and under each dimension, the related indicators were identified. For example, for thermal satisfaction dimension, indicators were determined as temperature, radiant temperature, relative humidity and temperature shift. In total, twenty nine indicators were identified. It should be noted that while determining the indicators, the goal was to define the unobservable facets of occupant satisfaction via indicators that can be assessed by the users. Therefore, the indicators which require data collection at buildings by using devices (e.g., CO_2 emmision) are not included in the scope of this study. In addition, possible sources of dissatisfaction for each indicator were determined from the literature. For example, for temperature sources of dissatisfaction were identified as 'too cold', 'too hot' and 'unstable'. These dissatisfaction sources are intended to be used for determining the needs of the occupants and therefore priority areas to work on in the pre-retrofit phase.

4. Conclusions

Occupants can be a useful and inexpensive source of information in identification of the retrofit actions required in office buildings. In this paper post-occupancy evaluation tools and standards as well as academic studies were analysed in order to understand the approach, dimensions and indicators used to measure occupant satisfaction. According to Turpin-Brooks and Viccars (2006), an effective occupant satisfaction measurement tool needs to give comparable results, be reliable and address all factors that relate to the needs, activities and goals of the people using the specific type of the building considered. Existing occupant satisfaction measurement tools however, lack an empirically validated construct and a holistic approach embracing different aspects of occupant comfort in office buildings. As a first step in developing the occupant satisfaction measure, occupant satisfaction dimensions and indicators in the literature have been reviewed systematically and organized in a hierarchical structure to ensure content validity of the model. The proposed occupant satisfaction construct is intended to be empirically validated with an appropriate method in the following stages of the research, also determining the possible interactions with comfort conditions, occupant health and productivity. This study is expected to help identify and solve existing problems that hinders occupant satisfaction and guide the design of retrofits in the office buildings to maximize building performance and users' needs.

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Appendix1: https://docs.zoho.com/file/07ojpcfe1018a0f0845e686860bfea2cf16e8

Appendix2: http://docs.zoho.com/file/07ojp0fa4a43c3b6348e7b65f02b7d9f53438

An Analysis of Student Experiences at South African University Construction Programmes

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Abstract

A good student experience at the university is important for both the student and the institution as it has been shown to improve student progression rate and improve the through-put of students. The quality of the academic experience enjoyed by students is determined to a large extent by the teaching and learning philosophy employed. For education in construction related studies, the general teaching and learning philosophy used is the traditional lecture approach which is strongly instructive in nature. However, for the Architecture programme, the studio approach, which exhibits attributes of a constructivist approach, is the *modus operandi* philosophy of teaching and learning. Notwithstanding that the Architecture studio approach is coupled with the instructive lecture approach, differences in student learning experiences are expected to prevail between students of Architecture compared to students of other construction related programmes such as Quantity Surveying and Construction Management due to the differences in teaching and learning philosophies. This study therefore sought to determine if there are in fact any differences in learning experiences offered by the Architecture programme compared with learning experiences in Quantity Surveying and Construction Management programmes due to the studio approach to Architecture education. To achieve this, a self-administered questionnaire survey was conducted with students at three South African universities offering Architecture, Construction Management and Quantity Surveying programmes. A total of 194 registered students were surveyed. Using the Kruskal Wallis test and the Mann-Whitney U test, significant differences were found in some experiences between Architecture and the combination of Construction Management and Quantity Surveying and also in individual associations between Architecture and Construction Management and between Architecture and Quantity Surveying. However, as expected no significant association was found in any of the measured constructs between Quantity Surveying and Construction Management. The results therefore suggest that there are significant differences in learning experiences between Architecture and other construction programmes due to the studio approach to Architecture education. However, the differences are moderated by the fact that Architecture still relies on a significant amount of instructive lectures alongside the studio approach.

Keywords: Student experience, Learning experiences, constructivist, instructive, Studio learning, construction programmes

1. Introduction

The quality of the student academic experience during university education is cardinal to the success of both the student and the institution and is critical for producing quality graduates (Morgan 2016). Student experience refers to all the aspects of student life including academic, social, welfare and support (Ibid). The academic student experience is significantly determined by the general philosophy underpinning the delivery of the education. Generally, the philosophy of education delivery can be broadly divided into the two groups of the traditional instructive approach and the more contemporary constructivist or student centred approach. Construction education has largely been delivered through the traditional instructive approach with the exception of architecture, which, through the use of the studio approach, exhibits strong attributes of a constructivist approach.

A constructivist learning approach is distinctive from the traditional instructive approach in a number of ways. It is structured so that the learning is centred on the student by having the student actively participating in the learning. The approach is also based on a two-way communication system between the learner and the instructor with both parties sharing knowledge and experiences to promote active construction of knowledge by the learner. The traditional instructivist teaching approach on the other hand is characterised by a passive and rather uninvolved learner receiving knowledge in a one-way transmission process. Some educators have described the instructivist approach as being unsuited to learning and suggested that it perpetuates the production of graduates who are ill prepared for professional practice (Jungst, et al. 2003).

Notwithstanding that architecture uses the constructivist studio based learning, it also incorporates a fairly significant amount of instructive lectures as well. However, the equally significant use of the studio learning is very likely to significantly impact on the academic experience of the students. Therefore, compared to the rest of the construction programmes which do not make any significant use of the studio based learning, differences in the academic experience of architecture students are very likely to exist. This study therefore investigates the academic experiences of students undertaking construction studies and posits that there are significant differences in academic experiences of students of architecture and the rest of the students pursuing construction studies.

2. Studio-based Learning

Studio-based learning (SBL) is an instruction approach which is centred on the collaborative application of several module contents and skills in a project the solution of which is presented for peer review and revised based on peer review (Vest, et al. 2011). It has received widespread application on architectural education practice whereby, while different design modules are taught separately, students are expected to demonstrate their understanding of these different distinct modules by applying their understanding to a design problem called a studio project (Hundhausen and Brown 2008; Nasir, et al. 2011; Vest, et al. 2011). In the SBL approach, students must construct a solution to a complex problem, present the solution to peers, participate in a critique ('crit') of the solution to peers and respond to criticism by revision or rebuttal (Hundhausen and Brown 2008). The lecturer plays the role of an instructor who both critiques and provides appropriate guidance to the student (Nasir, et al. 2011). The SBL approach is so central to the development of architects that no architecture programme is taught without it. Therefore, the results of the SBL approach to architecture education can be seen in its strict application of the philosophy. Owing to its remarkable success with architecture, other fields of learning have also embraced SBL. For example, Hundhausen and Brown (2008) applied the SBL approach to a computer science class where the students were tasked with developing the solution of an algorithm problem and reported evidence of the efficacy of the studio-based learning approach in a setting other than architecture education.

The studio approach in architecture education is based on the '*atelier'* system which has its history in the prestigious Ecole des Beaux Arts in Paris (Fricker and Fricker 2010; Lackney 1999; Oh, et al. 2012; Simon 1996; Van-Alen-Institute nd). The *'atelier'* system is an educational approach whereby apprentices in fine arts and architecture were trained by experienced 'masters' in an *atelier,* which is the French word for 'workshop' or 'studio' (Simon 1996). The Ecole des Beaux Arts, which is perhaps the oldest formal learning institution offering education in fine arts and architecture, used this approach since its inception in 1648 (Fricker and Fricker 2010). The approach was borrowed from the training of apprentices before formal education which involved experienced 'masters' taking on a small number of apprentices in their *ateliers* until the apprentices had mastered the art (Simon 1996). The *atelier* system lent itself very well to the training of architects because of the practical nature of art rather than science of architecture, and subsequently the need for apprentice architects to practice their craft in an architectural studio. The system worked so well that in fact as professional education shifted from the *atelier* to colleges and universities, and even as architecture education spread from Europe to America, and to the rest of the world, the studio approach became the *modus operandi* in architecture education (Lackney 1999; Van-Alen-Institute nd).

The student centred approach inherent in SBL is very similar to approaches found under constructivist learning models. Loyens et al. (2009) suggested four characteristics of a constructivist learning approach, namely, knowledge construction, cooperative learning, metacognition and authentic learning tasks. Knowledge construction in a SBL takes the form of the student piecing together knowledge from different modules and applying it to a novel problem thereby constructing new knowledge. The presentation of the suggested solution to peers and the instructors allowing for feedback through rebuttal or revision permits cooperative learning to happen. Metacognition, is built into the process by allowing students time to carefully reflecting on the responses provided by the peers and the instructor and subsequently revise their solutions after a 'crit' session. The studio project itself is normally the development of a solution to an authentic task. While this analogy between SBL and a constructivist lesson are drawn based on only one description of a constructivist lesson, even with other differently named characteristics of a constructivist lesson, the central tenets among all constructivist approaches are the same and so the analogy remains valid. Therefore, SBL very closely resembles a constructivist lesson.

3. Constructivist Teaching Approach

As illustrated in Figure 2, the constructivist teaching model allows a creative process to take place during the interaction between the different parties via the learning situation designed by the teacher. The constructivist teaching model facilitates students' creation of their own knowledge, as they are allowed to think more over the problems together and generate original ideas. So constructivist teaching is characterised by students' active participation in class when they construct knowledge. The focus shifts from the teacher transferring knowledge, to students constructing knowledge by themselves; that is, from teacher-centredness to student-centredness in a multi-directional manner (Yuen and Hau, 2006). Interchanges between student and instructor as well as between student and student are permitted and encouraged. Constructivist teaching by nature is empowering, because teachers assist students in developing new insights and making connections with previous knowledge while leaving the discovery of the knowledge to the students. This way, students are able to develop their own understanding of the subject matter based on previous knowledge and can correct any misconceptions they may have had. By explaining their ideas to other students, they are active participants in their own education and are able to come to a clearer understanding of the concepts being learnt (Ibid).

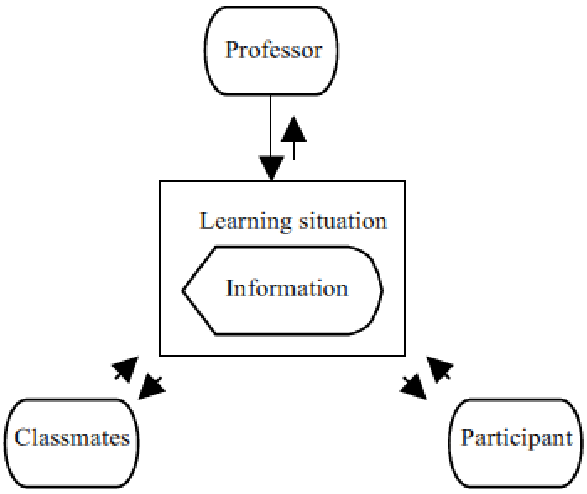

Figure 1: The constructivist teaching model as adapted from Yuen & Hau, 2006

4. Instructivist Teaching Approach

The traditional lecture approach to learning differs significantly from both the constructivist approach and SBL in that the traditional approach is strongly instructivist in nature. Instructivist teaching is most commonly understood as being a traditional, direct instruction, teacher/instructor-centred approach whereby students in the classroom are passively receiving information and knowledge. Put very simply, direct instruction means teachers/instructors telling students the things they need to know (Nasir, et al. 2011). The traditional classroom can sometimes resemble a one-person show with a captive but largely uninvolved and passive audience. This teaching approach can be seen graphically in the Yuen and Hau (2006) model shown in figure 2. The model illustrates how the traditional approach is instructivist in nature with a one-directional flow of information. Students are expected to passively receive the knowledge from the teacher with very little engagement with the lesson. In this approach, the teacher seeks to transfer thoughts and meanings to passive students, leaving little room for student-initiated questions, independent thought, or interaction among students as well as between students and the teacher. This teacher-centred method of teaching also assumes that all students have the same level of background knowledge in the subject matter and are able to absorb the material at the same pace (Lord, 1999).

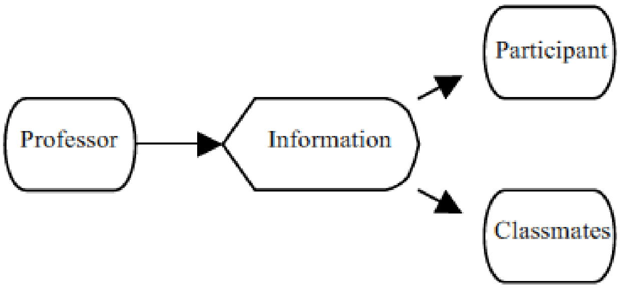

Figure 2: The teacher-centred teaching model as adapted from Yuen & Hau, 2006

5. Instructivist and Constructivist student experiences

Arising from the differences inherent in the teaching approaches of the constructivist and the instructivist models, differences in student experiences abound. In a constructivist academic environment, students experience a learner-centred approach rather than the teacher one-directionally communicating defined bodies of knowledge (Kember 1997). Active learning occurs multi-directionally with students engaged in discussing, questioning and solving problems and taking more responsibility for their own learning (Gibbs and Unit 1988; Prince and Felder 2006). In the instructivist teaching methodology, students are passive learners, receiving information without question. In a constructivist model, students actively construct their own meaning of knowledge (Bruner 1990) while in the instructivist model, they merely receive information.

The constructivist characteristics intrinsic in the SBL approach in the architectural design studio module therefore carries some, if not all, the differences in student learning experiences highlighted. Based on the description of the studio approach, four distinct differences in studio experiences with the traditional instructivist approach would be expected. Firstly, the role which the lecturer in an architectural design studio lesson plays changes from source of knowledge to critique and guidance instructor (Singer and Moscovici, 2007). Secondly, the nature of problems administered to students in an architectural design studio are complex with no single accepted solution and require students to combine knowledge from several modules to synthesize the solution. Thirdly, the students are engaged more actively with their lessons because of the 'crit' sessions which provide very effective formative assessment and the opportunity for the students to explain their thinking and therefore more effectively demonstrate their understanding of key design concepts (Hundhausen and Brown, 2004). Finally, the architecture design studio is different from the traditional lecture approach in that the mode of lesson delivery is strongly student centred as opposed to the strongly teacher centred approach in the traditional lecture system. These differences and others can be seen in Table 1.

Table 1: Comparison of Student Experience

Construct	**Students Experience**	
	Constructivist	**Instructivist**
Role, commitment and involvement of instructor	• Critique • Facilitating • Guiding	• Directing • Instructing
Nature of problems	• Complex • Generation of ideas	• Theoretical
Student engagement	• Active • Knowledge sharing • Knowledge creation/construction	• Passive • Uninvolved • Knowledge acceptance
Mode of delivery/transmission	• Group work • Two-way transmission	• Individual • One-way transmission

6. Research Design

Research was conducted to establish whether there are any differences in learning experiences between architectural students and the rest of the students engaged in construction studies due to the conceptual differences in instruction approaches used in the design studio of the architecture programme and the instructive approach used for the rest of the construction programmes. The research was designed to measure the perceptions of students about their educational experiences. The design of any research study is concerned with the plan to assemble suitable data for investigating and testing the research hypotheses (Welman and Kruger, 2001). The methods used to gather information depend on the type of data and the problem to be researched (Leedy and Ormrod, 2001). For this study, a self-administered questionnaire survey was conducted with students at three South African universities offering construction management, quantity surveying and architecture programmes. The student survey forms part of a larger national study that evaluates the experiences of students in their academic construction programs. The data were analysed using SPSS version 22.

The population of interest was all South African universities offering construction related programmes. However, due to resource limitations, convenient quota sampling was used to select a sample of three universities. Time and cost conveniences were the main criterion used for selecting the quotas. All students in the selected universities were then targeted for inclusion in the sample.

Four constructs measuring aspects of learning experiences identified from literature as being likely to exhibit differences between architecture students and the rest of the students pursuing construction studies were investigated. The four constructs are “Role, Commitment and Involvement of Instructors”, “Nature of Problems”, “Student Engagement” and “Mode of Delivery/Instruction”. Each construct had items ranging from 8 to 12 and responses were measured using a five-point Likert scale with 1 = “Strongly Disagree,” 2 = “Disagree,” 3 =“Neutral,” 4 = “Agree” and 5 = “Strongly Agree”.

The questionnaires were administered to all students present at the time of sampling in each programme at the selected universities. The sampling was done at different days for each of the universities. A total sample of 194 registered full-time students from all three universities was obtained.

7. Discussion and findings

The convenience sample comprised of 194 full-time registered students at three universities in South Africa, made up of 88 (45%) male and 105 (54%) female students with one student not responding. Students were registered in all years of study as follows:

- Architecture – 81 (42%);
- Construction Management – 41 (21%); and
- Quantity Surveying – 72 (37%).

The degree of internal consistency or Cronbach Alpha scores for the scales used for the four student experience constructs is shown in Table 2. All the constructs were found to have statistically high internal reliability, namely Cronbach Alpha values >0.700. The scores ranged from 0.902 (role, commitment and involvement of instructors) to 0.799 (nature of problems). There is therefore between 90.20% and 79.90% probability that the constructs each measure a single underlying concept with an error of at most 5%. The scales used to measure the four selected areas of student experiences are therefore reliable in their measure of the constructs.

Table 2: Reliability Statistics

Scale	Cronbach's Alpha	No of Items
Role, Commitment and Involvement of Instructors	0.902	14
Nature of Problems	0.799	8
Student Engagement and Empowerment	0.849	11
Mode of Delivery/Transmission	0.869	8

Descriptive statistics for the four constructs have mean scores ranging from 3.59 to 4.05 as shown in Table 3.

Table 3: Descriptive Statistics for Aggregate Scores

	Role, commitment and involvement of instructors	Nature of problems	Student Engagement and Empowerment	Mode of delivery/ transmission
N	194	193	193	194
Mean	3.588	3.863	3.833	3.772
Std.	0.624	0.570	0.586	0.641

The data were tested for relationships. However, before any tests of association were performed, a test of normality was performed to establish the statistical distribution of the data and therefore establish the appropriate statistical tests to use between parametric and non-parametric tests. Table 4 presents the results of the Shapiro-Wilk test of normality which tests the null hypothesis that the data are drawn from a population which follows a normal distribution. The significance values less than 0.05 suggest that there is no evidence to support the null hypothesis and so it can be concluded that the data is not normally distributed and therefore only non-parametric tests should be used.

Table 4: Test of Normality

	Shapiro-Wilk		
	Statistic	df	Sig.
Role, Commitment and involvement of instructors	0.982	193	0.013
Nature of Problems	0.971	193	0.000
Student Engagement and Empowerment	0.976	193	0.002
Mode of Delivery/transmission	0.977	193	0.003

To establish whether there were significant associations between the constructs measuring student experience and the different disciplines with the different instruction approaches, the non-parametric Kruskal-Wallis test was used. This test typically measures whether or not there are any differences in three or more sample means (Chan and Walmsley, 1997). It tests the null hypothesis that the samples are drawn from the same population.

Test statistics for the constructs "Role, Commitment and Involvement of Instructors" and "Mode of Delivery/transmission" are less than 0.05 as can be seen in Table 5. Therefore, for these constructs, the null hypothesis is rejected and it can be concluded that there are distinct differences in experiences among the three disciplines when it comes to these constructs. The three disciplines exhibit no significant differences in their perceptions of "Nature of Problems" and "Student Engagement and Empowerment"

Table 5: Association among all Disciplines

	Role, Commitment and Involvement of Instructors	Nature of Problems	Student Engagement and Empowerment	Mode of Delivery/transmis sion
Chi-Square	12.153	5.878	2.540	9.208
Df	2	2	2	2
Asymp. Sig.	0.002	0.053	0.281	0.010

a. Kruskal Wallis Test

b. Grouping Variable: Discipline

In order to establish whether the observed differences in the experiences of the respondents on "Role, Commitment and Involvement of Instructors" and "Mode of Delivery/transmission" can be attributed to the architectural students, individual associations between architectural students and construction management students and between architectural students and quantity surveying students and also between construction management and quantity surveying students were performed. The Mann-Whitney U test, which is a non-parametric test which compares two sample means to establish whether the means are equal or not. It tests the null hypothesis that the two samples are drawn from the sample population.

Table 6: Association between Architecture and Construction Management

	Role, Commitment and Involvement of Instructors	Nature of Problems	Student Engagement and Empowerment	Mode of Delivery/trans mission
Mann-Whitney U	1317.500	1233.000	1556.500	1173.000
Wilcoxon W	4638.500	2094.000	4796.500	4494.000
Z	-1.861	-2.235	-.458	-2.648
Asymp. Sig. (2-tailed)	0.063	0.025	0.647	0.008

a. Grouping Variable: Discipline

Table 6 shows that the experiences of students in Architecture are significantly different from those of Construction Management students in the constructs of "Nature of Problems (0.025) and "Mode of Delivery/Instruction" (0.008) since these are not coming from the same population. Also, Table 7 shows that when architecture students and quantity Surveying students are compared, significant differences in student experiences are found in "Role, Commitment and Involvement of Instructors" (0.001) and "Mode of Delivery/Transmission" (0.015).

Table 7: Association between Architecture and Quantity Surveying

	Role, Commitment and Involvement of Instructors	Nature of Problems	Student Engagement and Empowerment	Mode of Delivery/trans mission
Mann-Whitney U	1985.500	2418.000	2447.500	2254.500
Wilcoxon W	5306.500	5046.000	5687.500	5575.500
Z	-3.404	-1.710	-1.598	-2.422
Asymp. Sig. (2-tailed)	0.001	0.087	0.110	0.015

a. Grouping Variable: Discipline

Table 8: Association between Construction Management and Quantity Surveying

	Role, Commitment and Involvement of Instructors	Nature of Problems	Student Engagement and Empowerment	Mode of Delivery/trans mission
Mann-Whitney U	1277.000	1332.500	1339.000	1391.500
Wilcoxon W	2138.000	2193.500	2200.000	4019.500
Z	-1.190	-0.860	-0.820	-0.506
Asymp. Sig. (2-tailed)	0.234	0.390	0.412	0.613

a. Grouping Variable: Discipline

From Table 8, it is evident that there are no significant associations between the experiences of students registered for construction management and quantity surveying. This finding is not unexpected given that the mode of instruction is the same for both disciplines and firmly establishes the observed significant differences in student experiences originates from Architecture.

A correlation analysis revealed no significant correlations in student experiences when all the disciplines were grouped together. However, when Architecture was correlated individually with Quantity Surveying, significant correlations were found in the constructs of "Role, Commitment and Involvement of Instructor" ($r = 0.276$, $p = 0.001$) and "Mode and Delivery/Transmission" ($r = 0.196$, $p = 0.015$) as shown in Table 9.

Table 9: Architecture and Quantity Surveying

Role, Commitment and Involvement of Instructors	Correlation Coefficient	0.276**
	Sig. (2-tailed)	0.001
	N	153
Nature of Problems	Correlation Coefficient	- 0.139
	Sig. (2-tailed)	0.087
	N	152
Student Engagement and Empowerment	Correlation Coefficient	0.130
	Sig. (2-tailed)	0.110
	N	152
Mode of Delivery/transmission	Correlation Coefficient	0.196*
	Sig. (2-tailed)	0.015
	N	153

When Architecture was correlated individually with Construction Management as shown in Table 10, the associated student experiences with coefficients ranged from 0.204 to -0.241 with significant association in "nature of Problems" ($r = 0.204$, $p = 0.025$) and in "Mode of Delivery/Instruction" ($r = -0.241$, $p = 0.008$). No significant correlations were found between Quantity Surveying and Construction Management.

Table 10: Architecture and Construction Management

Role, Commitment and Involvement of Instructors	Correlation Coefficient	- 0.169
	Sig. (2-tailed)	0.062

	N	122
Nature of Problems	Correlation Coefficient	0.204*
	Sig. (2-tailed)	0.025
	N	121
Student Engagement and Empowerment	Correlation Coefficient	-0.042
	Sig. (2-tailed)	0.649
	N	121
Mode of Delivery/transmission	Correlation Coefficient	- 0.241**
	Sig. (2-tailed)	0.008
	N	122

8. Conclusions

There are significant differences in learning experiences between students of Architecture and students of other construction related disciplines. Differences in students' learning experiences were found in comparisons of Architecture with Quantity Surveying and Architecture with Construction Management in two of the four constructs studied. No significant differences were found between Quantity Surveying and Construction Management. The significant differences found in associations with Architecture coupled with the absence of significant differences found in associations without Architecture suggest that student learning experiences in Architecture differ significantly from the rest of construction programmes.

While individual modules taught in Architecture are delivered through the traditional instructive approach similar to the rest of the construction programmes, Architecture differs from the rest of the programmes in that it is further characterised by the studio approach which is much more student centred and therefore exhibits attributes of constructivism. Therefore the difference in learning experiences found in associations with Architect and absent in associations without Architecture can be attributed to the studio nature of the learning approach used in Architecture programmes since it is the only variable of difference between Architecture and the other construction programmes. The differences found in the constructs of "Role, Commitment and Involvement of Instructors" and "Mode of delivery/Instruction" further support the notion that the studio approach is responsible for the differences since it the module where the role of the instructor differs from the role played in other modules. Also, studio is the only module where the mode of instruction is different.

Differences were expected to be larger and to be present in all four constructs studied. The absence of differences in some of constructs may be attributed firstly to the fact that even if architecture relies on the studio approach, it still has modules taught through the instructive approach and therefore the effect of the studio approach is moderated. Secondly, students may have given their opinions in some instances rather than their experiences. An element of reporting perceptions rather than experiences may have crept into the responses particularly in the responses from the construction management and quantity surveying students due to how the programmes are in fact taught in the South African universities. Therefore, in this kind of survey, one needs to be extremely cautious and provide very clear instructions to the participants to avoid misunderstanding of what is expected from them.

While this study has established differences in learning experiences between Architecture and Quantity Surveying and Construction Management in some learning experiences, it remains to be established whether the differences are positive towards Architecture or otherwise. This is worth establishing so that the viability of a studio approach to other construction programmes can be investigated.

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Design and Engineering Understood as Processes of Learning

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Abstract

The purpose of this paper is to develop an analytical model for further verification of design and engineering as processes of learning. Such a model should in particular be able to uncover that design projects mature progressively through interactive processes with strong reciprocal and sequential dependencies. We assume that the linear waterfall style of project management for design and engineering is not adequate for coping with the nature of design and engineering. Following the verifications, the next step in this research is to develop a model for improved design management.

The paper addresses the nature of design and engineering and learning theory, and contributes to an improved understanding of the phenomena in question.

Keywords: design, learning, analytical model

1. Introduction

Project planning and engineering are activities that aim to create a foundation for some kind of artefact, e.g. a building with functionality defined by the customer, a bridge or a ship. Kalay (2004) refers to design as a cyclical relationship between two paradigms; design as problem solving, where the designer attempts to produce solutions to ill-defined problems, and design as puzzle making, where design is seen as a process of discovery, where given parts are synthesized into a new and unique whole. The design process, particularly in its early stages, can be characterized by a progressively clearer understanding of the scope, reciprocal interdependencies (Thompson 1967, Kalsaas and Sacks 2011) between different disciplines and subjects, and iterative processes and loops. Iterations can be positive or negative (Ballard 2000).

Several authors characterize Last Planner System (LPS) as a system of learning (e.g. Ballard, 2000; Rooke, 2005; Koskela et al., 2010), which is tied in particular to the high level of focus on involvement, and the mechanisms that are related to the evaluation of completed work plans, and root-cause analysis (continuous improvement). However, it seems like there has been a lack of contributions to uncover, in depth, why this is the case. Some exceptions are Kalsaas (2012) and Skinnarland and Yndesdal (2012). Kalsaas analyses LPS through a learning perspective, which is based, in particular, on Kolb`s (1984) experiential learning theory and Illeris` (2009) model of workplace learning. Skinnarland and Yndesdal (2012) focus on LPS as a system of knowledge development. The authors ties their theories to collective learning processes, inter alia, Nonaka and Takeuchi`s (1995) well known SECI model.

In the context of this paper, the authors are trying to understand the design process as a learning activity. The relevance is tied to the ability to gain a greater theoretical notion of design as a learning phenomenon, which will create an understanding that can be used to improve design management. For instance by providing a framework that utilizes the learning process in the most effective manner. The paper is structured as follows: at first we investigate the architectural design process, then we look at a selection of learning concepts. Finally, we discuss an analytical model for future research.

2. The architectural design process

Throughout the evolution of design practice, there have been countless attempts to tackle the challenge of understanding, mastering and explaining the processes behind our built environment. The first generation of design methodologists' focus on the design process as something sequential and linear in the 1960s, has long been challenged (Lundequist, 1992). The understanding of the architectural design process as a complex universe of predictable and unpredictable interactions, interrelations and interdependencies between actors and their actions, relates to observations of the practice of architectural design made by researchers such as Cuff (1991), Kalay (2004), Lawson (2006) and Schön (1991).

According to Cuff (1991), the design process is a social construction, where buildings are collectively conceived. Kalay (2004) refers, as previously described, to design as a cyclical relationship between problem solving and puzzle making. Lawson (2006) describes the design process as "a negotiation between the problem and solution through the three activities of analysis, synthesis and evaluation," and challenges the comprehension of the design process as a sequence of activities. He sees the design process to be a simultaneous learning about the nature of the problem and the range of the possible solutions. In the beginning of the design process, the architect, the engineer or the client do not know exactly how the building will look like, what are the problems to come or even what are the requirements to be fulfilled. Schön (1991) characterizes design practice as a reflective dialogue between the designer and the design situation and he emphasizes the crucial role of tacit knowledge. This kind of "feeling of" can be expressed, for instance, by experience-based, intuitive and unconscious habits and actions. This knowledge embodied by the practitioners involved in architectural design is crucial, but hard to grasp and unlock.

The features of the architectural design process described above are closely related to cognitive processes and design thinking. Some features are, however, also given by regulating external factors. Examples of these are (highly simplified):

- The delivery of design information and project material to the stakeholders (client, the building authorities and contractors) are regulated in phases. Each phase presents a higher level of detail and information depth, and each has to be approved by the stakeholders before moving on to the next phase.
- The time and performance related definitions of these phases are mostly specified in the project contracts. These might again be regulated by guidelines or regulatory demands on national level.
- The architectural design process is situated between the statement of the brief (more or less defined) and the start of the building production on the construction site. In practice, limited time resources, tough project budgets and the contractual models might often call for an overlap of the phases (e.g. starting up the work on the construction site before the design phase is completed).

Bearing the two above-mentioned groups of features in mind, the practitioners involved in the architectural design process must deal with an interplay between highly iterative, unpredictable and non-linear activities on the one hand, and regulated and linear activities on the other. Moum (2009) uses the metaphors of "baking bread" and "playing jazz" to highlight and simplify the different character of these features of the architectural design process. Baking bread could be seen as a linear, predictable, explicit and measurable process - based on for instance repetition and routine. This can be related to the activities described above, which are central in order to drive the processes forward due to the agreed time and cost. Playing jazz is on the contrary a rather improvised, intuitive and tacit process leading to a unique performance, based on "the feeling of", on talent, practice and experiences. This process might be compared with the hard-to-grasp elements of the architectural design practice described in the beginning of this section. This "something" going on in the head of the designers, is also a magical "something" resulting in the unique and great architectural solutions and buildings. The "baking bread" and "playing jazz" metaphors are representing co-existent processes in the architectural design practice. The interplay and balance between these are crucial for what actually gets built.

3. Concepts of learning

3.1 Experience-based learning theory

Kolb (1984) emphasises that learning is a process rather than a result. He furthermore claims that knowledge is a transformation process continuously created and re-created, it is not an independent entity that can be acquired or transmitted. Knowledge creation occurs at all levels, from the most advanced forms of scientific research to the child's discovery that being stung by a wasp is a painful experience that is best avoided in the future. "Knowledge" is the outcome of a transaction between social knowledge and personal knowledge. Social knowledge (Dewey, 1938) is the civilised objective accumulation of previous human cultural experiences, whereas personal knowledge is the accumulation of the individual person's subjective life experiences. Knowledge results, then, from the transaction between these objective and subjective experiences in a process called learning. Hence, according to Kolb, to understand knowledge, we must understand the psychology of the learning process; and to understand learning, we must understand the epistemology – the origins, nature, methods, and limits – of knowledge. Kolb draws heavily on Piaget (1970a) when he emphasises the need for epistemological understanding.

Furthermore, Kolb builds above all on Lewin (1951), Dewey (1910, 1934, 1938, 1958) and Piaget (151, 1968, 1970a, 1970b, 1971, 1978) when developing this well-known model for experiential learning. In this model, the process and structure of learning are depicted as a four-stage cycle involving four adaptive learning modes. These evolve from 1) concrete experience; 2) reflective observation; 3) abstract conceptualisation; and 4) active experimentation. This learning cycle can be understood as a continuous spiral where the different cycles of adaptive learning are repeated in order to allow for further learning. An onion can be used as a metaphor for this process, each layer representing a level of knowledge. Combining the four learning modes, Kolb divides them into two dimensions, where they represent pairs of dialectically opposed adaptive orientations, namely; 1) concrete experience versus abstract conceptualisation; and 2) active experimentation versus reflective observation. The abstract - concrete dialectic is one of "prehension". Prehension is a concept invented by Kolb to describe the representation of two different and opposed processes of grasping or taking hold of experience in the world. This either by relying on conceptual interpretation and symbolic representation, a process described by Kolb as "comprehension" – or by relying on the tangible, felt qualities of immediate experience, which he describes as "apprehension". The active-reflective dialectic is seen as one of transmission, representing two opposed ways of transforming what has been grasped through the prehension of experience. Either through internal reflection, a process Kolb describes as "intention" – or through active external manipulation of the external world, described as "extension". There is thus a clear "division of labour" between these two dimensions of learning; namely that of capturing or grasping experience, and of ensuring that what is grasped, is transported to the level where it is translated into internal understanding and/or external action.

3.2 Workplace learning

Whereas Kolb's model is primarily a model for individual learning processes, Illeris' (2009) model, expanding on the works of Jørgensen and Warring (2002) and Botterup (2000), helps integrate an understanding of individual learning into an understanding of learning in working life. For workplace learning, Jørgensen and Warring (2002) have developed a model based on the concepts of learning environment and learning progress, where learning is seen as taking place in the intersection between the learning environment of the workplace and the learning progress of the employees. A distinction is made between the technical-organisational learning environment and the social learning environment. The technical-organisational aspect is constituted by the material conditions tied to technology and to the way the work is organised, which may, for example, facilitate or limit work variation, and thus impact on the possibilities for learning. The work community and social interaction constitute the social learning environment. Learning progress is linked to each employee's background and stage of life, as well as to his or her capacity to be open to and benefit from learning. Learning takes place in a dynamic interaction between the learning environment and the individual's learning progress.

Illeris (2009) divides the technical-organisational learning environment into six categories: 1) division of tasks/work; 2) work content; 3) scope for decision-making; 4) scope for using one's qualifications; 5) scope for social interaction; and, 6) work strain. A rigid division of work can undermine the individual's perception of the work as meaningful (Taylorism). Work content is linked to the work's social significance and to its significance for the individual (learning progress). The scope for deciding over one's own work is connected to the style of leadership (dialogue versus orders from above) and to the organisational structure (flat structure and decentralised decisions versus hierarchical, bureaucratic structure). Illeris points out that the opposing ideas and interests, which emerge in the encounter between different trades or professions, can create fertile learning environments. They can, however, also help consolidate mutual myths and images that place the other party in the role of being an opponent. Technological conditions are very important for the scope for social interaction and for the social learning environment. Work performance pressures (speed and intensity) can hamper learning because they interfere with the time or physiological/mental energy needed in order for learning, development, experimentation and trying out of new ideas to take place.

Based on Botterup (2000), this part of the model can be expanded to include "work practice". Work practice is connected to society in the interface between the technical-organisational environment and the social learning environment – which is now expanded and described as "the social and cultural learning environment". The practice concept contains what actually takes place "in practice", but it also includes practice as a constituting expression of human consciousness and learning.

In the general learning model, which is individually oriented, Illeris (2009) distinguishes between three dimensions: the cognitive dimension; the psychodynamic dimension; and the surroundings/society. The acquisition process of learning takes place between the cognitive and the psychodynamic dimensions, which in their turn interact with society; whereas work identity is found in the tension between the cognitive and emotional dimensions. The cognitive dimension includes aspects of content and reason. It is linked to what Habermas (1984, 1987) describes as "the system". The psychodynamic dimension covers motivational and emotional aspects, and is linked to Habermas's "lifeworld". It is society that provides the conditions for learning. The lifeworld is tied to communicative rationality, and the system to instrumental rationality, and the two are strongly intertwined. Lundvall (1992) relates "instrumental" rationality to the expected outcome of interaction (cause-effect); and "communicative" rationality to intuition, worldviews and other factors related to communication. Habermas's theoretical contribution is often used in the innovation literature; see e.g. Moodysson (2007) and Kalsaas (2011).

Illeris distinguishes between different forms of learning in the cognitive dimension. He describes "assimilative" learning as a general form of learning: it is used in everyday life in the encounter with new impressions and impulses. This is also the most common form of learning in schools, as the students' knowledge is gradually built up over time. "Accommodative" learning is a more demanding form of learning, as it transcends boundaries. In this kind of learning, we cannot immediately understand or relate to what is happening. It requires that existing understandings are overcome or broken down, which in turn requires creative efforts to restructure what is already known, through reflection. This is denoted “relearning” in Kolb’s work. So-called “aha experiences” and a perception that “the pieces have fallen into place” occur in relation to this form of learning. Accommodative learning is crucial in any attempt at introducing improved work practises. “Transformative” learning is the most demanding form of learning examined by Illeris. We may encounter this type of learning if we lose our job and have to retrain in order to get a new one, which often means that we have to develop a new worldview or a new basic outlook. This can be perceived as a life crisis on the personal level.

The psychodynamic dimension of learning, with its emotional, intentional and motivational patterns, is influenced by the cognitive dimension in the shape of our knowledge and skills. For example, so-called “bad chemistry” between individuals can drastically hamper our ability to learn. However, if we gain better insight into the work of those we do not initially feel sympathetic towards, such emotions may change. The reasons for defensiveness and resistance to learning are found in the emotional dimension. Illeris sees the factor of “defending identity” – which is one of several mental defence mechanisms – as crucial in this context. In our working lives we often establish an identity tied to something we master well, and which others also consider us as proficient at. For example, someone may be good at using an advanced control system, PLC controlling, programming, and so on. Strong work identities can easily lead to active resistance to any change, which might threaten these identities – such as change that involves an accommodative learning process. According to Illeris, the general tendency for adults is that the more demanding and complicated the learning requirements, the greater the psychodynamic barriers in the shape of defensiveness or resistance. Levin and Klev (2001) point out that learning is often prevented because we wish to avoid situations in which individuals might lose face. This is also a central concern in Argyris’s (1990) works. This phenomenon can be linked to the psychodynamic dimension.

The best conditions for workplace learning are found in the area where work practice and work identity overlap. It is possible to imagine that if there is no such overlap, individuals might try to modify their work practices in such a way that they become aligned with their work identity, or they might resign and look for work with a different employer.

3.3 Learning loops and learning cycles

Ashby (1960) and Argyris and Schön (1996) distinguish between single-loop and double-loop learning. Single-loop learning can be conceptualised as “Doing Better”, and double-loop learning as “Doing Differently”. It is part of the nature of this difference between double and single loop learning that beginning to do things in a different way is more demanding than pursuing the already established strategy, but with a few adjustments, in terms of the learning involved (in other words, assimilative versus accommodative learning). Expanding on Ashby (1960), Argyris and Schön (1996) argue that for a company, “doing differently” might require external resources to be brought in to help with the improvement work. Thus, greater competence on grasping via comprehension can be built through action research approaches where academics and researchers cooperate with the company. This relates to the traits considered by March (1999; see below) as limiting the value of experiential learning.

Rooke (2005) relates Kolb's (1984) experiential learning cycle to Deming's Quality Cycle (Deming, 1986), also widely known as "Plan-Do-Check-Act". "Plan" relates to abstract conceptualisation; "Do" to active experimentation; "Check" to concrete experience; and "Act" to reflective observations. Deming's quality circle, which draws on his joint work with Shewhart from 1939, is, in all its simplicity, widely applied in lean implementations and popular among consultants in the field. However, unlike Kolb's work (1984), the quality circle does not offer any conceptualisation of learning as such. Rather, it is assumed that learning is likely to take place along the course of the Plan-Do-Check-Act cycle.

3.4 The limitations of experiential learning

According to March (1999), learning from experience does not produce perfect results by itself. It has its limitations. Firstly, experiential learning tends to exaggerate the importance of actual events relative to the events that might have occurred, and "thus to be quite sensitive to the rate of experience relative to the change in the world" (p. 332). Secondly, experiential learning tends to close the door on experimentation, according to March. It is fairly easy for a fast learner to fall into a pattern of repeating rewarding behaviour, and to stop reaching for the best possible performance. This can mainly be attributed to the ways in which strategies, competence and aspirations adapt simultaneously. Thirdly, experiential learning is not a good way to learn theories of behaviour. The starting point for March's line of argument is that if behaviour conforming to one theory produces rewards, the other theories will tend to be neglected.Because of these problems, simple experiential learning in organisations is a flawed process. However, research and consultation can supplement this learning; not by attempting to substitute it but by helping to mitigate the limitations of ordinary and experiential knowledge.

Fujimoto (1999) avoids the problem of the limitations associated with experiential learning by distinguishing between "routinised manufacturing capability" and "routinised learning capability" on the one hand, and "evolutionary learning capability" on the other in his study of learning in the Toyota Company. Evolutionary learning capability, he argues, is a "nonroutine ability that affects creation of the above routine capabilities themselves through irregular processes of multi-path system emergence" (p. 17).

4. Towards an analytical model – design and learning

A qualitative model can be created by establishing causes and effects between internal variables, expectations, and contexts (Barth 1966). This model might appear to be similar to a quantitative model, but the variables are assigned with qualitative values, not numbers. The model is subject to empirical testing, and with the same values on the variables, the same result can be expected. Thus, different values on the same variables can provide other results. This concerns an analytical generalization where the transfer value might be larger than the case itself.

Creativity, problem solving, decision-making, and attitude change, are according to Kolb (1984) other words for experiential learning. Previously in this paper, problem solving was presented as one of two paradigms in design. The other mentioned paradigm is puzzle making, which can be connected to creativity. This part of design work, was related with «playing jazz» earlier in this paper. Decision-making is an obvious part of design, where decisions on some parts must be made in order to advance processes, even if it might be necessary to make changes later. In addition, attitude change can be connected to accommodative learning (Illeris 2009) and re-learning (Kolb 1984). During the design process it is imaginable that attitude changes are connected to the way designers and engineers work together, e.g. when transitioning the collaboration to Big Room organizing. Innovation can also be connected to design, especially when the design in question has something unique about it, e.g. signature buildings. In the innovation literature, learning is considered as a fundamental process for innovation, and knowledge as the most strategic resource.

Another possibility is to relate design to the value shop model for value configuration (Stabell & Fjeldstad 1998). This model, which is an alternative to Porter's value chain concept for intensive technology (Thompson 1967), is represented as a circle of five generic activities: problem finding and acquisition, problem solving, choice, execution and control/evaluation. When the participants have reached the control/evaluation phase, the circle can be repeated if it is desirable. The relevance for design in the value shop model becomes obvious when we think in terms of puzzle making and problem solving, where problem finding and solving, and choice can be related to reflection and abstract conceptualization in Kolb's learning theory. Furthermore, execution is the equivalent to active experimentation, and control/evaluation can be considered as concrete experience.

Experiences indicate that the design of complex construction projects gradually matures. The designers learn gradually during projects, thus getting a better understanding of the scope, and the issues are solved gradually towards a "good enough" design. In the context of design theory earlier in this paper, it is mentioned that design tasks includes «the joy of discovery, and the frustration of fruitless explorations». In other words, there is much trial and error in the early stages of design, and trial and error is, in this context, an apparent part of the learning process with active experimentation, concrete experience, and reflective observation/evaluation. Concrete experience is, however, virtual as the drawings represents a model of the real world. Furthermore, abstract conceptualization will be included in some cases, e.g. during structural analysis.

4.1 A minor case study illustrating project planning and learning

In order to advance the understanding of the design process and the respective learning processes, we provide an example from a rehabilitation project of a villa (Table 1). The villa was originally constructed in 1953 during Norway's post-war period. The building was in a poor condition, compared to modern requirements for indoor climate, insulation, bathroom, etc.

Table 1. The design process and the respective learning processes in a villa project.

Building authorities	The client	The architect
	The client has a vision of upgrading the building to modern standards. He wants to elevate the ceiling to make room for a loft with an ocean view. In addition, he wants to upgrade the building in accordance to the latest energy standards.	*The architect pays a visit, and discusses the vision with the client. The architect inspects the building in question, and then he sits down and starts sketching the new improved version in his notebook. Based on the knowledge he has acquired through experience, he is able to quickly understand how to implement the upgrades efficiently, e.g. create a new entrance, which gives access to both floors including stairways and storerooms.*
	The client discusses the upgrades with the architect in several iterations. One of the first changes in regards to the architect`s suggestion is the idea of building a conservatory. The client provides the architect with an idea from a magazine. He encourages the architect to come up with additions and enhancements to the conservatory. The alternative that the architect provides is chosen after discussions of functionality and esthetics.	
Preliminary meeting with the local building authorities.	*The idea of partitioning the lot is put on hold after the meeting, as it requires rezoning.*	
Approval that the submitted drawings can be treated as an exemption from the zoning plan's height requirements.	*Application for building permit. None of the neighbors complain.*	
Requirements that the drawings set absolute requirements for legal height, and that the apartment downstairs will require a new application.	*The client makes an effort to adapt the drawings to the requirements from the local authorities. The apartment downstairs is removed from the drawings in order to prevent a delayed startup.*	*The architect adjusts the drawings in accordance to the requirements of the local authorities.*
The local building authorities approve the drawings.		

After the first visit from the architect, the drawings were revised several times throughout the following months. However, the major concept and facade of the building was mainly decided during the two hour long visit by the architect. When the client had started the design process, changes was generated through internal discussions in the client's family, discussions together with friends, and by studies of other construction projects, etc. Clearly, when the client is participating in a construction process, the buildings in the environment are observed in a new way. Ideas and inspiration are absorbed when observing and analysing other solutions. The final project change gradually, and in the context of this simple example the learning is especially happening for the client.

5. Conclusions

The paper verifies that learning is a central phenomenon in project planning, however, this version is unable to provide a complete analytical model of the phenomenon.

Future research will focus on developing an analytical model of learning in engineering. Such a model should in particular be able to uncover that design projects mature progressively through interactive processes with strong reciprocal and sequential dependencies.

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Enhancing Student Learning Through Formative Assessment in an Enquiry Based Setting: Some Reflections

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Abstract

Across Higher Education and Further Education there is strong research evidence that assessment has a strong link with learning and a key factor in this link is formative assessment. The aim of the research project was to establish if a deeper understanding and application of enquiry based approaches to student learning could be achieved through the implementation of Enquiry Based Student Learning where continuous formative assessment strategy was adopted. Through an action research approach, the qualitative data gathered and analysed from questionnaires, focus group interviews and reflective diaries culminated in findings to show that this learning paradigm significantly improved the competence, understanding, motivation and confidence of those participating in the research. The main recommendations arising from the study were that a form of student-centred pedagogy such as enquiry based learning aligned to continuous and formative assessment could be used to better reflect projects and problems typical of those found in real-life industry situations.

Keywords: Assessment, Enquiry based learning, action research and FALLS

1. Introduction

Traditional lecture-based teaching methods are being replaced or supplemented by approaches which call for reframing the roles and identities of both teachers and learners. Enquiry-Based Learning (EBL) is one such approach. This paper reports on a study investigating the perceptions through reflection of staff and students involved in an EBL capacity building through a formative assessment approach project in a construction management undergraduate programme. An action research methodology offered an appropriate framework within which to explore and understand the formative assessment driven approach to enquiry based learning in this course and offer reflections about it effect on student learning. The findings are discussed using sociocultural learning concepts relating to activity theory and communities of practice. The paper concludes that EBL may improve the quality of teaching and learning in higher education, particularly in the context of built environment education, but careful consideration should be given to the dynamics of the specific context in which it is introduced.

2. Exploring the Landscape of Built Environment Higher Education

Education, as defined by Dewey (1938), is fundamentally about the teacher and the student and the transmission of knowledge, skills and values. This process has always remained the same. However, the manner in which the process occurs today has changed dramatically.

The BE as a holistic entity has changed considerably over many decades. These changes have been in areas as diverse as technology, materials, security, planning, utilities, design, management and finance. Involved as educators and researchers, the community of the BE has responded to these changes: it produces the 'change-makers' and continues to play a vital role in the management of change through the formation of craftspeople, graduates and researchers and the production of knowledge. Since the times of Aristotle and Plato society has found it desirable to categorise the different forms of knowledge in an attempt to make the world more intelligible (Gaarder, 1995). Ratcliffe (2007) proffers that while the Built Environment is both vague and elusive it is a generic phrase of distinction and pertinence and is best portrayed and understood 'as a set of processes' rather than one single entity. This set of processes includes planning, design, construction, regulation, finance, transportation and information. Griffiths (2004) describes it as a range of practice-orientated subjects concerned with the design, development and management of buildings, spaces and places.

In HE the discipline of BE has begun to make significant headway as a recognised discipline where schools of BE have been set up. While school and department configuration is often dependent on the culture of a HE institution, reference to BE is an acknowledgement of the existence of this discipline. In the Irish HE context, while still at a developmental stage, the field of BE has begun to be recognised and embedded as a distinct discipline with BE schools and faculty emerging in the organisational structures of HE institutions across the country.

There is a distinctly defined structure to the education of BE professionals in the US where reference to the term BE is not preferred. The BE domain is not a recognised entity, as it is in a European context. This is because the industry is more fragmented than elsewhere. Each domain/discipline has its own identity and it would appear that each performs independently. This fragmentation relates very much to the way the players in the industry act out their roles. Historically, the education of construction professionals has been aligned with the way the industry presents itself. An aspect that has an impact on where programmes are positioned is the culture and make of a university. There are a number of common approaches that have been adopted by universities that include:

Architecture aligned with construction management/science

Engineering where CM is aligned with engineering focused programmes.

What is much in evidence is the need for structured and embedded professional and vocational skills, knowledge and competencies for the future AEC experts and that schools where students are engaged in the collaborative learning are advancing toward this.

2.1 Enquiry Based Learning

Enquiry based learning (EBL) has the potential to develop students as a scholar (Hodge et al, 2008). It provides opportunities to engage with a range of different learning experiences and styles and, in turn, may lead to an innovation (Healey, 2005) and represents a shift away from more passive methods. This approach involves the transmission of knowledge to students to more facilitative teaching methods through which students are expected to construct their own knowledge and understandings by engaging in supported processes of enquiry, often carried out in small groups. In the context of this piece of research, it is important to highlight the student voice. For example, one of the student taking the course remarked on their experience that:

'You go out of this class with your head buzzing, rather than feeling you've just passively sat there listening to what the lecturer had to say. You can't be passive, you have to be involved and committed on this tasks set' (student D)

Research into EBL proffers that it can improve the student experience, with the potential to enhance recruitment, satisfaction and retention. However, it should be pointed out that both students and staff need to be supported when making transitions in adopting or adapting to new approaches to teaching, learning and assessment, especially where more open-ended approaches, such as active learning, is involved in EBL (Kahn and O'Rourke, 2005). EBL is a constructivist pedagogy that intends to develop deep learning by allowing learners to use an enquiry-based approach to engage with issues and questions that are real and relevant to the subject being studied (Milentijevic et al., 2008). It also places students in realistic, contextualised problem solving environments where projects can build bridges between phenomena in the classroom and real-life experiences (Blumenfeld et al., 1991). Projects set can have varying complexity, but all will relate in some way to the fundamental theories and techniques of the chosen discipline (Mills and Treagust, 2003).

2.2 Formative Assessment Strategies

Assessment is a powerful driver of learning and lies at the heart of the learning experience. Formative Assessment within this EBL situation involved methods that focused on understanding rather than just memory recall and surface learning where elements of the Formative Assessment Led Learning Strategy (FALLS) were shared and explored by the lecturer with the participants. It was in an effort to change the perception that learning and building on your experiences is a challenge and it is not just about getting the correct solution; but more a move to gain an understanding of the meaning of the project task, that motivated this research study. As assessment 'drives learning' (Boud, 2007, and Boyd, 2007) the design of a EBL approach linked to an appropriate assessment strategy would result in meaningful and enhanced learning in the subject area. So, linking learning tasks with assessment tasks provided the platform for this project. It was found that the project tasks used in the research study needed to be carefully constructed and related to real world design problems. Previous work on tasks suggests that they serve as critical links among student motivation, cognition, instruction and learning (Blumenfield et al, 1991).

Many tools can be used for assessment within EBL, but all are pushing towards the common goal of creating a framework to assist learning and understanding through formative assessment (see table 1, FALLS conceptual framework). This framework should support students in their assessment, self-assessment, and presentations whilst also facilitating reflective learning (Scott and Fortune 2013) The integration of learning, instruction and formative assessment within EBL is necessary and one cannot generally go without another The approach to this project was based on those principles and embedding four elements of FALLS.

In EBL, the process of constructing an applied distinct project (in this case a number construction detail design task), also focuses the student or student team to think through the steps of the process and complete tasks in a logical sequence, similar to a construction team in the workplace. As there was a sequential, logical and reflective path to be followed in this process, and where an understanding had to be achieved in order to progress through the design, the reason for rote learning was practically removed and it was a case of learning by doing. It is the belief of this researcher that this is more representative and worthwhile to built environment students to achieve an understanding of why and where they can use their experience and previous knowledge directly in their approaches to professional life and in many instances their own personal life.

1) assessment for learning conception
2) student-centred learning pedagogy
3) preparation for feedback
4) feedback methods and dialogue
5) staff development
6) staff-student relationships.

Table 1 FALLS conceptual framework

3. Research Methodology

In the educational environment research exists in many forms and can range across a variety of topics and engage in a diverse array of methodologies and methods to answer particular research questions. All research, including Built Environment (BE) educational research, needs to be subjected to careful and considered methodological assessment and rigour. Traditional forms of theory are grounded in a logic of binary divides (McNiff & Whitehead,, 2005) and thus can tend to exclude the notion of practitioner research. For example, this might be an academic applying other people's theories to their practice or, as is the case here, a researcher engaged in examining other people's practices and extracting a theory or framework. The primary concern, in relation to methodological issues, is to ensure that the research is conducted within the parameters of a methodology that appropriately addresses its aims. Therefore, an approach that accommodates change, such as an action methodology or participatory action research methodology, seems to offer an appropriate framework within which to explore and understand the assessment practices of BE academics on undergraduate higher education programmes.

The research itself is a study into the views of students and the researcher in the field of construction management on assessment followed by an exploration of FALLS practice that was developed to help to lead to an improvement in how students learn in construction education. The action research case study that is being presented involved cycles of interactions between the researcher and the research subjects that had two separate objectives:

1. Participant learning to build capabilities and enhance ability to understand and generate constructive behavioural change through reflective action on assessment practice

2. Generation of research findings for the researcher on the usefulness of FALLS as a tool to enhance such actions by the participants as improving their learning.

Iterative cycles of learning and development of research understandings, however, can be challenging to balance, as the motivations and benefits of the different parties can compete with each other (Steinfort, 2010). In this case study, the AR process described by Brannick and Coghlan was adopted because the research objectives aligned with their broad definitions of action research should be (2010, p. 4):

- Research in action, rather than research about action
- A collaborative democratic partnership
- Research concurrent with action
- A sequence of events and an approach to problem solving.

A significant reason an action research approach was chosen was because it combines both learning and generation of new research knowledge through a series of iterative cycles across multiple cases. This was considered to be an ideal way to explore the research objectives in such an emergent situation. The learning aspect of the research is that the participants learn some techniques that they then try to implement as part of their own environment and then reflect on what resulted from that (and ideally go through iterative cycles to further develop their capabilities on the use of the methods to continue to enhance their ability to influence others and enhance outcomes). The research aspect is to understand how the application of the FALLS impacted the participants. In these situations, it was not possible to predict what the outcomes would be and the participants needed to use reflection before and after the intended action in order to optimise the outcomes and determine reasons as to why they got the results they did. The role of the researcher in this research was to guide the participants in the use of the FALLS, assist with planning the intended interventions and collate reflections from the participants. An aligned perspective was presented from McKay and Marshall (2001), who proposed the 'dual imperatives of action research' as being problem solving (a form of learning within a specific issue context) and a contribution to research. They explained the difficulties of researching the process being taken whilst actually applying the process to create outcomes in terms of developing solutions to real problems, and they suggested the AR approach was ideal for this.

Action research – which is also often referred to as Participatory Action Research (PAR), community- based study, co-operative enquiry, action science and action learning – is an approach commonly used for improving conditions and practices in a range of environments (McNiff &Whitehead, 2005). It can be used to involve practitioners conducting systematic enquiries in order to help them improve their own practices, which in can offer the potential to enhance their working environment and the working environments of those who are part of it – students, practitioners (contractors), clients, and the like. The purpose of undertaking action research is to bring about change in specific contexts, as Parkin (2009) describes it. Through their observations and communications with other people, action researchers are continually making informal evaluations and judgments about what it is they do. This approach can offer an embedded approach to reflection and so lead to improvement.

4. Analysis of the research

This research study was carried out on just one course from a very large curriculum in which rote and traditional forms of learning is seen to be extensive. Data collection took place over the period February 2014 to June 2014 for the research investigation part of this enquiry. During that period and beyond, the data collected were assembled and analysed in a phased approach. Each phase of the research process was documented and the data recorded appropriately as per good practice.

With very few exceptions, the students who participated in this study agreed that they found the FALLS method of learning, teaching and assessment more productive to their learning needs, more engaging through challenging real-life design work, and more resourceful in providing them with the competencies they need to work within their chosen discipline. What is generally agreed throughout the research literature is that modern society requires a fundamentally different conceptual discourse for assessment (Clegg and Bryan, 2004). Such assessment activities should not only address the immediate needs of certification to students on their current learning, but also contribute in some way to their prospective learning (Boud and Falchikov, 2006).

Society now demands more than passive graduates who have complied with a rigid regime, and employers and professional groups are placing expectations on institutions to deliver graduates who are prepared for and can cope with the real world of work (Boud, 2007). Student-centred learning can foster knowledgeable, competent, reflective and committed learners (Mentkowski, 2006), that are more prepared for the unorthodox type of real work problems that are typically associated with engineering and built environment disciplines. Students may escape from poor teaching through their own activities, but they are trapped by the consequences of poor assessment, as it is something they are required to endure if they want to graduate (Boud, 2007). The more we can engage students in assessment activities that are meaningful to them and which contribute to their learning, the more satisfying will be their educational experience (Boud, 2007).

5. Discussion

What emerged from the focus group sessions and individual feedback was that most participants reported that they had never used formative assessment methods in any previous class setting. At the early stages of the research the reasons for this were not evident, as most of the participating group suggested their level understanding of assessment was that it was about '*exams*'. However, further analysis of the data showed that although their understanding levels were sufficient to learn construction detailing for summative assessments, the relationship and link between these calculations and real-world construction methods tasks was unclear to most students.

In a focus group session, student E commented that, *'I always had the ability to to prepare well for my exams, but I didn't know why I was doing them'*. There appeared to be general agreement with this from the group. Student C also reported that *'I didn't know where in construction or on site these methods could be used, they were just written on the board and we were told to follow them for the exam'*. From the student's perspective there seemed little reason than to continue with any effort to understand, when they could see no practical value to do so. Based on the evidence of the projects submitted by students, along with the research data analysed, it appears reasonable to suggest that the majority of the students have the ability to learn construction detailing and apply that knowledge and are happy to use them once they can see a clear and practical purpose to do so. There was a general consensus among research participants that having gone through the FALLS method and in construction tasks they could now use this knowledge and apply it to a real building situation. Student F commented that *"I could now see what the construction details were doing in the project tasks; it's more like what is expected of us in industry"*.

There was general consensus among each group that learning through FALLS was a better learning experience than they had previously. Many students expressed a sense of enjoyment in the learning experience and thought that other courses should be delivered in this manner. During the focus group sessions, it was most interesting to listen to students still discussing knowledgeably with each other, the approach to solving their particular tasks they had used in the various projects a number of weeks previously. When questioned on this they expressed an ease of understanding having used these formulas to produce an end product. Student A made the point that, *"when I did construction calculations before I finished with a number that meant nothing. This time I had to go and find certain aspects to match and also make sure it would fit in the space. Now it means something to me"*. Most of this group agreed that they now had a deeper understanding of this subject and they had also learned where they could be used within construction detailing.

From the research data, there is strong evidence to suggest that the students strongly engaged and were more motivated to broaden their learning about this subject area. When given an opportunity to learn and apply it to their chosen field they willingly undertook the tasks and were interested in coming up with a workable solution. Most of the comments relating to this in the focus group interviews and classroom discussions concurred that studying questions and subjects for an end of term summative assessment was not increasing their competence, knowledge or skills in the chosen area of study. In fact, all of the focus group participants agreed with the words of student F; *"it would have been great to do all our subjects and design them within a project building. I would definitely have learned much more about construction management"*. In addition, student C followed on to say; "*if we were assessed on this it would be much better and we would learn far more than trying to remember questions for an exam".* Student B also made the point that; "*it would be great to see how all the different systems like project planning and on-site supervision join up with each other in a building project. At the moment we just do everything separately for examinations. It is just read out and I can never see how they all link together*".

It would appear from the responses that the students indicated complete satisfaction with the FALLS approach but, more particularly, the linking of the assessment to their learning. The use and practice of applied processes that are task orientated with feedback contributed to a distinct increase in (construction) confidence levels over the course of the research study. With this increase in confidence, many students throughout the research period, showed initiatives to extend their (construction) skills beyond the curriculum. An example of this was the extremely high attendance during and after class throughout the semester. It is the contention of the researchers that students attend class if there is a reason to.

One of the major aims from this research project was to provide a platform that enabled students to gain a deeper understanding of construction technology and its application in the construction process through a task orientated approach with a formative assessment focus. The findings of each individual action research cycle hold that the majority of those who participated in the research reported a distinct increase in both their level of understanding and in their competence, in the use of applied construction methods.

The early interviews with students indicated that their confidence around the use and understanding of the application of calculations was lacking. However, later findings revealed that they gained confidence in their knowledge and understanding through the task orientated approach. Student B commented, *"The tasks we did helped me get a better understanding of why and where the construction details could be used to building design. I now also feel more confident in my ability to use them in relation to my job".* Most felt they would now be more able to accomplish many design- orientated tasks and work related problems from the experience of this approach. The feedback from the majority of students together with all of the research findings has shown that a task orientated approach with the underpinning of a strong formative assessment strategy, when used in the correct circumstances, has the capacity to create learning environments that are facilitative to deep levels of learning and understanding.

The findings and discussions presented in detail above, along with positive feedback from students during the course of this study, leave us confident to report that we believe a deeper understanding and application of applied calculations and calculations can be achieved through the implementation of FALLS and assessment within a construction detailing module.

In regard to the case study presented, many of those students who participated in the research still make contact (mostly via email, IM, and text messages) about the impact of this assessment approach on their learning. They reflect and report on their memories of our classes and how it allowed them to see and develop a more diverse approach to their learning, but most of all, it provided them with an opportunity to explore and achieve the best in themselves. In sharing this research enquiry and the findings, in no way is it intended to convey a naive, heroic, or triumphal tone. It is nevertheless most rewarding to share the reflections about small change and the transformation that has impacted on a small number of students. The author remains hopeful that that experience shaped and changed their lives for the better.

6. Conclusions

Much current practice as to ways of linking research and teaching reflects tradition, but there is considerable variability in approaches within subject disciplines. Enquiry-based learning, for example, may be infrequent in some disciplines, and occur at different stages of the curriculum in other disciplines. However, innovation is possible, as is shown by examples such as, inquiry-based learning in this case and the use of research based assignments in the

It is hoped that through the sharing, description and analysis of this very concrete action research case study examples, learners, educators and researchers can come to recognise students' intelligences and cultures in the learning environment through dialogues initiated from multicultural literature, while critically exploring hard issues, such as diversity, gender equity, strength and power, and considering multiple perspectives. I do not offer an answer, as there is not a single one: what I do offer are perspectives; my perspective and that of the students who endeavored to problematize their learning issues around assessment as a way to deal with enhancing their learning.

As an educator, much has been learned through action research alongside my students while merely seeking to provide access for all learners to a more structured and beneficial approach to formative assessment. I would like to offer encouragement to all academics and those in education development to begin 'to re-create and rewrite [these] ideas' (Freire, 1970: xi) and to start implementing learner centred responsive pedagogies through deep explorations and dialogues. I would further encourage the use of the FALLS in the classroom as a strategy for challenging the perceived issues that surround assessment practice.

Action research projects test knowledge in action and those who do the testing are the interested parties for whom a base result is a personal problem. Action research meets the test of action, something generally not true of other forms of social research. Conventional researchers worry about objectivity, distance, and controls. Action researchers worry about relevance, social change, and validity tested in action by the most at-risk stakeholders.

Looking to the wise words of Ralph W Tyler (1949):

> *"The real purpose of education is not to have the instructor perform certain activities but to bring about significant changes in the student's patterns of behaviour".*

The real challenge lies in the fact that we as teachers need to bring about significant changes in our patterns of teaching in order to achieve that. All aspects of learning, teaching and assessment should form part of any reflection.

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Can the Performance of the IT Industry Help the Other Industries Perform?

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Abstract

The Best Value environment was introduced into the Netherlands in 2006. By 2008 testing was being done by a partnership of Arizona State University and Scenter (private entity led by Sicco Santema). In 2010, the $1B fast track projects were procured by the Rijkswaterstaat, and by 2012, the Best Value approach had become a core practice of the professional procurement personnel. The Performance Based Studies Research Group (PBSRG), the creator and licensor of the Best Value Performance Information Procurement System (PIPS) targeted three industries which shared the management, direction and control (MDC) characteristics of the construction industry: the medical industry, the ICT industry and the professional services industry. The ICT industry has the worst performance even though it has the highest rate of change in its technology. A case study is being conducted with the large, traditional ICT vendor, to see if they can successfully implement the characteristics of the best value approach and overcome the traditional nonperformance of the ICT industry. Their progress and challenges will be compared to the challenges in the construction industry. If the issues are the same the solutions should then be applicable in the construction industry.

Keywords: IT industry, performance, supply chain issues, large organization, Best Value

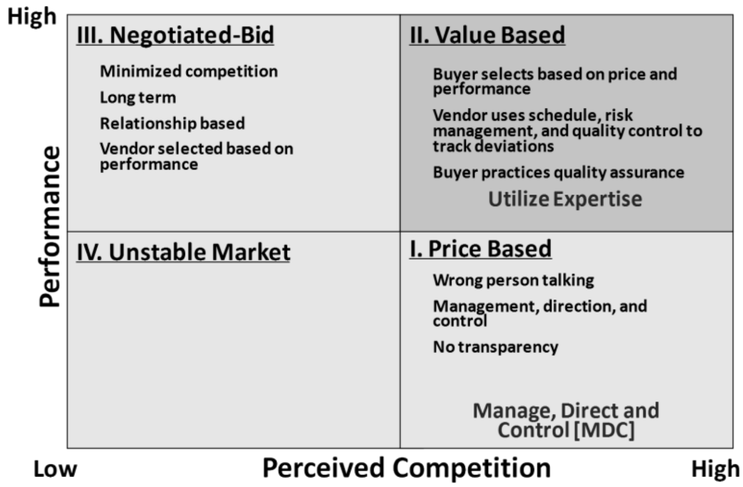
1. Collusion in the Dutch Construction Industry

In the early 2000s collusion was identified in the Dutch Construction industry. The cause of the collusion was identified as contractor greed (Doree, 2004; D. Kashiwagi & J. Kashiwagi, 2011). In response to these allegations the government moved to penalize the guilty parties but discovered that the penalized amounts would be greater than the profit generated by the identified vendors. In order to maintain stability in the industry a few scapegoats were identified and penalized, while the rest of the industry was persuaded to build a case against the scapegoats by providing information on the collusion. Those who volunteered information were promised to be exonerated.

1.1 Construction Industry Structure (CIS) Model

The source of poor construction industry performance has been identified as an owner generated problem and not a vendor generated problem (Figure 1).

Figure 1: Construction Industry Structure (CIS) model



(Information Measurement Theory by Dean Kashiwagi, 2014a, Tempe: Ksm-inc.)

The CIS identifies that the major difference between low performance and high performance is caused by the owner's use decision making, and attempt to manage, direct and control (MDC) to minimize risk, instead of utilizing expertise. The results of this practice include (Kashiwagi, 2014a):

1. Poor performance
2. Higher costs
3. Inefficiency
4. Decision making
5. Need for relationships to be formed to solve problems
6. Lower value of expertise
7. Commodity practices
8. Non-transparency (an environment where the source of the problem is not easily identifiable).

The concepts of the CIS was being presented in CIB conferences in Trinindad, Tel Aviv and Singapore, and eventually led to a fellow CIB member (George Ang, Ministry of Housing). George Ang then brought Dean Kashiwagi into the The Hague, Netherlands to present to the various ministries in 2004.

2. New Academic Research Approach

At this time, the construction management academic research experts in the Netherlands did not come to consensus about the CIS model and explanation. It seemed too simple, the overriding concept being that the vendors were at fault, and the Dutch construction management researchers felt that the Dutch culture was different from the American culture. Only one source, Dr. Dean Kashiwagi from PBSRG/ASU proposed that it was the owners and not the vendors who were at fault, and he was using deductive logic, common sense and case study tests in the United States to validate his proposal.

An effort was made by Dr. Kashiwagi to involve more researchers, but his insistence to run industry tests without consensus of all the researchers led to a failed effort. Instead of using the conventional rout of academia, Dr. Kashiwagi, began applying PBSRG's deductive approach, using industry testing with visionary industry personnel to start the research. Bypassing the discussion and consensus of the Dutch Construction Management academic researchers in the Netherlands, Dr. Kashiwagi, went right to the industry and formed partnerships to test out the CIS concepts. Dutch visionaries in one of the major construction companies (Marc Gillissen), multiple visionaries in the Rijkswaterstaat, and a visionary professor in marketing and supply chain at Delft University (Sicco Santema) identified the CIS model explanation and the Best Value (BV) PIPS as a solution to change the environment of the delivery of services resulting in the following actions (D. Kashiwagi & J. Kashiwagi, 2011):

1. Heijmans Construction licensed the Best Value Performance Information Procurement System (BV PIPS) from ASU.
2. Rijkswaterstaat was also licensed with the BV PIPS technology from ASU.
3. Scenter (private consulting company led by the visionary Sicco Santema) and the Delft University were licensed with the technology.
4. Scenter was trained by PBSRG. They ran small successful BV PIPS tests in 2008-2009 (Van de Rijt, Hompes & Santema, 2010).
5. Rijkswaterstaat ran a huge test by procuring $1B "fast track" infrastructure projects using BV PIPS (called Best Value Procurement or BVP) assisted by Scenter and PBSRG.
6. The fast track project results using BVP minimized procurement transactions and costs for all parties by 50%, vendors reduced construction time by 25%, and tests confirm that the CIS model is accurate and 90% of all project cost and time deviations are caused by the owner. They also confirm that the MDC activities of the owner's project managers was the source of most issues (Van de Rijt, Witteveen, Vis & Santema, 2011).
7. As a result of the "fast track" projects, NEVI (third largest organization of professional procurement personnel in the world) licenses the BV PIPS technology from Arizona State University (ASU) and begins to educate and certify all procurement personnel in BVP and the CIS and the underlying logic of the BV PIPS approach which is called Information Measurement Theory or IMT (PBSRG, 2012). The BV PIPS approach which moves the paradigm from the price based MDC environment to the utilization of expertise environment is now one of the major thrusts of NEVI. They have recently hired a new Director of BVP education and are expanding their offerings to assist all stakeholders in understanding of the BV PIPS approach.
8. The RISNET organization comprising of risk managers and professional engineering groups also licensed the technology from ASU.

The history of changes within procurement paradigm in the Dutch construction industry along with dominant project successes validated the CIS model. The model and the BV PIPS or Best Value Procurement (BVP) is now accepted and used as a mainstream model in the procurement of services in the Netherlands. The traditional academic research model of performing a literature search of existing concepts, proposal of a theoretical solution based on the literature search, survey of industry experts to identify which industry characteristics are most influential in the collusion, and presentation in academic journals to seek consensus in the academic world was not used due to the extensive time and impracticality. The process would be too lengthy, would not assist the industry in a timely manner, and would utilize opinions of industry and academic personnel that were “a part of the existing problem.” The Dutch results are supported by the following results of PBSRG/ASU in the United States and other countries:

1. 22 years of research testing, $16M of research funding, 1,800 tests, 98% customer satisfaction delivering $6B of services (PBSRG, 2015).
2. Most licensed technology (45 licenses) developed at ASU, one of the top research universities among universities without a medical school.
3. Two five year longitudinal studies identify the client and their representatives as the largest source of project cost and time deviation. Vendors create minimal risk when transparency allows the identification of the sources of risk (D. Kashiwagi & I. Kashiwagi, 2014).
4. 250 journal conference publications showing that management, direction and control (MDC) results in poor performance. (PBSRG, 2015).
5. Validated the CIS or IS model, and identified that the paradigm must be changed for delivering construction services (Kashiwagi, 2014b).
6. CIB W117 committee on the Use of Performance Information in the Construction Industry has done research work in seven different countries and 32 different states in the United States validating the same concepts.

3. Problem in the ICT or IT Dutch Industry

The delivery of services in the IT industry is perceived as being non-performing. The following has been documented on the nonperformance of the ICT industry:

1. ICT non-performance is estimated as high as 75% (D. Kashiwagi & I. Kashiwagi, 2014).
2. Major consulting company claims that the projects are too complex, and the complexity is causing the nonperformance.
3. New project management model, the agile approach, which maximizes communication and documentation, movement in smaller increments of time, and works from beginning to end instead of from the end to the beginning (Scrum Alliance, 2013).
4. Dutch government inquiry is held to identify the source of the ICT industry nonperformance and the large amount of resources being wasted on ICT projects. The result of the inquiry shed no more understanding of the problem (Tweede Kamer, 2014).

One of the larger ICT industry partners was identified as being in collusion with Dutch government officials (Zembla, 2014). Even though the company has not been convicted of crime of collusion, the company was cast in a poor light. At the same time, PBSRG was notified of another large government client was having problems with another major ICT vendor on a best value project.

4. Proposal

Past research results show that the client/owner is the biggest source of risk in the delivery of construction services. Because the source of risk is not technical (client/buyer using MDC to deliver projects and minimize risk), the authors propose that the problem is not a technical problem (complexity of the technology, lack of technical expertise, or complexity of the requirement). The authors propose that the CIS or IS, identifies that poor performance and collusion is caused by the client attempting to manage, direct and control (MDC) projects. The authors propose that the client is creating an environment which is:

1. Nontransparent, confusing and based on relationships.
2. Does not utilize expertise.
3. Filled with decision making from non-experts.
4. Resulting in inefficiency, ineffectiveness, and poor performance.
5. Not understanding what risk is and how to utilize expertise because experts have no risk.
6. The areas of risk management and project management have to be redefined and new paradigms must be utilized to increase the performance of the ICT industry.

5. Methodology

1. The researchers will search and identify an ICT vendor that does not utilize MDC to deliver their service. Their performance will be identified.
2. If the performance is dominantly higher than the industry performance of 25% success, the authors will investigate if the problem of MDC is in the ICT industry.
3. Identify a large traditional ICT vendor and identify if they have a bureaucratic or MDC environment.
4. Identify if the large traditional ICT vendor has a performing project or a BV project.
5. Analyze the project to identify what made the project different.
6. Analyze the owner/client of the performing project and identify what they did differently.
7. Also identify if the client/owner visionary is facing resistance from MDC personnel in his own organization.
8. Identify an effort with a large ICT vendor responding to BV project request that resulted in the client using decision making and MDC to eliminate the vendor’s BV effort.
9. Identify the difference between the price based and BV environments, and identify the difficulty for a large ICT vendor to change into a BV oriented vendor.
10. Analyze the results of the case studies to see if the environment delivering ICT services is in the price based arena resulting in low performance.

6. Research Case Studies

Schuberg Philis (SBP) is one of the ICT companies in the Netherlands that is known for their high performance and unique company structure (D. Kashiwagi & I. Kashiwagi, 2014). After studying SBP it was confirmed that SBP was an expert company that delivered high performance (See table 1):

Table 1: Schuberg Philis Overall Performance Line

1. They are the top rated ICT vendor in the ICT infrastructure area (in every category measured).
2. They have a project performance of 89.36% on time, 95.74% on budget, and 93.62% customers satisfied on 47 large projects in the last six years.
3. Of the six most critical ICT providers that support financial vital infrastructures as stated by DNB (same function as Federal Reserve Bank); they are the only vendor with 100% customer recommendation for outsourcing.
4. In the last four years, their business process uptime performance is 99.994.
5. Their customer satisfaction rating was 8.9 in 2013 – highest in the IT market for 7 years in a row, 2 full points above the market average (6.9).

Some unique characteristics about their organizations is that (D. Kashiwagi & I. Kashiwagi, 2014):
1. They have no MDC.
2. They have very high performance.
3. The authors conclude that Schuberg Philis is a BV company that delivers high performance.
4. They prove that if a vendor is BV oriented (no MDC), they will deliver very high performance.

Table 1: SBP Performance Metrics

The traditional ICT industry is in the MDC environment resulting in low performance. The authors will identify large traditional ICT vendors and show that they are in the MDC or bureaucratic environment.

6.1 Case Study of Large Traditional ICT Vendor

One traditional ICT Vendor was accused of being in collusion. In their efforts to change the public perception and mentality of the company the vendor began to investigate the Best Value Approach. As the BV approach stressed "win-win" relationships and utilization of expertise to deliver high performance and low costs, the vendor formed a BV core group to achieve these results. The BV core group discovered

#	*Criteria*	*Metrics*
1	*Total # of projects in last 10 years*	*991*
2	*# of large projects (€150K- € 3.3 Million)*	*47 (72)***
3	*% of large projects on time*	*89.36%*
4	*% of large projects on budget*	*95.74%*
5	*% of large projects customers satisfied*	*93.62%*
6	*Highest customer satisfaction 7 years in a row (Market Average)**	*8.9 (6.9)**
7	*Recommended by customers by year*	*100% 5 years in a row*
8	*Business Process Availability past 4 years*	*99.994%*

* Market average was taken from 2014 Giarte Report
**72 projects existed however; documentation older than 6 years was discarded and not available.

that many of the experts within the company were already thinking and acting with the BV approach. An example of this was identified as a performing project at the Port of Rotterdam.

The project was investigated to identify its status. Five key participants on the buyer's side were interviewed and the status of the project was reviewed. Findings include (Port of Rotterdam project participants, personal communication, June 6, 2015):

1. The owner/client's procurement manager utilizes BVP as the procurement approach.
2. The client PM faces resistance from own organization.
3. BV approach required a change in paradigm from MDC to utilizing expertise on both the buyer and vendor side. Required vendor and buyer to go through a learning curve.
4. The paradigm shift had been a big challenge to the project for both the vendor and the buyer.
5. The project is successful, and the project team identifies the project as a success.

Table 2: Project Participant Interview Summary Responses

#	*Criteria (10 is strongly agree, 5 is don't know, 1 is strongly disagree)*	*Results*
1	*The owners' inability to utilize expertise of expert vendors is a source of risk and poor performance.*	*8.2*
2	*Unlike Schuberg Philis, which was already practicing a BV approach, many larger traditional companies (using MDC and reactive behavior) have a very difficult time changing to the BV approach.*	*7.6*
3	*Owners also have difficulty changing from the MDC approach to the best value approach.*	*8.2*
4	*Until larger vendors change their approach, the industry will not have the momentum to change paradigms.*	*6.2*
5	*Large owners would have a difficult time changing the traditional buyers and project managers' paradigm.*	*5.8*
6	*The owner have a difficult time implementing a clarification period.*	*5*
7	*The implementation of a clarification period would tremendously increase the project performance.*	*9.4*
8	*A clear plan which includes the functions of all the stakeholders would increase the performance of the project.*	*8.2*
9	*The best value approach changes the project management, risk management and the definition of risk (what the vendor does not control).*	*8.6*
10	*Decision making is reduced if the expert's plan is utilized.*	*8*
11	*The best value approach is the optimal approach to increase project value and performance.*	*8.4*
12	*The expert vendor can utilize the best value approach even if the selection methodology was a more traditional relationship award, if it implements a clarification period, a weekly risk report, and creates transparency.*	*6.6*
13	*Rate the vendor's performance (1 is unacceptable, 5 is average and 10 is outstanding).*	*8.4*
14	*What would the performance be under the traditional approach?*	*5.6*
15	*Was the performance delivered by the BV vendor higher than would have been delivered under the traditional approach (MDC)*	*4 out of 5 (yes)*
16	*Is the traditional PM model (MDC) accepting of the BV approach?*	*5 out of 5 (no)*
17	*Did the PMs have to change their paradigm to do BV?*	*3 out of 5 (yes)*

6.2 Case Study of Large Traditional ICT Vendor Submitting on a BV Effort

This large traditional ICT vendor attempted to win a Best Value project. Being coached by an A+ BV certified expert the vendor understood the BV process and knew they would require true experts in order to secure this project. Due to this the ICT vendor put their best experts on the project; one of their best project managers and best technical experts on Oracle. In responding to the request for proposal of the buyer they attempted to show how they could provide a high expertise in relation to the buyer's project objectives. In one of the three two-page documents some of their main substantiations of their expertise include (personal communication, July 7, 2015):

(Objective 1 & 4): The key personnel of the supplier are an experienced project leader Transition and an experienced service delivery manager, which contributes to the objective of unburdening with regards to system management and a risk-free and effective transition The project leader Transition has successfully:

1. *Brought 2 ERP environments to system management through a transition in the past 4 years. The results were:*
    a. *Deviation regarding time and budget 0% (Fixed Price projects);*
    b. *Average project budget €5.1 million;*
    c. *Customer satisfaction 8;*
    d. *On average more than 10 interfaces and 20% custom work.*
2. *Taken care of 3 ERP implementations in the past 7 years, including decharge. The results were:*
    a. *All 3 > 3 million;*
    b. *Deviation regarding time and budget less than 5%;*
    c. *Customer satisfaction 8.*
3. *Implemented information security 1 time at a government agency so client and supplier are compliant to the information security policy (BIR).*
    a. *Deviation regarding time and budget 0% (Fixed Price Project);*
    b. *Budget 70 days;*
    c. *Supplier received decharge.*

The service delivery manager was responsible at two EBS & BI clients for 3.5 years for the delivered services (FAB, TAB and TB) and achieved the following results:

1. *Client 1:*
    a. *System management budget €325,000 per year;*
    b. *Customer satisfaction: 8;*
    c. *17 EBS modules, 16 interfaces and 164 custom work components;*
2. *Client 2:*
    a. *System management budget €1,860,000 per year;*
    b. *Customer satisfaction 8;*
    c. *22 EBS modules, 12 interfaces and 157 custom work components;*
    d. *Score of 8.4 for availability and 7.1 for performance EBS platform*
    e. *Availability 99.98% (24/7)*

(Objective 5): *Provider allocates a certified experienced information security specialist on the project that has a proven track record in meeting the compliance of managed systems. This contributes to the objective of fulfilling all requirements regarding the protection of personal data and information security. Supplier allocates an information security specialist:*

1. *Certified CISSP (associate)*
2. *Who ensures the information security policy for 55 ERP contracts (34 EBS, 21 SAP) and performs 6 compliancy checks every month.*
3. *Finds an average of 1 customer security incident per month and manages it.*
4. *Supplier has been audited by an external party and holds the certificates ISO/IEC 27001 (Information Security for all types of organizations). 130 system management contracts are part of the certification. The system management contract of Buyer will also fall under this.*

(Objective 1 & 3): *Supplier achieves an availability of the production environments of at least 99.8%, 24*7 (excluding agreed maintenance slots), this contributes to the objectives of Buyer for continuous availability, availability outside regular office hours and makes working from home possible. Supplier achieved this high availability in 2014 at three similar clients with EBS/BI system management contracts:*

1. *Average availability production 99.95%;*
2. *Average number of managed interfaces 17;*
3. *Average number of users 1750.*

(Objective 2) *Supplier achieves the desired service levels from the SLA from day 1, this contributes to the effective cooperation with Buyer and in particular with Functional System Management. Performances of the supplier in 2014 are:*

1. *Handled a total of 1294 technical EBS client notifications for 34 system management contracts*
2. *Achieved SLA response time in 91%;*
3. *Achieved SLA resolution time in 92%*
4. *Achieved SLA resolution time for 14 technical EBS client notifications with priority "Very high" in 100%.*

The results of this submittal shocked the IT vendor as they had thought they had provided sufficient information to reflect their expertise to this project. However, the client/buyer rated them neutral rating of six on a scale 2 to 10 in their claims of expertise for the following reasons:

1. Good linking support to performance targets; Applicant thus demonstrates in principle to achieve all project objectives.
2. Applicant shows experienced people which are more likely to have done ERP transitions and less frequently EBS transitions.
3. Many quantitative substantiation of the claims which the question is how verifiable (and dominant) are these numbers? Performance support is limited in relation to the actual Buyer proposed approach. This makes Vendor less clearly understand the mission.
4. Conclusion: Vendor provides a relevant achievement underpinning; here, however, shows no (dominant) added value that justifies a higher score than neutral.

6.3 Case Study of another Large Traditional ICT Vendor Winning a BV Effort

In the initial development phase of the best value approach another large IT vendor began competing and investigating the approach. The Vendor bid and won a telephone/communications integration project. However, due to the buyers and Vendors inexperience with Best Value and the current maturity of the BV approach in the Netherlands key elements of the process were overlooked such as the clarification phase. The project ended in failure with the Vendor unable to deliver the client's expectations and the project reverting back to a traditional approach of management, direction, and control.

Since then, the Vendor has become more involved and educated in the BV effort and has formed a BV core group for the company. The BV core group has become knowledgeable and successful in winning project bids and educating company individuals to deliver high performance, some key indicator of success includes (See Table 3) (personal communication, October, 29, 2015):

1. +/- 10 members (solution consultants, bid manager, project managers)
2. Internal training sessions (since 2013 63 training sessions, > 600 participants)
3. 100% success rate in going to the interview phase of project bids when BV team is part of bid team, 67% when BV team is in a support role (less active role), and 36% when BV team is not involved at any level.
4. 56% success rate in winning bids, 25% when BV team is in a support role, and 18% when BV team is not involved at any level.
5. Vendor is expanding their effort from the sales/marketing group to the project management group and are observing that level of expertise has diminished due to long period of owner's MDC approach to ICT services.

Table 3: Vendor BV core team bid results

Involvement of BV Team	*% to next phase interviews*	*% to next phase: clarification/won*
BV team part of bid team	*100%*	*56%*
BV team support role	*67%*	*25%*
BV team not involved	*36%*	*18%*

7. Conclusion

The problems in the ICT industry are the same problems that were faced in the construction industry. Using deductive logic, it is clear that the ICT industry is having the following issues:

1. A vendor was identified who does not use MDC in the delivery of their service by using expertise.
2. The high performance ICT vendor has no performance issues. Their performance is dominantly better than the other large vendors.
3. The study of their performance shows that they are in the BV environment. A bank study identified the most dominant ICT vendors in the Netherlands. The high performance vendor is one of the vendors.

Two of the other large ICT vendors who are trying to gain the capability to deliver performance were approached. Both vendor environments were in the price based environment (bureaucratic, difficulty identifying expertise, and difficulty in meeting the requirements of a BV effort). Both large ICT vendors were engaged in a BV effort, and both clients had problems in implementing the BV environment due to a lack of understanding of the BV paradigm. In both cases the clients were facing the resistance of traditional approaches to delivering projects. Both clients showed that there must be a paradigm shift in not only the vendor's approach but the client's approach. Both large ICT vendors have visionaries who realized the importance of changing the project management and risk management paradigms.

The research shows that the CIS model can be utilized for any industry. It also validates that the largest source of risk is the owner's decision making, and their use of management, direction and control (MDC) to minimize risk and deliver performance. The authors propose that the use of expertise will reduce project cost and increase vendor profit.

The ICT industry is in the price based environment where the owners are attempting to manage, direct and control (MDC) the vendor to minimize project cost and risk. The ICT industry is facing the same issues as the construction industry. The results of this study propose that the owners can increase project value and minimize project cost by utilizing expertise. By observation of both industries and the case study results over 20 years in multiple countries and cultures, the changing of the environments from a price based environment to a BV environment requires experts who think differently (see into the future before they do a project, identify the project requirements in simple terms that all stakeholders can understand, identify everyone's role in the delivery of the service, and minimize the risk of the project by transparency and not control to assist everyone to see into the future and not be surprised).

The ICT case studies have shown that resistant stakeholders resist because they do not understand the future outcomes, and will cooperate if they can see the future outcomes. This is the requirement of the expert, to simply and create transparency so that all stakeholders can see the future outcomes. This environment requires a new project management approach and a new risk management approach, both of which the Dutch best value effort is working to develop.

This research has also validated through deductive logic and mixed methods the Industry Structure model. It has identified that the owner/buyers have created an environment of collusion through their MDC based procurement systems. The Dutch ICT industry collusion case is no different from the Dutch construction collusion case. The research also shows that the BV model has worked in both industries and can assist vendors in the Dutch ICT industry to improve.

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Stakeholder Integration and Innovation Effectiveness in Sustainable Construction Projects

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Abstract

This paper studies the effect of stakeholder integration in achieving effective innovations to deliver more sustainable construction. The motive is the current global shift towards innovation as nations have realized its importance as a major driver for economic growth and competitiveness in the market in addition to the rising awareness of sustainable development and its long-term benefits globally and in the construction sector specifically. The multidisciplinary and multi-party nature of construction projects though, necessitates a well-established framework to integrate stakeholders for achieving an effective sustainable innovation in their projects in addition to considering the different factors that influence that. This paper represents the literature that it derived its framework from. It conducts an exploratory literature review, where it investigates that literature on the aspects that are believed to be influencing stakeholder integration and the effectiveness of innovation such as open innovation and cross boundary collaboration, leadership and team identity. Then the paper proposes a conceptual framework that links the different constructs together and explains them briefly. Finally, it discusses the qualitative method that it intends to use to collect data to validate the framework in future research.

Keywords: innovation, sustainability, leadership, stakeholder integration, team identity

1. Introduction

A global shift towards innovation has been witnessed as nations have realized its importance as a major driver for economic growth and its essential role in strengthening the nations' competitiveness (Hall and Vredenburg, 2003).

The construction sector is under massive pressure to develop new practices or improve existing ones to have a less threatening effect on the environment and at the same time achieve social and economic sustainability. Although the change rate in construction is slower and the sector is considered stable, innovation became a vital source of their competitive advantage and a major element to accommodate changes in their complex products and processes (Eaton et al., 2006).

The fragmented, yet interdependent, nature of construction projects nurtured its complexity demanding a high level of coordination and integration amongst a large number of internal and external stakeholders to have an effective innovation in their projects. This becomes more vital when dealing with sustainability, which adds a new priority and more stakeholders that have different interests. A well-managed stakeholder integration process helps the different stakeholders to work together to increase comfort and quality of life by achieving sustainable innovations that decrease negative environmental impacts.

Previous studies have derived most of the conclusions about innovation implementation influencers in firms from the social science school of thought. Rogers (2003) focused on the effect of organizational climate on innovation implementation capability, West and Anderson (1996) related it to the characteristics of top management teams while Xu (2007) found a link with entrepreneurship. All of these studies are focused on the firm level and despite the increased interest in innovation at project level there is still a significant grounds to cover in this important field. Dickinson et al. (2005) shed the light on the issue at the design phase of the project and recommended more research at the project level claiming that most research tackled different aspects of innovation and stakeholder integration at the organizational level leaving some gaps when projects at involved. In addition to that and despite the number of research that has been done about innovation in the construction sector in the past twenty years, there is an obvious lack in studying the role of stakeholders in project innovation.

Rogers (2003) states that it is vital to communicate innovation through a complex social system overtime to achieve an effective innovation. He adds that stakeholder interactions and communications are usually critical factors that may affect innovation. Hall and Vredenburg (2003), Hart and Sharma (2004), and Buchel et al. (2013) agree with Rogers (2003) and considered stakeholders interaction as a major influencer. Research has also examined the impact of leadership on innovation effectiveness such as the work of Howell and Shea (2001) who studied the influence of leadership style, the characteristics and the behavior of the leader on facilitating or hindering innovation. However the link between leadership, stakeholder integration and innovation effectiveness is missing especially in the context of construction projects. This link becomes more important in the context of sustainability due to the significant role that stakeholders play in setting the sustainability agenda.
This paper, therefore, looks carefully in the literature to find the knowledge gaps and to build a framework that links the different factors to provide a clear understanding of the impact of the dynamics of stakeholder network on the success of sustainable innovations.

2. Sustainability and the need for innovation in the construction sector

Innovation is assumed to be the main driver for economic growth. It toughens the competitiveness of countries and sectors as well as individual organizations (Hall and Vredenburg, 2003). It provides a long-term profitability of firms and plays a major role in their success and continuity. However, competitiveness alone is no longer the sole driving force in the world economy. Recently, there is a predominant shift in strategy towards competitiveness and sustainability throughout the world. Competitiveness in such an economic environment is expected to be achieved through innovating products and services, processes and models that are environmentally, socially and economically viable and sustainable.

The construction sector is one of the most challenging sectors to achieve a sustainable innovation. Due to the size and importance of the construction industry to national economies and the amount of environmental damage it causes, a lot of pressure is put by nations on the sector to use more effective measures to deliver more sustainable projects, hence, the need for a shift to develop and implement sustainable innovations.

In the context of construction, innovation is defined by Slaughter (2000, p.2) as "a nontrivial improvement in a product, process, or system that is actually used and which is novel to the company developing or using it."

According to Peansupap (2004) innovations in construction can be categorized into: (1) innovation in materials, equipment and methods, (2) management innovation which are new management techniques that facilitate the process of management and administration, (3) information technology innovation refers to the electronic infrastructure and equipment which can be either software or hardware.

One of the most challenging steps to achieve sustainable innovations in the construction sector though is bringing all of the multi-disciplinary stakeholders into an agreement. Since construction projects are usually the outcome of the effort of the collaboration and coordination of multiple stakeholders, within and outside the project supply chain. Although the supply chain itself is considered the primary stakeholders of the innovation project there is no doubt the significant influence "external" stakeholders have on the innovation.

Cooper and Rousseau (1999) presented a view of the supply chain in construction projects as an 'extended enterprise' where the different parties (including project developer, architect, engineering firm, contractor, subcontractors, suppliers, regulators and users) operate as business units in collaboration representing the different functions they deliver (marketing, design, engineering, components manufacture, supply, assembly, delivery) for an entity regardless of who owns them.

In the context of construction megaprojects, it is not enough to deal with the supply chain as it is commonly and widely known; extensive intra and inter-organizational coordination is required. Recognizing changes in the competitive environment and accordingly structuring the supply chain resources to effectively meet the customers' real demands is crucial (Fawcett and Magnan, 2002).

Through conducting a survey across some innovative companies in construction, Egbu et al. (1998) found out that the organizational culture that allows flexibility in communication is a major influencer. Mitropoulos and Tatum (1999) also pointed out the culture of the organization that values innovation is important in adopting innovations. They also added that management's attitudes towards new technology and the ability of management to capture improvements to existing practices are crucial factors that influence innovation. On the other hand, Nam and Tatum (1997) noticed the importance of the role of the champions and leaders to bring out successful innovations. Blayse & Manley (2004) then identified and summarized major influencers such as the culture of the organization, the absorptive capacity, the innovation champions, knowledge codification and an innovative strategy.

Certainly, good effort from scholars is observed to enrich the body of knowledge regarding the influencers of innovation in the construction field. Nevertheless, only little research links these influencers with stakeholder management and networking techniques to facilitate innovation. Thus, more empirical studies are required in order to increase the understanding on how stakeholder integration can affect innovation in the field and how the leader play an effective role in facilitating or rendering such relationship positively or negatively.

In addition to that, it is noted that researchers unfortunately has ignored the project level and focused mainly at the firm level due to the difficulty in tracking the various activities undertaken by the heterogeneous stakeholders in the many stages of a construction project (Ozorhon, 2003; Dulaimi et al., 2002; Blayse and Manley 2004).

3. Open innovation and cross-boundary collaboration

For effective sustainable innovations in the construction sector, cross-boundary collaboration and communication and eventually the integration of stakeholders are vital.

The growth of companies in the 20th century, the increase number of knowledgeable workers and their mobility, globalization and the ease of knowledge transfer, the private venture capital market and their support for new ideas are some of the major factors that made the protection of intellectual property very difficult, Chesbrough (2003) and Heap (2010) argue.

This encouraged organizations to adopt open innovation. The idea of open innovation is not very new though it wasn't termed as such. It has been used in the construction industry continuously as the nature of the projects requires cross-boundary collaborations within the supply chain. Nevertheless, the supply chain is considered primary stakeholders, thus, the traditional way of collaborating in the supply chain ignores secondary and invisible stakeholders that can have much influence on the final innovation product and hence its performance. Therefore, open innovation strategies that are known today can overcome this issue.

The networking nature of open innovation allows for more innovation opportunities. Koschatzky claims that those who do not inter this network will have to deal with serious competitive disadvantages and may have their knowledge base reduced making it difficult to exchange relations with other organizations (in Enkel et al., 2009).

The challenge with open innovation networks is to find the right new stakeholders and learn how to deal with them in addition to motivating the internal stakeholders that forma the supply chain towards achieving the common goal of innovation. For chains that aim to deliver innovations, it is very important to align motivation in the supply chain to bring the different parties of the chain, which have different interests, into a mutual agreement to ensure the successful development and implementation of the innovation.

Hall and Vredenburg (2003) discussed the ambiguous and complex impact of secondary stakeholders on the attempt to achieve innovations and stressed that it is of extreme importance to consider them while initiating the innovation process. Hall and Vredenburg (2003) and Hart and Sharma (2004) argue that the traditional ways of innovation focus only on a narrow range of stakeholders; thus, unexpected rejections and hindering will be faced when attempting to deliver the innovation. They also stressed on the fact that dealing with a wide range of important yet, invisible, stakeholders in this case is very crucial.

Once the stakeholders are clearly defined and identified, they can be integrated to create positive collaborative relationships among each other for the benefit of the innovation (Sharma and Vredenburg, 1998).

4. Leadership for sustainable innovation

Leadership reflects the goal-directed influence that one person has over other members of an organization or a group in guiding, structuring, facilitating relationships and activities. Thus, the role of the leader is key for the project to function in an effective and innovative manner (Nam and Tatum, 1997). It is the leader's role and power to introduce new ideas, goals and innovations in projects; therefore, leadership style is considered a crucial attribute in influencing innovation (Bossink, 2004).
Transformational leadership (Jung et al., 2003), innovation championing (Howell and Higgins, 1990), leader-member exchange (Graen and Uhl-Bien, 1995) are the major leadership styles that have been identified to have a positive influence on innovation.

Many researchers have linked transformational leadership to innovation such as Howell and Avolio (1993) and Jung et al. (2003). According to Jung et al. (2003) this leadership style is the preferred style to enhance innovation; they introduce creativity and innovation by actively engaging followers' and stakeholders and link their identities to the collective identity of their organization, thus raising their intrinsic motivation rather than just providing them with extrinsic motivation to perform their tasks. Through the development of important vision and mission, transformational leaders raise the followers' understanding of the value of the desired outcome, thus raise their performance and their willingness to exceed their self-interests for the sake of the organization (Howell and Avolio, 1993). This type of leadership also promotes collaboration by stimulating collective goals, building trust, empowering people, developing competence and offering visible support (Jung et al. 2003).

Leader-member exchange style suggests that innovativeness has a direct relationship with the relationship between the leader and the followers (Scott and Bruce 1994). It relies on the effectiveness of developing mature partnerships based on trust and support. This leads the employees and stakeholders to risks and deviate from the status quo (Scott and Bruce, 1994).

The last leadership style is the championing behavior. Rogers (2003) claims that a leader with an innovation champion personality have a direct influence on innovation diffusion. The presence of an innovation champion has been widely related to the success of innovations (Howell and Higgin, 1990; Howell and Shea, 2001; Nam and Tatum, 1997).

Champions have the power to affect the internal distribution of power and resources, strategic actions, and performance either positively or negatively. In addition, they can determine some internal organizational consequences such as the speed and position of career progression and the motivation or retention of members. On the cross-functional level, champions can promote communication between stakeholders and facilitate effective decisions about the innovation projects (Howell and Shea, 2001).

These different leadership characteristics have different influences on the ability to integrate stakeholders to achieve the ultimate goal of innovation. This study will investigate this further keeping in mind that the leader can be a person in the innovation project or the entire management team of the project.

So, through literature, leadership has an influence on stakeholder integration, and stakeholder integration facilitates the effective development and implementation of the innovation. However, these are general findings and the dynamics that actually take place in the project are missing in the literature. How can stakeholder integration influence the innovation? What happens in the innovation team if stakeholders are integrated? What are the dynamics that take place at the project level?

5. Innovation team identity

Unlike innovation at the organizational level, where the norms, roles, tasks of members are defined by the corporate law, corporate governance and the formal organizational structure (Child, 1972); innovation at the project level defines the tasks and roles of members through informal rules that the team adopt to regulate team members behavior gradually (Rese and Baier, 2012). In this case, the norms that define team members' behavior are highly dependent of the interactions among them and are related to the group identity (Postmes and Spears, 2000).

Rese and Baier (2012) argue that it is vital for the innovation team members to develop a specific self-concept as a team, which reflects the identity of that team. Here comes the significant role of the leader as discussed previously where the different styles of leadership enhance this behavior in different ways.

The formation of team identity is explained by social identity theory developed by Tajfel and Turner (1979). They claim that group identity is the feeling of belonging o individuals to certain groups that create some emotional and value significance to them and a sense of membership.

Team identity develops when team members interact with each other. Rese and Baier (2012) encourage the close communication of the project's team members to achieve a common understanding of the innovation project. Interacting behaviors of the team members are either presented in tasks or in socio-emotional behaviors.

The membership to a specific team is determined by group boundaries. Boundary is an important issue in construction projects as the team members are assigned to different organizations and they interact with different groups. Being aware of the goal of innovations and having a clear definition of the goal makes them in risk of having a conflict of interest with the goals of the organization that they originally come from and they might face significant opposition in this situation which leads to substantial conflicts. Thus, shedding the light of how to manage this for the favor of the innovation project is very crucial Rese & Baier 2012.

Friedlander (1987) identifies some dimensions that affect the quality of group boundaries: boundary clarity and permeability, the degree of cohesion between group members, the degree of match between group members' functional identity and local language, and the climate within the team (in Rese & Baier 2012).

Boundary clarity is the degree to which the innovation team is independent of other teams (Rese & Baier 2012). Teams that work on projects are less structured than organizational teams, thus, they need to deal with more uncertainty and ambiguity necessitating additional clarity. This assists in strengthening team membership, thus their commitment to the common goal.

Boundary permeability on the other hand deals with information flow and the circumstances that can hinder or facilitate the inward and outward flow of communication (Alderfer 1977; Agazarian 1989). Ellemers et al. (1988) claim that the more permeable the boundary is, the stronger identity the team can have.
Cohesion is another important dimension that can affect the identity of the team. According to Festinger et al. (1950), cohesion is the desire of the innovation team members to remain in the team and to commit energy and resources to the common innovation project. This element is very important and is very much related to the development of a common understanding by pursuing common goals and tasks, which results in facilitating team identity and membership.

The last element that increases membership of the team members and consequently strengthens their identity in the innovation project is the shared perceptions of the team's policies, practices, and procedures (Reichers and Schneider, 1990) promoting innovation, cooperation, and mutual support.
These elements have been empirically proven to increase innovation project performance (Rese and Baier, 2012) and are influenced by the leadership style as discussed earlier.

6. Conceptual framework

From the literature, there are different factors that influence innovation effectiveness, however, the concepts are fragmented and not linked to give an overall picture of the dynamics that take place at the project level. Hence, this research establishes the missing links through the following framework (Figure 1). The framework suggests that in an open innovation context, leadership influence stakeholder integration, which results in decreasing ambiguity and giving a clear definition of project's goals. Having that leads to establishing a strong team identity that have a passion and dedication towards the innovation thus increasing the chance of having a successful and effective innovation.

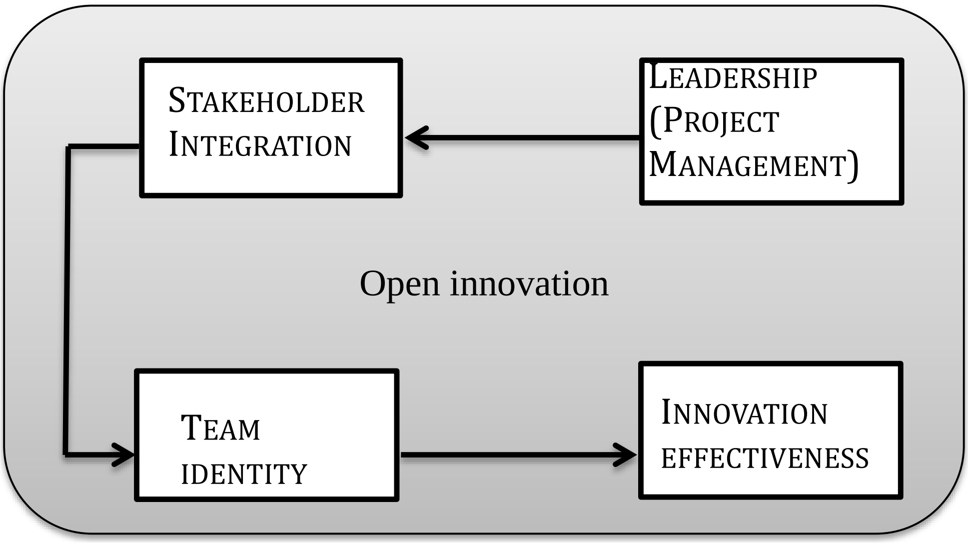

Figure 1: Framework

Each of these constructs are explained below:

Open innovation is the use of purposive inflows and outflows of knowledge to accelerate internal innovation and expand the markets for external use of innovation, respectively (Chesbrough 2006, p. 2)

Leadership the goal-directed influence that one person has over other members of an organization or a group in guiding, structuring, facilitating relationships and activities ((Nam and Tatum, 1997).

Stakeholder integration is the ability to create positive collaborative relationships with a wide range of stakeholders (Sharma and Vredenburg 1998).

Team identity is the feeling of belonging of individuals that create some emotional and value significance to them and a sense of membership (Tajaful and Turner 1979).

Innovation effectiveness is the overall project's outcome that results from implementing the innovation. In this study's context: it is financial, social and environmental effectiveness, which arises specifically from implementing the innovations.

The following table shows the measures that are used to assess each construct based on the existing literature:

Table 1: Measures of the study constructs

Construct	Construct	Measures

number	name	
1	Open innovation	• Co-creation with partners • Alliances • Joint ventures • Cooperation • Customer involvement • Employee involvement • Social network • Spin offs • Selling IP
2	Leadership	• Championing: - Internal distribution of power, resources, strategic actions, performance. - Communication with stakeholders. • Leader-member exchange - The effectiveness of developing mature partnerships based on trust and support. - Leads employees and stakeholders to risks. • Transformational leadership - Introducing creativity and innovation by actively engaging followers and stakeholders and links their identity to the collective identity of the project. - Empowering people. - Building trust. - Developing competence. - Offering visible support
3	Stakeholder integration	• Cooptation - Dealing with direct stakeholders that vary in salience. • Buffering - Close links with representative organizations to avoid dealing with unnecessary people. • Meta problem solving - Networking • Mutual learning - Mutual dependence between unlike organizations managed by processed adaptations.
4	Team identity	As a team: • Cohesion • Boundary clarity • Degree of match • Local language • Climate • Permeability As individuals: • Self categorization • Evaluation • Importance • Attachment

		• Social embeddedness • Cognitive awareness • Behavioral involvement
5	Innovation effectiveness	• Financial • Social • Environmental

This framework will be used to guide the next stage of the research that involve a deeper analysis through the production of case studies and interviews with key parties in selected case studies that are involved in sustainable developments. It will promote for open innovation and knowledge sharing and cross-boundary learning. Although it studies the concepts at a project level, it gives insights on how managing integration can lead to a better management of sustainable innovations in general. In specific, it will aid in understanding how the dynamics of stakeholders play a role in the team behavior towards achieving the sustainability goals of their projects and at the same time understand the role of the leader in steering stakeholders towards supporting the projects goal through a better integration.

7. Conclusion

This paper intended to build a conceptual model that explains the effect of stakeholder integration on innovation effectiveness in sustainable construction projects. The researcher investigated the theory and literature on the subject of stakeholder integration in the construction field and proposed direct and dynamic links with open innovation, leadership and team identity. These links are believed to have direct and indirect influences on the effectiveness of innovation.

Due to the multiplicity of stakeholders and their various interests, powers and urgencies in construction projects, they have a direct influence on innovation. Unfortunately, through a thorough literature investigation, empirical studies that investigate the influence of stakeholder networks and their integration in the construction project are very scarce and usually cover how the culture and climate of the organization play a role in integrating stakeholders. This leads to missing some important aspects that can be addressed in order to foster innovation through a better integration mechanism that supports open innovation in construction projects.

This research will promote for open innovation to achieve sustainable development and knowledge sharing and cross-boundary learning. Although it studies the concepts at a project level, it gives insights on how managing stakeholder integration can lead to a better management of innovations in general. In specific, it will add to the construction projects as the conceptual framework that will be developed and thoroughly validated will be applicable in projects that seek to diagnose the condition of their innovative practices. It will also offer many implications that can guide firms to strategize innovation and ultimately improve their business performance.

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The Impact of Client Involvement on Project Performance: Case of the Kingdom of Saudi Arabia

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Abstract

The construction sector in Saudi Arabia is the largest and fastest growing market in the Gulf region. This strong economic position has encouraged the Saudi Government to take the opportunity to implement spending and launch many construction projects. However, a United Nations Development Programme Report indicated that Saudi Arabia was not progressing well in implementing effective management and achieving good organisational performance. This was clearly demonstrated by the number of projects suffering delay, which increased from 700 projects in 2009 to 3000 projects in 2013. The lack of client involvement in the construction of public projects has been identified as the main cause of many operational problems such as cost and time overruns, disputes, errors, uncertainties in plans and specifications, and increased maintenance costs. This paper investigates client's involvement in construction project delivery and its impact to project performances. A questionnaire survey was distributed to various government agencies of the Kingdom of Saudi Arabia (KSA). Descriptive statistical analyses were used to assess the current practices of clients' involvement and its impact to project performances. The relatively low client involvement has a negative impact on the projects' ultimate outcomes. This condition has negatively affected the time completion of construction projects in Saudi. It was also indicated as the main cause of quality problems in Saudi's construction project.

Keywords: client involvement, project performance, Saudi Arabia

1. Introduction

The construction sector in Saudi Arabia is the largest and fastest growing market in the Gulf region (Samargandi et al., 2013). This strong economic standing has encouraged the Saudi Government to take the opportunity to spend money on many projects. In the last five years, Saudi Arabia has experienced a construction boom with over 16,500 ongoing public projects and a total value equal to US$956 billion (Ministry of Finance, 2012). However, a United Nations Development Programme Report indicated that Saudi Arabia was failing to make real progress in achieving good management and organisational performance (United Nations

Development Programme, 2009). This was clearly demonstrated in the number of projects experiencing delay, which increased from 700 projects in 2009 (Althynian, 2010) to 3000 projects in 2013 (Anti-Corruption Commission, 2013).

Construction project management practices in Saudi Arabia are varied (Bubshait and Al-Musaid, 1992) due to the different nationalities of the construction industry professionals. Furthermore, the quality of public projects has varied among government agencies due to the different approaches used. Some examples of problems experienced in construction projects in Saudi Arabia include cost and time overruns, disputes, errors, uncertainties in plans and specifications, and increased maintenance costs. The lack of client involvement in public construction projects has been proposed as the main cause of myriad problems (Althynian, 2010).

This paper investigates client's involvement in construction project delivery and its impact to project performances. The paper starts with a literature section, which briefly discuss the construction sector in Saudi Arabia and the important of client involvement in delivery construction projects. It is then followed by describing the research method that was selected to achieve the aim of the paper. Results of the analysis are then presented in the subsequent section, followed by the discussion of the findings. The paper is concluded by presenting the key findings of the study.

2. Literature Review

2.1 Construction Sector in Saudi Arabia

The varying degrees of client involvement in public construction projects has been identified as a reason for the various levels of quality achieved in different construction agencies in the Kingdom of Saudi Arabia (Bubshait, 1994, MEED, 2010). In the relationship between the parties in Saudi projects, the consultant has traditionally been considered as the major player in the construction project, and this approach has served to isolate the contractors from the client (Kometa et al., 1996). This isolation reduces the client's influence on the project and makes the client dependent on the consultant (Assaf and Al-Hejji, 2006). Furthermore, there is a perception among the clients in government projects in Saudi Arabia that the consultants are often correct, even if their recommended resolution is different from the client's preference (Alnuaimi et al., 2009).

Construction projects in Saudi Arabia experience major delays (Al-Kharashi and Skitmore, 2009). Some studies have been carried out on the causes of these delays in Saudi construction projects. Assaf et al. (1995) found that the most important causes of delay were related to client involvement in project processes such as involvement in planning and design, and slow responses when making decisions and granting approvals for materials. Al-Barak (1993) found that the causes of failure in some construction projects in Saudi Arabia were related to the clients' lack of experience and weak involvement in project activities. Assaf and Al-Hejji (2006) found that delays in construction projects originated mostly in client-related factors. Al-

Khalil and Al-Ghafly (1999) found that slow decision outcomes by the client were a major cause of project delay in Saudi Arabia. It appears that the problems experienced in construction projects in Saudi Arabia are mainly caused by the low level of client involvement during project activities. The weak decisions in the early stage of a project will result in a conflict between all parties in the later stages. Therefore, client involvement during the formative and early design stages of a project is a critical factor that must be taken into account if a project is to be delivered on time, to budget and to the desired quality (Love et al., 1998).

2.2 Client Involvement in Construction Projects

A successfully constructed project begins with the client (Ryd, 2004). Clients who are closely involved in managing a project are usually the most satisfied with the project quality (Bubshait and Al-Musaid, 1992). However, the client has duties and responsibilities when involved in the construction process. Clients should identify and adopt effective practices that contribute to high performance in their involvement in the construction process (Al-Kharashi and Skitmore, 2009).

Involvement is determined by the degree to which the project team fulfils its responsibilities to each phase of the total construction process (Bubshait, 1994). Clients need to perform their duties and responsibilities to have the optimum involvement required during the construction project phases, namely, the planning phase, design phase, construction phase, handover phase, and operation and maintenance phase. The degree of client involvement is based on taking the right decision during the construction project processes. Generally, client involvement procedure is based on the weight of the client's experience (Nutt, 2006). Therefore, for many construction projects, making good and timely decisions is not an easy task to accomplish.

Client has three common expectations for the project delivery: high quality, low cost; and finished on time (Forgues, 2006). Client's objective is to get the balance right between all these elements in order to meet the client's project delivery expectation. The importance of the client role was highlighted in the ASCE Quality in the Constructed Project Manual (ASCE, 2012). The manual describes the high impact that the client has on the construction project, which in many cases may determine the project's success or failure. Therefore, the clients' involvement in the early stages constitutes an initial phase of the construction process and provides the link between the client and the project (Institution of Civil Engineering, 1996).

3. Research Method

For this study, a questionnaire survey was selected as the research method. The development of the questionnaire followed Leedy (1997) four practical guidelines, which are: using clear language, meeting research aims, planning development including distribution and collection, and creating a solid cover letter. The survey was written in two languages (English and Arabic) which are appropriate for the participants. Close-ended questions with ordinal and nominal scales were employed. Instructions were also provided at the beginning of each section for completing the questionnaire.

The questionnaire consisted of three main parts. Part 1 was designed to obtain some demographic information about the participants. Part 2 was designed to identify the degree of client involvement in construction projects. Part 3 was designed to identify the impact of the current client involvement practices on the delivery of construction projects in Saudi Arabia.

A pilot survey was conducted in order to identify any further need of revision. A sample of 9 respondents was selected to complete the survey to test the content validity of the questionnaire items. The questionnaires were distributed in both languages (Arabic and English) based on the preference of the participant. Email and post were used to distribute the questionnaires

4. Results

The questionnaire survey was distributed to 315 potential participants in 21 government agencies of the Kingdom of Saudi Arabia (KSA). 17 of the 21 (80.95%) agencies responded, with a total of 223 questionnaires (70.79%) were returned, giving the researcher more precision and more confidence in regard to understanding the sample population. Among the respondents, 42.6% worked in public agencies and 57.4% worked in semi-public agencies. The project types that the respondents built include: building; infrastructure; industrial; and other.

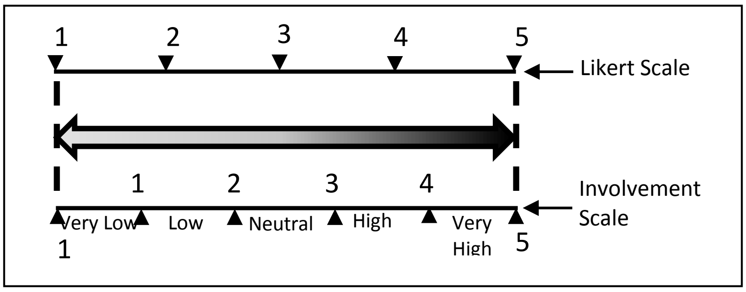

Figure 1: Likert and involvement scale profile used for Part 2 in the questionnaire

Descriptive statistics for the respondents' involvement as clients were produced, using the mean as the measure of central tendency. Although the median would theoretically be a more accurate measure because the data were ordinal, the mean was used due to the nature of the data. To locate the level of involvement, the "involvement scale" was developed in five intervals: "very low", "low", "neutral", "high" and "very high". The involvement scale was calculated by dividing the four intervals in the Likert scale by the five involvement intervals. The result was

0.8 for each interval. Therefore, the "involvement scale profile" was built based on the five-point Likert scale (Figure 1). Skewness and Kurtosis test was conducted for normality distribution. The Cronbach's alpha test was used to evaluate the consistency and reliability of he questionnaire.

Table 1 presents the results on the respondents' level of involvement as clients in the planning phase. The average level of client involvement was considered low, ie 2.07(Figure 1). The planning phase in a construction project is normally executed by the client. In this study, the planning phase was represented through 11 tasks.

Table 1: Mean ranking of client involvement in planning phase

Code	Planning Phase Activities (Tasks)	Rank	Mean
Part2_A_6	Approval of the project cost	1	1.54
Part2_A_11	Feasibility study of the proposed project	2	1.61
Part2_A_10	Description of the responsibilities and powers of each member	3	1.72
Part2_A_4	participating in the project	4	1.86
Part2_A_8	Studying how to secure funds to finance the project	5	1.94
Part2_A_9	Studying the impact of the project on health and safety	6	2.04
Part2_A_5	Establishment of a criterion for the selection of project location	7	2.11
Part2_A_1	Estimation of the project cost and the time required for its completion	8	2.21
Part2_A_2	Assignment of task force (consultant, engineer etc.) to conduct	9	2.50
Part2_A_3	preliminary studies for the proposed project	10	2.58
Part2_A_7	Studying the requirements of the beneficiary of the project	11	2.68

The respondents' level of involvement as clients in the planning phase tasks was varied but low across all the tasks; involvement in three tasks was ranked as very low (scale 1 to 1.8); involvement in seven tasks was ranked as low (scale 1.8 to 2.6); and involvement in one task was ranked as neutral (scale 2.6 to 3.4).

The design phase was represented through 11 tasks. Table 2 presents the results on the respondents' level of involvement as clients in the 11 tasks in the design phase. The respondents' level of involvement was higher in the design phase than in the planning phase. The average client involvement in design phase was 2.64, which is considered to be neutral involvement based on the involvement scale profile (Figure 1). Clients and designers usually work together during this phase. The level of involvement was low or neutral across all the tasks: involvement in five tasks was ranked low (scale 1.8 to 2.6) and involvement in six tasks was ranked neutral (scale 2.6 to 3.4).

Table 2: Mean ranking of client involvement in design phase

Code	Planning Phase Activities (Tasks)	Rank	Mean
Part2_B_4	Negotiating design price with the qualified designers	1	2.04
Part2_B_3	Selection of design team	2	2.07
Part2_B_7	Evaluation of design and taking the necessary decisions	3	2.47
Part2_B_10	Update drawings and specifications to reflect the requirements of location or environment	4	2.54
Part2_B_1	Arranging the papers and documents of the construction contract	5	2.57
Part2_B_5	Provide the designers with the necessary information for the project	6	2.70
Part2_B_2	Qualification of designers bidding on the project	7	2.74
Part2_B_11	Use of some technical standards for the descriptions of material quality or construction methods to be followed during the project	8	2.80
Part2_B_9	Monitor and guarantee design quality	9	2.93
Part2_B_6	Following the progress of design	10	2.97
Part2_B_8	Review of design documents (e.g., drawings and specifications)	11	3.19

Table 3: Mean ranking of client involvement in construction phase

Code	Planning Phase Activities (Tasks)	Rank	Mean
Part2_C_3	Negotiating contract price with the contractors qualified to do the job	1	1.67
Part2_C_1	Qualification of contractors competing to implement the project	2	2.49
Part2_C_4	Interpretation and clarification of ambiguities in the contract documents and drawings	3	2.50
Part2_C_2	Explaining the objective of the project and providing the necessary information for bidding	4	2.60
Part2_C_5	Review the documents that submitted by the contractor	5	2.85
Part2_C_9	Establishment of a system and written code to ensure implementation quality, to be referred to by personnel in charge of implementation quality assurance and control	6	2.96
Part2_C_10	Emphasis on implementation quality by conducting necessary tests for the various implementation stages	7	2.99
Part2_C_6	Taking necessary decisions against contractor claims during project implementation	8	3.26
Part2_C_11	Regularly visit project site during implementation stage	9	3.31
Part2_C_8	Stress implementation quality and monitoring safety principles during project implementation	10	3.53
Part2_C_7	Monitoring and control of implementation methods and cost, as well as work schedule and contractor productivity	11	3.60

The construction phase was represented through 11 tasks. Table 3 presents the results on the respondents' level of involvement in the 11 tasks in the construction phase. The respondents' level of involvement as clients in the construction phase was ranked as the second highest level of involvement across all the project phases (following the handover phase). The average client involvement in the construction phase was 2.89. The level of involvement across the tasks was varied: involvement in one task was ranked as low (scale 1 to 1.8); involvement in three tasks was ranked as a low (scale 1.8 to 2.6); involvement in five tasks was ranked as neutral (scale 2.6 to 3.4); and involvement of two tasks was ranked as high (scale 3.4 to 4.2).

The respondents' involvement as clients was the highest in the handover phase among all the phases. The average client involvement in the construction phase was 3.19, which is considered to be neutral involvement but close to high involvement based on the involvement scale profile. The handover phase was represented through three tasks. Table 4 presents the results on the respondents' involvement as clients in the three tasks in the handover phase.

Table 4: Mean ranking of client involvement in handover phase

Code	Planning Phase Activities (Tasks)	Rank	Mean
Part2_D_1	Establishment of criteria for acceptance of completed project	1	3.09
Part2_D_3	Monitoring the process of testing and commissioning	2	3.11
Part2_D_2	Review of contract documents after completion of the project	3	3.36

The respondents' level of involvement in the operations and maintenance phase was the lowest amongst all the phases. The average client involvement in the O&M phase was 2.06, which is considered low involvement based on the involvement scale profile (Figure 1). Table 5 presents the results on the respondents' level of involvement as clients in the O&M phase.

Table 5: Mean ranking of client involvement in O&M phase

Code	Planning Phase Activities (Tasks)	Rank	Mean
Part2_E_1	Prepare the maintenance plan describing the maintenance schedules and lists the tasks	1	1.93
Part2_E_4	Building up the inventory including the important spare parts to maintain and operate the project with minimum "down time"	2	1.98
Part2_E_2	Prepare the operation information such as to assist in solving problems and prevent unexpected expensive	3	2.09
Part2_E_3	Record the warranties and certificates reference information	4	2.24

The respondents were asked, "To what extent were the projects implemented" in relation to the following goals and expectations: (1) time, (2) cost, (3) quality, and (4) operational satisfaction. Table 6 presents the results on the respondents' level of agreement in term of the impact on the client involvement on project delivery.

Table 6: Impact on project delivery

Code	Project Objectives	Mean	Std. deviation
Part3_1	Time	1.87	.678
Part3_2	Cost	2.84	.793
Part3_3	Quality	3.09	1.083
Part3_4	Operation	3.14	1.203

For more understanding of the impacts of client involvement, this impact was investigated in three ways, which are based on: (1) the overall data; (2) organisational type (public or semi-public); and (3) project type (building, infrastructure, industrial, and other). Figure 2 presents a summary of the results.

As shown in the neutral and negative impacts depicted in Figure 2, the respondents reported that projects were implemented with time delays, higher costs than contracted, the typical quality was not high, and operations were slightly satisfactory. This indicates that a low level of involvement during the construction project phases (as presented in Table 1 to 5) has a negative impact on the end of the project regarding the desired goals of high quality, low cost, on-time completion, and no major disruptions in operations.

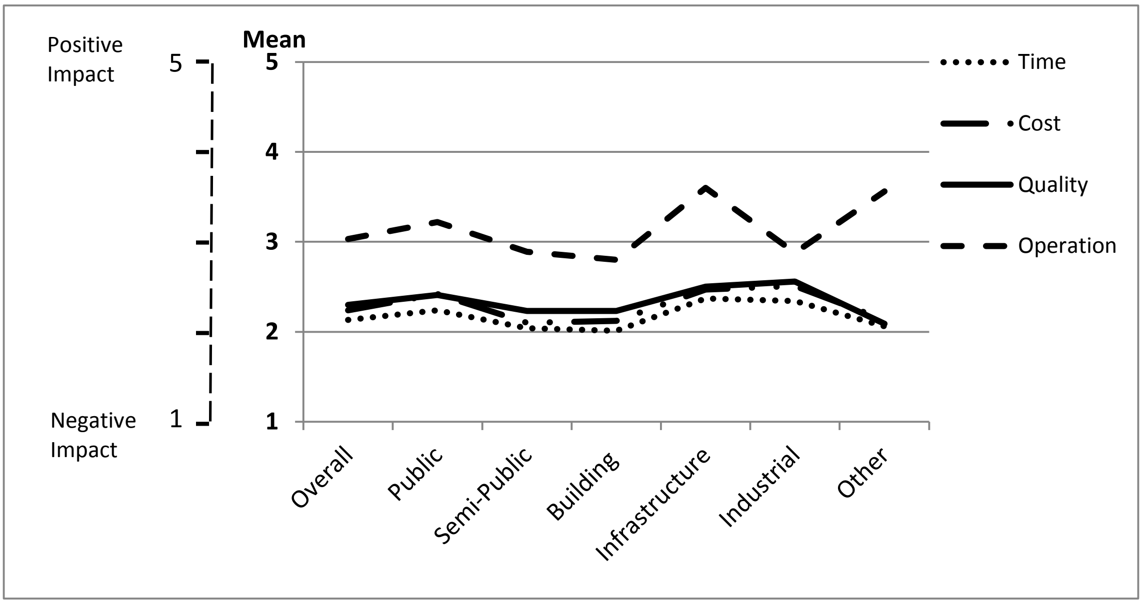

Figure 2: Impact of client involvement on project implementation

5. Discussion

As identified in this study, the construction project process has five phases with 40 tasks that measure most activities during the construction project cycle. The survey revealed that clients had inadequate involvement in 38 out of 40 tasks in the construction project phases. This low level of involvement is very likely to have a negative impact on the project outcomes.

In the planning phase, the average client involvement was 2.07 on the involvement scale, which is considered low. The levels of client involvement in "Approval of the project cost", "Doing feasibility study of the proposed project", and "Describing the responsibilities and powers of each member participating in the project" were very low. These three tasks are highlighted as an example to illustrate the importance of the planning tasks. The planning phase includes activities that require a high level of authority to make decision, such as "Approval of the project cost". In any large project in Saudi Arabia, government agencies require formal approval from the Ministry of Finance before awarding the contract (Government Tenders and Procurement Law, 2006). The restrictions imposed by the Ministry of Finance for approval of a project reduce the ability of clients to innovate in construction due to limitations in the project budget. Therefore, according to the specialist in budget, the budgetary and financial management system in Saudi Arabia needs to reform and change (Albassam, 2011).

Another important activity in the planning phase is "Undertaking the project feasibility study" which is an analysis of the ability to complete a project successfully, taking into account legal, economic, technological, scheduling and other factors. The consequences of not doing the feasibility study correctly may be sufficient to stop the project. The risk of this consequence was evident in the low client involvement in this task. Low client involvement in the planning phase may account for the dramatic increase in the number of project delays in Saudi Arabia in the last three years (Anti-Corruption Commission, 2013).

While the planning phase is important for making the right decisions to start the project, the design phase is no less important for the project. Eighty percent of a project can be specified at this phase (Whelton et al., 2002). In this study, the average client involvement in the design phase was 2.64 on the involvement scale which is considered neutral involvement. Clients need to have advanced knowledge to be able to review the design documents. It is recognised that more involvement by project client in the early design stage has a positive impact on delivering the construction project successfully.

It is important to recognise the close relationship between the design and construction phases. The design phase is a process of creating the description of a new project, usually represented by detailed plans and specifications, while the construction phase is a process of identifying the activities and resources required to make the design a physical reality. Clarification in design documents leads to less conflict between the client and contractor (Al-Sedairy, 1994). This study found that clients did not pay enough attention to the tasks that need to be implemented well before constructing the project during the tender selection process. These tasks are "Negotiating the contract price with the contractors qualified to do the job", "Checking the qualification of contractors competing to implement the project", "Interpretation and clarification of ambiguities in the contract documents and drawings", and "Explaining the objective of the project and providing the necessary information for bidding" as presented in Table 3. Lack of attention to these tasks might result in conflict in the construction project. These conflicts occur most frequently in the key relationships of the contractor and the client, and the contractor and the consultant. Research has found that the conflict was likely to occur most strongly in the later stages of a project under construction (Althynian, 2010). Therefore, it is important to emphasise that the client needs to be pay more attention to the design and construction phases.

The handover of the project to the client at the end of the construction is a very important stage of the project procurement process and facility operation success. Reflecting the importance of the handover phase, the level of client involvement in handover tasks was found to be near a high level of involvement. A well-organised, efficient and effective transfer of information from project contractors to the owner of the project is essential. The commissioning and fine-tuning of operations during handover can impact heavily on the use of the project if not managed in a structured manner.

At the end of a project, project satisfaction is measured during the operations and maintenance. However, in this study, the level of client involvement was found to be the lowest amongst all the project phases. Successful operations and maintenance of a completed project is closely associated with the level of client involvement. Therefore, the project team benefits by giving careful consideration to the operational and maintenance objectives during the project's planning, design and construction stages. One suggestion for clients to consider during the construction process is to assign a special O&M representative to advise the project team on how to complete the product in a manner that best achieves the project's O&M needs.

6. Conclusions

The construction sector in Saudi Arabia is the largest, strongest and fastest growing market in the Gulf region; however, the construction sector in Saudi Arabia has faced many challenges during the recent construction boom. These challenges include the lack of real progress in achieving good management and organisational performance, variability in quality among the projects commissioned by government agencies, increasing project delays and cost and time overruns, lack of planning and design, and weak supervision by the government agencies of the construction project process.

The findings from this study show that the current client involvement in construction projects in Saudi Arabia is at the level of neutral or low involvement. Among the five project phases of the construction process, the design phase was ranked as the priority phase for client involvement during the construction project. This is then followed by the client involvement in the planning phase. However, the study found that the respondents had low involvement as clients in both the planning and the design phases. This was suggested as the reason of weak decision-making in the early stage of the project, which could result on conflict in the later stages of the projects. The remaining phases were ranked in importance as follows: (3) construction phase; (4) handover phase; (5) operations and maintenance phase. The relatively low client involvement has a negative impact on the projects' ultimate outcomes. This condition has negatively affected the time completion of construction projects in the Kingdom of Saudi Arabia. It was also indicated as the main cause of quality problems in Saudi's construction project.

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The Role of Product and Service Innovations in the Finnish Construction Industry

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Abstract

Indent to succeed, the construction industry must offer quality products and services that are in line with customer demands. The objective of this study was to describe the role of product and service innovation in the Finnish construction industry by sectors. This study was qualitative in nature. Research followed a two-fold process: 1) analysis of Finnish construction patent data, provided by the Finnish Patent and Registration Office (PRH), and 2) a case study. The purpose of this research was to explore patenting activity in different construction sectors and its relation to product and service innovation within construction companies.

Our results indicate that patents have a significant role in the construction product sector. The building sector is also innovative, but generally in organisational structure and market innovations rather than in product or service innovations.

The role of development activities in Finnish construction industries is complex. Innovation seems to be quite straightforward in the construction product sector because these companies are seeking to produce the 'right' products. The issue of innovation is more complicated in other construction sectors. Even the definition of what a 'product' is varies among building construction companies. As a result, the products offered to customers might be inappropriate or ineffective in meeting customer requirements. On the other hand, the provision of services has become a more important part of many companies' operations.

The construction industry faces problems and challenges in many operational areas. Earlier studies have claimed that building construction is a very conservative field in the industry. The results of this study bear out this idea. The study provides support for managers considering development activities as a solution to better serve customers and increase innovativeness within the organisation. Innovation has a significant effect on a nation's economy and competitiveness by expanding employment opportunities, increasing economic growth and improving the standard of living.

Keywords: Patents; Innovation; Process; Development; New products and services

1. Introduction

How does the construction industry understand development and its benefits? The construction industry is usually not considered innovative compared with other industries (Sexton and Barret, 2003; Winch, 2003). In fact, the building construction sector is sometimes accused of being backward and stuck in the 19th century. While other lines of business have been able to increase their productivity, quality and value, the construction industry has suffered from a lack of innovation (Winch, 2003).

The competitive advantage of an enterprise depends on its ability to create more value than its rivals (Porter, 1985; Brandenburger and Stuart, 1996). Industrial innovation includes not only radical innovations but also incremental technological advances (Trott, 2012). High levels of innovation embedded in products, services and processes increase the possibility for growth and profits (Pleatsikas and Teece, 2001; Sattler, 2003). According to Trott (2012), innovations can be divided into seven typologies: 1) product, 2) process, 3) organisational, 4) management, 5) production, 6) commercial/marketing and 7) service.

In most countries, the construction industry is known to be a slow adopter of new processes and technology, which hampers the innovation process (Wandahl et al., 2011). Many researchers argue that the whole construction sector (including manufacturers of building products and systems, designers and property managers) makes up about 15% of the gross national product of most nations (Marceau et al., 1999; Seaden and Manseau, 2001). Achievement of innovation and development and the drivers of and barriers to development are comprehensively interrelated with the features and evolution of the industry (Pavitt, 1984; Malerba, 2004).

In current markets, new product development and innovation are essential for value creation (Hurmelinna-Laukkanen et al., 2008). New product development in today's business environment is challenging because of short product lifecycles, technical complexity, market uncertainties and rising costs of development (Bhaskaran and Krishnan, 2009; Cooper et al., 2001). To succeed competitively, enterprises need to offer products and services that meet the various needs of customers and the marketplace (Ulrich and Eppinger, 2011). The framework of development is about defining, designing and developing new products or services for the product portfolio (Ulrich and Eppinger, 2011; Cooper, 2001).

The construction industry is generally thought of as a large, dynamic and complex industrial sector which plays an important role in a country's economy. However, the industry is commonly criticized for being non-innovative and conservative (Bygballe and Ingemansson, 2014). This underlines the crucial need for such an economically important industry to become more innovative, specifically in the area of product development. A major objective is the designing of products in response to customer demand. In general, buildings are known as the main products of the construction industry, and the industry has put much effort into implementation of new production and procurement philosophies (Ozorhon et al., 2009). Yet, the construction industry, by nature, has many unique problems, and the importance of taking measures to improve the performance of the industry has now been recognised in several countries at various levels of socio-economic development (Ofori, 2000). According to Kajander et al. (2012), the top management of companies operating in the construction sector recognise that sustainability innovations are relevant to business development. This study aimed to answer the following research questions:

RQ1: What is the role of Finnish construction patent creation in different sectors?

RQ2. What is the role of product and service innovations in the Finnish construction industry?

2. Method

The research process was divided into five phases: study design, data collection, data analysis, results and conclusion. First, background research was conducted to obtain an adequate outline for the analysis of the role of development in the construction industry. A two-part data collection phase followed: 1) a construction patent data report from 2004 through 2014 was ordered from the Finnish Patent and Registration Office (PRH) and 2) a semi-structured interview questionnaire was developed, and company representatives were selected for interviews. Company representatives were interviewed to clarify current managerial level practices of development. The patent and interview data were then analysed, and conclusions were made. The research process for this study is presented in Figure 1.

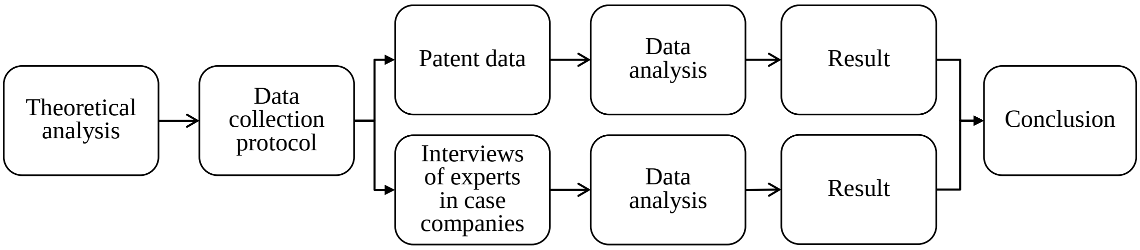

Figure 1. Research process

Qualitative research refers to any type of research that produces findings not resulting from statistical or other means of quantification (Corbin and Strauss, 2007). However, multiple data collection techniques can be employed in case studies and are likely to be used in combination with one another (Saunders et al., 2007, p.139). Moreover, both qualitative and quantitative evidence can be collected in a case study (Yin, 2003); in fact, Yin (2003) encourages using both techniques. In line with Yin's (2003) guidelines, a combination of qualitative and quantitative evidence was collected in this study. However, the main focus was on qualitative analysis.

Construction industry patent data from 2004 to 2014 was ordered from the PRH. Analysis of Finnish patent data according to the construction sectors defined by the Confederation of Finnish Construction Industries (CFCI) required the creation of a mapping table that included PRH classifications, CFCI sectors and International Patent Classifications (IPC) (see Appendix, Table 4). The CFCI's five sectors are 1) building construction, 2) construction products, 3) infrastructure, 4) heating, plumbing and air-conditioning (HPAC) contractors and 5) surface contractors.

The interviews were conducted with six companies (see Table 1). The number of cases was limited to six in order to achieve an in-depth understanding of the phenomenon studied. These companies were able to offer comprehensive study material relevant to the phenomenon, including information about products and/or services, business models, development projects, factors contributing to the development process and factors making development difficult. Topics that were company specific are not reported. The selected participants held positions related to their company's development. Their experience and current interest in development ensured high motivation and up-to-date knowledge about the topics discussed. Semi-structured interviews were conducted in which the following questions were asked: 1) What types of products and services does the company produce? 2) Who are the company's customers? 3) What do customers buy? 4) What is the company's business model? 5) What kind of development does the company expect? 6) What factors contribute to the company's development? 7) What factors make development difficult for the company? and 8) How do you see the future of the construction industry in Finland? The interviews lasted up to two hours and were recorded and transcribed. The main characteristics of the case companies are presented in Table 1.

Table 1. Company characteristics

Case	Sector*	Size**	Turnover M €	Role of interviewee
1	HPAC contractor	Small	5	CEO
2	Building construction	Large	550	Head of regional business unit
3	Construction products	Medium	12	CEO
4	Building construction	Medium	82	CEO
5	Building construction	Large	730	Head of regional business unit

Building construction	Large	710	Head of regional business unit

* Classified by CFCI.

** Company sizes by number of persons employed, classified according to the EU Commission definition (2005) of small and medium-sized enterprises (Micro, 1–9; Small, 10–49; Medium, 50–249; and Large, > 250).

3. Results

The patent propensity rate is a potentially valuable indicator for innovative activities (Arundel and Kabla, 1998). Patents are the granted exclusive rights by a government authority for an invention, which must be a new method of doing something or a solution to a technological problem. The invention can be a product or a process.

3.1 Finnish construction patents

Patent data was requested on March 26, 2015 from the PRH, and the patent data that was acquired contained information on 7,330 construction patent applications from 2004 to 2014. Information extracted from the patent data file included the following: 1) application number, 2) year of application submission, 3) patent number, 4) year of issue, 5) year of publication, 6) patent applicant, 7) patent inventor, 8) International Patent Classifications (IPC) category and 9) abstract.

The trend line of the patent data in Figure 2 shows a peak in the number of applications (871) in 2010. The drop in the number of patent applications in recent years can be explained by an 18-month protection period starting from the time of submission; during the protection period, applications are not made public.

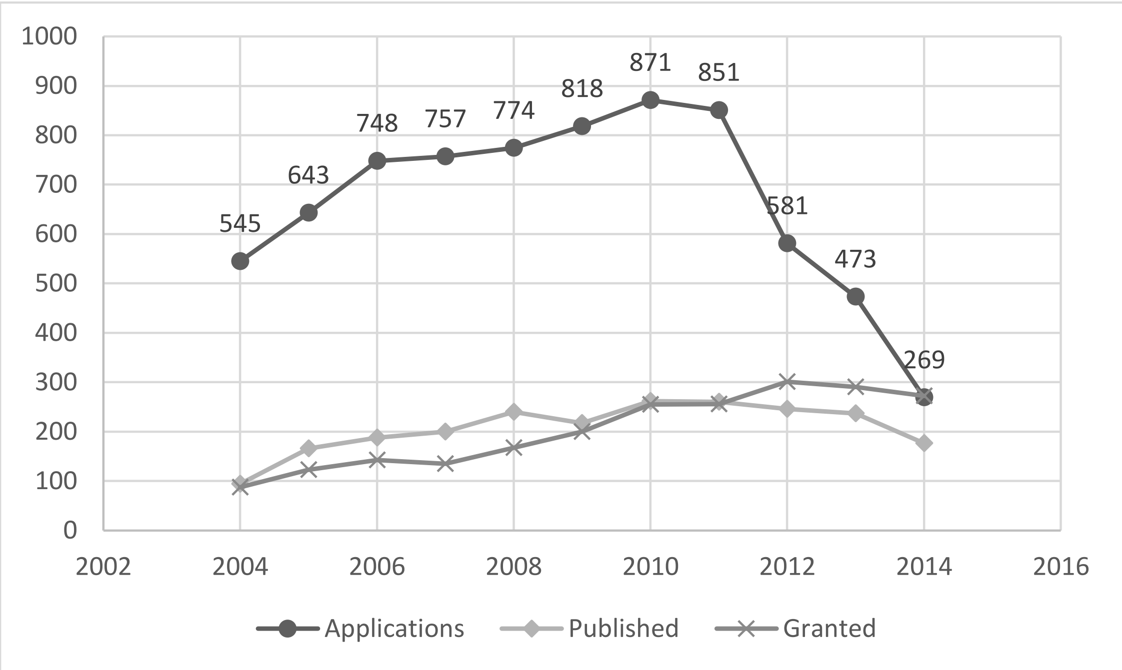

Figure 2. Patent applications and published and granted patents from 2004 to 2014

In addition, Figure 2 shows the trend of publication of Finnish construction patents from 2004 to 2014. The highest number of patents (262) was published in 2010. The lowest number of patents (94) was published in 2004. During the time interval from 2004 to 2014, the PRH issued the highest number of patents (301) in 2012 and the lowest number (87) in 2004. The trend of Finnish construction patents that are granted by the PRH can also be seen.

3.1.1 Role of patent creation by sector

In order to determine the patent creation per sector, the classes and subclasses of construction patents classified by the Finnish PRH (Appendix, Table 3) were reclassification to match the CFIC sectors (Appendix, Table 4). One CFIC sector, surface contractors, was not found in the PRH construction patent classification. The number of patents issued in the different construction sectors is illustrated in Figure 3.

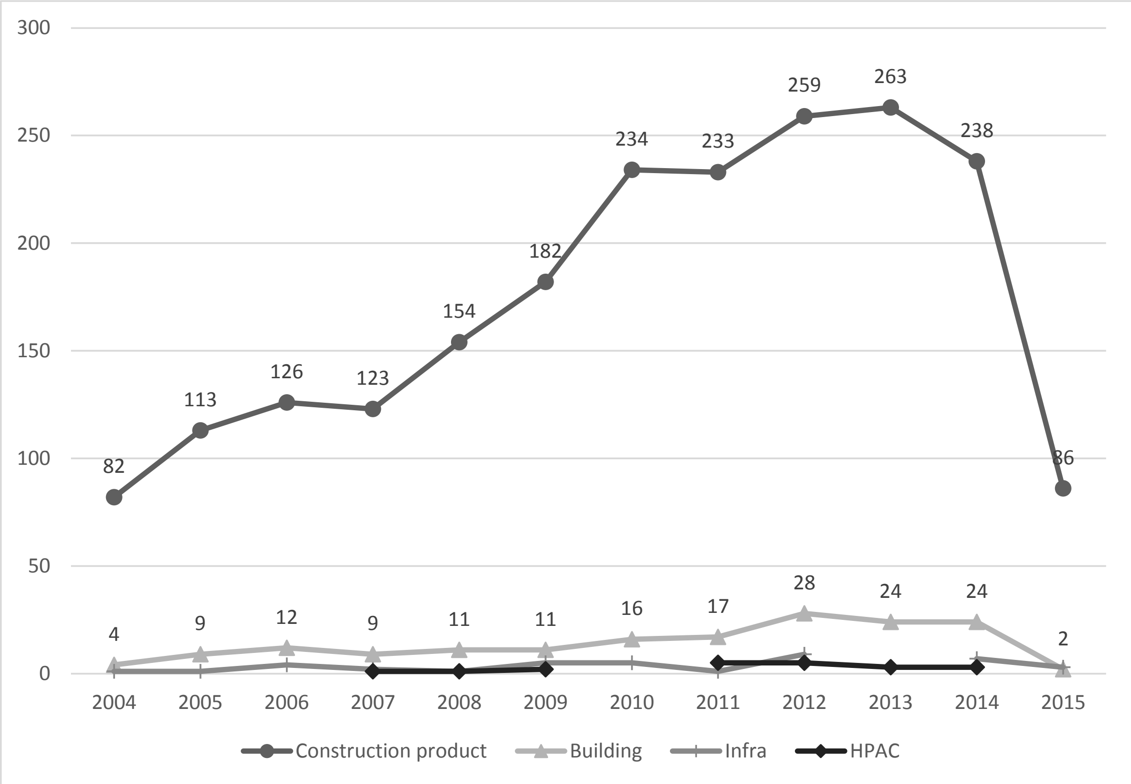

Figure 3. Patent creation per sector in the Finnish construction industry

The largest number of patents was issued in the construction product sector (90% of the total number), followed the building, infrastructure and HPAC sectors (about 7%, 2% and 1%, respectively).

3.2 Case interview results

Case 1: The company does not need to develop any of its own products because it is a subcontractor of HPAC installation services for municipalities and construction companies. The subcontracted installation services are the product that customers want to buy from it. The company does not have a written business model in use. It has pursued some development activities in the past, including implementing new marketing methods and changing the organisational structure. The main barriers for development are lack of available resources and time.

Case 2: The company offers real estate- and maintenance-based services and has several products: housing production, property development and commercial construction. The main customers are home buyers, apartment managers, institutions and the public sector. As a guarantee, the company solves customers' problems; in general, households, institutions and the public sector entities are looking for a service to help them find a place to construct a home or building. The company's business model is production, renovation and commercial construction of different types of housing. The company has made improvements in the areas of organisational structure and customer service. Some innovation has occurred in the construction of buildings. The main barriers to development identified in Case 2 are the attitude and ability of managers, outdated practices, budget limitations and overall mentality of the personnel. It is common for people to believe that investing in development is not guaranteed to get results.

Case 3: The company's products are concrete tiles, walls and pillars. The company also provides planning, delivery, installation and consulting services for business-to-consumer and business-to-business customers. Many customers buy concrete structures and installation services together. The business model is to provide concrete products. The company has made innovative developments in several areas, including products, processes, organisational structure and marketing. The case company has not been granted patents since they are issued by a head office. Factors hindering development activities are retirement of workers and personnel reductions.

Case 4: The company's main products are apartments and office buildings. Services are provided primarily for institutional real estate investors. Customers include companies, municipalities and institutions. These customers expect professional services and prefer to buy turnkey solutions. The company's business model is turnkey land development. The offer will provide solutions to the property developers. It attempts to do more than just offer the lowest price in the bidding process. The company has made organisational and process innovations. One example of development is an innovation in roof installation. Barriers to development are tight regulations, lack of resources and internal managerial thinking which will block progress.

Case 5: The company provides products related to customer demand and land development. The company offers real estate services for companies, municipalities, industry and institutional real estate investors. Customers buy a wide variety of products, from family houses and investment properties to office buildings. The business model is residential and commercial building and land development. The company has made several innovations in safety and organisation. A good example of development is a new system of schedule management. The projects themselves are the biggest barriers to development because customers tend to want the company to provide the same services they have always provided. The second biggest barrier is financial limitation.

Case 6: The company's products are housing, public buildings and renovation. The offered services are related to project development, and customers are municipalities, households and institutional real estate investors. Households hope to achieve their dreams by buying good-quality buildings. The business model includes land development and residential building. Development activities have focused on organisational, marketing and service innovations. Barriers to development are reluctance to assume risks and concern about investing in development activities.

The results of the case study are summarized in Table 2.

Table 2. Summary of development activities of case study companies

Case	Patents granted	Development types	Barriers
1	-	New marketing methods and reformed organisational structure	Lack of available resources and time
2	1	Organisational and customer service development	Attitude and ability of managers, outdated practices, budget limitations and overall mentality of the personnel
3	35	Product, process, organisational and marketing innovations	Retirement of staff and personnel reductions
4	-	Organisational and process innovations	Tight regulations, lack of resources and overall managerial thinking
5	2	Innovations in safety and organisational development	The projects themselves and monetary issues
6	1	Organisational, marketing and service innovations	Resistance of personnel and management's reluctance to invest in innovation

4. Discussion

As mentioned above and summarized in Figure 3, patents have a significant role in the construction product sector. The building sector also innovates, but innovations are related to organisation and marketing rather than to products or services. In contrast, the infrastructure and HPAC sectors do not generate a large number of patents.

As explained by Abbott et al. (2010), the measurement of innovation is quite difficult. From 2004 to 2014, 90% of the issued patents in the Finnish construction industry were in the construction product sector. The building sector was next, with about 7% of the total patents. The infrastructure and HPAC sectors had about 2% and 1% of the patents, respectively. This indicates that development activities occur mainly in the construction product sector, and invention very rarely takes place within the building and HPAC sectors. The surface contractor sector was not analysed in this study because this area was not included in the PRH construction patent classification index.

Many in the construction industry do not believe that investing in innovation will bring immediate profit, nor is it always certain that investment in innovation will bring benefit to the industry. Clients are considered the major drivers of innovation, so it would be beneficial to consider clients' thoughts when developing an innovation strategy. Similarly, other innovation drivers such as the business culture, human capital, organisational structure, technology, research and development, and partnering and knowledge management should receive equal focus from management.

The role of development activities in the Finnish construction industry is complex (see Table 2). Yet, development activities appear to be quite easy to implement in the construction product sector. This is easy to understand when one considers the goal of producing the 'right' products. The issue of development is more complicated in the other construction sectors. Even defining what 'product' companies offer to customers might be difficult. This is why 'service' types of development are more common in these sectors.

The interview results suggest that homes, offices and public buildings are common products of the Finnish building construction sector. However, some companies provide services instead of products. Households, municipalities, institutions, and institutional real estate investors are common customers of construction companies. It was noted that some companies did not have a clear business model. That is in line with the findings of Pekuri et al. (2013) that construction companies have significant problems describing their business models and value-creation logic. This leads to the question of what impact this has on the industry.

Globally, Finland ranks seventh in innovativeness after Sweden, Denmark, Switzerland, South Korea, the United States and Japan. South Korea's position as an innovative country has so significantly improved during the past few years that the EU now estimates it to be the world's leader in innovation (European Innovation Scoreboards, 2015). This would suggest that the Finnish construction industry should set the construction industry of South Korea as a benchmark and as a model from which it learn and improve.

Major barriers to development in the building construction sector, noted in the interviews, were the lack of resources and resistant attitudes at the managerial level. The need for workers with new and advanced skills at all organisational levels was expressed. Other barriers mentioned were monetary issues, such as limited budgets, old-fashioned thinking, strict domestic regulations and worker retirement. In addition, some of the interviewees said that the construction projects themselves block development in the building construction. The reason for this is that the project execution does not provide any room for innovative development. On the other hand, enthusiastic managers, new competitors, customers, goals for development projects, and quality of products and services were stated as factors that contribute to development.

The results indicate that development is occurring in the Finnish construction industry. Most of the interviewees appeared to understand that innovative ideas and activities are important for their companies to be competitive in the marketplace and that they must do more than just offer the lowest price in the bidding process. Many realise that innovations are essential to securing a solid position in the industry, whether these innovations are made by the company itself or in cooperation with universities or polytechnics. However, the interviewees did not believe that patents were the proper way to protect their innovations, which shows that the patenting process is not very familiar within the building construction sector. Also, the fact that many development projects are managed at the head office level might cause resourcing conflicts in regional business units.

The cause of this the lack of product and service innovation in the building industry must be seriously considered. One quite commonly cited justification is that the building industry is project-based and almost all construction work is carried out within a project context and project structure. A second one is that, since every project is unique, advantages from scale or repetition are not predictable. It must be examined as to whether or not these are sustainable justifications.

It is argued in this report that development activities are one of the major factors for companies to be competitive in the market. Gann (2000) mentions that competitive companies are able to make deep-rooted cultural changes while maintaining engineering and technical strengths. Thus, it is essential to focus on innovation activities.

5. Conclusions

The construction industry faces problems and challenges in many operational areas. In this study, the development activities of the Finnish construction industry were examined. Many earlier studies have claimed that construction is a very conservative field. The results of this study bear out this view. When looking at the construction product sector, development activities can be easily defined because it is a product-driven business sector. In contrast, other construction sectors do not seem to be involved in much development activity when the number of granted patents is used as an indicator.

The building construction sector implements development activities, but these tend to relate to the development of the organisation or internal processes. The reason is partly that ‘product’ as a concept is not as easily understood in other construction sectors as it is in the construction product sector. Moreover, large building construction enterprises face the challenge of head office centralization and managed development, and the ability to use resources for internal development varies among regional business units. In these cases, regional business unit managers will have a very significant role in education and in introducing new operational models.

The building construction sector is also disadvantaged by old-fashioned management models used by site and unit managers, a situation that may prevent introduction of new and advanced operational methods. Managers may ask why changes should be made if the model has operated well enough for the last twenty-five years. On the other hand, the significance of development activities has been rightly understood by some companies, and these companies have invested in development in response to market situations by changing their business models.

5.1 Limitations and future research

This study focused on the role of product and service innovations in the Finnish construction industry. The limitations of this study could be addressed by further research.

First, the number of companies interviewed in this study was limited. Second, further research should measure innovation throughout the patent life cycle. For example, a sample of granted patents could be selected, and a questionnaire related to the intended future use of the patented innovation could be sent to the company or creator. Survey results would indicate whether that particular patent was a successful innovation or not. This would give a view of the overall level of innovativeness within the construction industry. Additionally, the innovativeness of each construction sector could be evaluated and compared.

Finally, a deeper analysis must be done on how a project’s context and the structure of its working methods actually block customer preference-based innovations. Also, future research could benefit from a comparison to other industries, such as the shipbuilding and aerospace industries.

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7. Appendix

Table 3. Finnish construction patent classification by Finnish Patent and Registration Office

	Subclass or title	**IPC class**
Human necessities	Construction of roads, hydraulic engineering, water supply, building, locks, keys windows, ladders mining	A21, A21B,A21C, A47, A47H, A47K
Fixed construction	Construction of roads, hydraulic engineering, water supply,* building, locks, keys windows, ladders mining	E01, E01B, E01C, E01D, E01F, E01H, E02, E02B, E02C, E02D, E03, E03B, E03C, E03D, E04, E04, E04B, E04C, E04D, E04F, E04G, E04H, E05, E05B, E05C, E05D, E05F, E05G, E06, E06B, E06C, E21, E21B, E21C, E21D, E21F
Mechanical engineering	Machine in general, combustion engines, machine or engine for liquids, positive displacement machines for liquids, engineering elements or units, steam generation, combustion apparatus heating, refrigeration or cooling, drying, heat exchange In general	F01, F01B, F01C, F01D, F01K, F01L, F01M, F01N, F01P, F02, F02B, F02C, F02D, F02F, F02G, F02K, F02M, F02N. F03, F03B, F03C, F03D, F03H, F04, F04B, F04C, F04D,F04F, F22B, F22D, F22G, F23, F23B, F23C, F23D, F23G, F23H,F23J, F23K, F23L, F23M, F23M, F23N,F23Q, F23R, F24, F24B, F24D, F24F, F24H, F24J, F25, F25B, F25C, F25D, F25J, F26B, F28, F28B, F28E, F28D, F28F, F28G

Table 4. Finnish construction patents classified into SFIC construction sectors

Category	**IPC category symbol**
Building construction	=IF(OR(Z9=‘E02’;Z9=‘E03’;Z9=‘E04’;Z9=‘E04D’;Z9=‘E04G’;Z9=‘E21’;Z9=‘F01K’;Z9=‘F02C’;Z9=‘F02K’;Z9=‘F23’;Z9=‘F23B’;Z9=‘F23D’;Z9=‘F25C’;Z9=‘F25J’);’Building’;’’)
HPAC	=IF(OR(Z9=‘F01P’;Z9=‘F02’;Z9=‘F02P’;Z9=‘F22’;Z9=‘F22D’;Z9=‘F24’;Z9=‘F24C’;Z9=‘F25’;Z9=‘F26’;Z9=‘F28’;Z9=‘F28B’;Z9=‘F28C’;Z9=‘F28F’);’HPAC’;’’)
Infrastructure	=IF(OR(Z7=‘E01’;Z7=‘E01B’;Z7=‘E01C’;Z7=‘E06’;Z7=‘E21C’);’Infra’;’’)

SECTION

3

Innovative design and construction

Design Revolution for Affordable Housing in Tropical Country

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Abstract

Malaysian demographics are changing rapidly. With the increasing working population in major cities and towns, housing affordability problems among middle income households become widespread as many of these households are not covered by existing housing assistance programs. Prefabrication and modular construction are believed to be the solution for constructing houses that meet the vast number of demands in urban areas in a short period of time. Yet, as a housing strategy, it is still considered unresponsive to local climates and conditions with low acceptance rate, due to the lack of variability and an individual identified design. At this juncture, how prefabricated housing design can be evolved from mass repetitive production level to mass customization level that account for flexibility and variability is the primary issue to be explored. A good design can contribute to affordability through reducing the construction costs and the life-cycle costs while maintaining liveability. This paper discusses an alternative design strategy which is deemed to bring improvement to the country's prefab housing industry with respect to time, cost, and quality. The proposed design strategy entails open plan that enable retrofit and reconfiguration to be made quickly, economically, and repeatedly, without involving excessive site labour, time, and cost; as compared to the currently adopted design strategy which is associated with rigid structure, interlocking plan, and predetermined function. Besides, it is a combined design and construction system that makes use of the Industrialised Building System (IBS) construction method to produce a variety of housing design options that meet possible user requirements not yet identified at the design stage, while retaining principal uniformity to facilitate the execution of simple but accurate construction with a minimal initial cost. By taking into consideration the passive design strategies extracted from the tropical vernacular architecture – the traditional Malay house – the proposed affordable housing design makes possible the creation of dwellings that adheres to the context of contemporary technology, tropical adaptation, and cultural responses.

Keywords: Prefabrication, affordable, housing, design, customization, tropical country

1. Introduction

Due to increases in population, many world regions were forecasted to encounter an urgent need for new housing in the coming decades. According to a recent United Nations (UN) report, an additional three billion people will be needing housing across the world by the year 2030, which means that approximately 100,000 houses per day are required to be produced in order to meet such a pressing demand by 2020. Malaysia is of no exception in facing the mass housing problems when moving towards a higher level of urbanisation. In 2013, the Malaysian government, through the collaboration between the state governments and the private sector, targeted to deliver 1 million mass houses to the public in 5-year time, which is equivalent to an average of 200,000 houses annually. This challenge inevitably calls for the innovative building technology that has the dual benefits of economy as well as speed in construction.

Prefabrication is, no doubt, an obvious choice for the quick, efficient, and inexpensive housing construction and delivery, in meeting the ever-increasing demand for mass housing in the country. The strength of the prefabricated house lies in its lower capital and developmental costs by using purposely made components which are mass produced in great quantity. In some mass housing developments, industrial approaches to construction coupled with value engineering, were found to help slash cost by about 30% and delivery times by up to 50% (MGI, 2014). Since the primary determinant of mass housing construction is cost, prefabrication is always an attractive option to be adopted. However, there are some hindrances to change in this respect. Advances in technology may allow concept like standardisation and prefabrication potentially to address many of the problems facing the house-building industry, but questions arise whether mass houses being developed now are capable of adapting to occupant's ever-changing requirements, as the current demand for new housing seems moving towards mass customisation and agile production, which greatly increases the choices offered to customers rather than culminating in the standardised housing types of past experiences. Changes in the demographic make-up due to the diversity of family typologies and household arrangements have generated a need for housing that can adapt to different privacy, space, use requirements, and life styles. Prefabricated houses, on the other hand, have rigid structure, interlocking plan, and predetermined function, in which very few of them are open plan that enable retrofit and reconfiguration to be made quickly, economically, and repeatedly (Gan et al., 2015). This, consequently, leads to the question whether mass population is being accommodated in suitable dwellings. Similarly, given the need for sustainability and the generally important consideration of environmental and social values in the longer term, it is essential that a long term view be taken and that the needs for flexibility, maintenance and eventual disposal (or re-use) be addressed at the design stage.

Studies show that residents of mass housing in Malaysia are generally not satisfied with their housing conditions (Karim 2012; Isnin et al 2012), where a presumed need for flexibility in design, room size and fittings has precluded use. For example, criticisms have been made with regard to the People's Housing Project Scheme (PHP) (Figure 1) – an initiative by the government to solve the problem of existence slums and squatter areas – on the architectural design including the lack of storage area, small size and deep location of the kitchen, minimum external wall area, complicated partitions, less cross ventilation etc. (Sahabuddin and Gonzalez-Longo, 2015). Most of them end up renovating houses to tailor-suit their needs before occupancy (Rostam et al 2012; Nurdalila 2012; Erdayu et al 2010). This is largely due to the nature of the current mass housing architectural strategy, namely the convergent design system, which is a "one fits all" design initiative where housing is likely to be designed around the capability of a given product, instead of around the end-user (Zuhairi et al., 2015). Thus, houses designed for the average family are deficient in meeting the mass housing sustainability objectives as they are leading to further compromise the occupant's needs. Besides, the convergent design system implies extreme compartmentalization and dissociation of internal elements, where service spaces such as kitchen, bathroom, etc. are built internally by interlocking with space, making the service spaces difficult to interchange (Zuhairi et al., 2015). Houses designed and built with such system are solely based on the economic concepts of housing that only measure affordability, ignoring the potential of sustainable housing design that offers social and environmental benefits, not to mention in addressing the needs of the householder with regard to emotional satisfaction and economic performance.

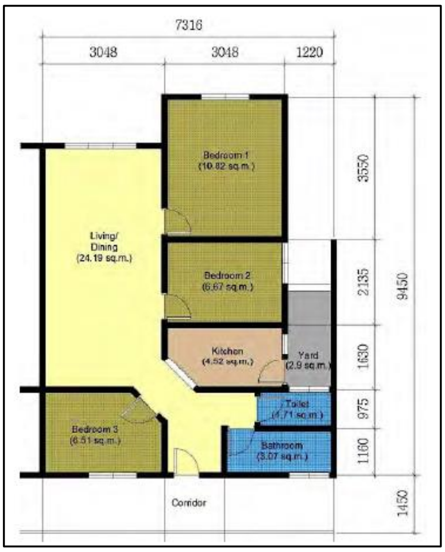

Figure 1: Layout plan of a PHP unit (Goh & Ahmad, 2011)

Apart from that, the potential social resistance to the ideas of prefabrication and standardisation in housing is still prevalent. Various perceptions, opinions, and images spring to mind when considering the prefabricated housing due to a number of buildings constructed in the past were judged to be of poor quality. In fact, prefabricated housing in Malaysia has been plagued with bad publicity such as leakage, inflexible for the repair and maintenance, as well as a resemblance of low cost housing projects which are basic and pay minimal attention to the aesthetics of the building (Figure 2). While some of the problems to prefabricated housing may not be an issue now with the application of new technology, such as using advanced water-proofing or innovative jointing method for solving the leakage problem, the image of prefabricated housing is still strongly tarnished by the general perception that the lifespan of such housing is likely to be less than that of "conventional" built housing – consists of a reinforced concrete frame and brick, beam, column, wall, and roof, which was cast in situ using timber framework. It is the programmes of poor quality and poorly designed prefabricated housing that have given rise to a notion that the process of prefabrication per se, rather than particular products, was at fault. On top of that, prefabrication construction in Malaysia has been associated with a cost increase of 10% compared to conventional construction (CIDB, 2007). Since moving towards mechanized and industrialized systems involves high capital investment on heavy equipment and mechanized construction facility, along with availability of cheap foreign labour in the country, the industry players are unlikely to switch to an unfamiliar system in order to secure their projects, particularly for those small contractors who involved in the small scale development (Foo et al, 2015).

Figure 2: Examples of low cost housing projects – Tunku Abdul Rahman Flat in Kuala Lumpur (left) and The Rifle Range Road Flat in Penang (right)

2. Good Design for Mass Housing

Regardless of the barriers that influence its uptake among the industry players, prefabrication construction is still believed to be the appropriate solution for today’s mass housing problem. To allow for the successful application of prefabrication, in Malaysia particularly, the following past mistakes need to be recognised and addressed: (i) Quality – previous lack of quality has led to the perceived reduction of value associated with prefabricated housing; (ii) Attention to detail – poor detailing in the past has led to technical problems and a general perception of poor value; (iii) Life cycle performance – failure to consider the practicalities and costs associated with maintaining these buildings had led to some prefabricated housing becoming difficult to maintain. Hence, how prefabricated housing can evolve from the mass repetitive production level to the mass customization level that account for flexibility and variability, as well as becoming responsive to the local condition and social acceptability, is worth to be explored.

According to Evans (2014), a good design can be the critical difference between an affordable development that succeeds – one that satisfies its residents and neighbours, enhances the community where it is built, and continues as a stable part of the community for decades – and one that does not. Given that each dwelling unit is a primary structure which would contribute to the quality of life, and the root causes leading to housing quality problem are identified as issues related to housing layout and design, surrounding environment, maintenance, location, amenities, and building material (Živković and Jovanović, 2012), house builders should be aware of the potential for a good design in responding to the evolving social behaviour, and strike to take advantage of technology in the housing production process through integrating housing design with industrial construction system. In other words, each dwelling unit should be designed, in such a way that it is economically and easily adjustable, while adheres to the context of contemporary technology, tropical adaptation, and cultural responses (Gan et al., 2014). The key element for a good design is the realization that lifestyle – as one of the defining characteristics of peoples' lives as citizens, consumers, and householders – is a feature that shifts in accordance with a dynamic lifecycle process. A home that can be altered with minimum effort and expense at a time of change in the lives of its owners is a home that evolves with the lifecycles of its household rather than becoming rigidly obsolete in the conventional manner (Friedman and Krawitz, 1998).

The present paper, thus, proposes a flexible housing design system for the modern urban mass housing in tropical country. By adopting flexibility as the inherent architectural design strategy, the system is able to provide the physical spatial arrangements that are conductive for the socio-cultural wellbeing of a community along while complementing the environment. Besides, the system combines both machine production and mass customization, offering more than 10,000 possible designs including prefabricated structures, factory-made structures, dwelling plan and flexible design, to provide an affordable and sustainable housing for all. It makes possible the creation of dwellings which may grow old yet without becoming obsolete; incorporating the latest design ideas and technologies, yet have a sense of history on the Malaysian housing design (the *rumah kampung* design); allowing the communities to live for generations, yet incorporating the potential of adaptation.

3. Divergent Dwelling Design (D3)

Divergent Dwelling Design, or D3 in short, is a combined design and construction system directly responses to the fundamental demographic and economic pressure that heightened the need for an appropriate solution for the urban mass housing. It makes use of the open plan design concept and the Industrialised Building System (IBS) construction method, to produce a variety of housing design options that meet possible user requirements not yet identified at the design stage, while retaining principal uniformity to facilitate the execution of simple but accurate construction with a minimal initial cost.

The proposed D3 basic architectural plan is a square shaped plot (Figure 3), having a plurality of "dynamic" space lots (where the bathroom, kitchen, and other dwelling services located) arranged peripheral of the plot so as to be in contact with the outdoor environment; and a plurality of structures such as the dining room, bedroom, or any other spaces located in the "core" space lot which is capable of being arranged, modified, and customised in plurality of designs according to the user's needs. While the plot is standardized to allow for efficient manufacturing, it can take any desired shape including square, rectangle, as well as other polygonal shapes (Figure 4). With the built-in architectural flexibility, D3 basic dwelling unit can be divided into more than one plan, in which the occupant can choose the floor plan they want to live before moving in, thereby achieving harmony between the basic structure and the various sizes of dwellings in the long term. This is similar to the automotive industry, where each individual functional unit is freely bonded with the core structure to serve different occupants' requirement.

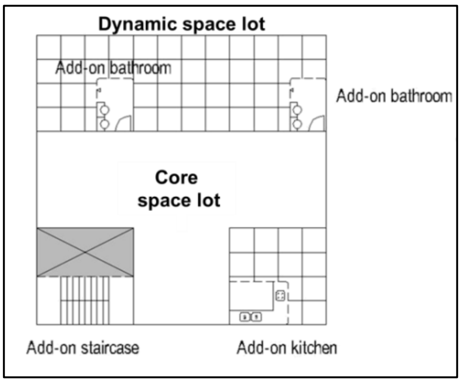

Figure 3: D3 basic architectural plan

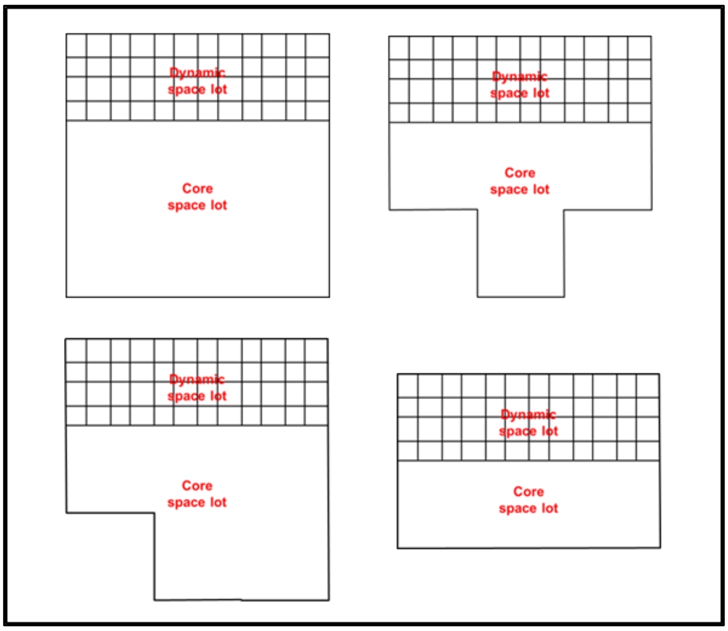

Figure 4: Various shapes of D3 basic dwelling unit

Every D3 building is designed and built in such a way that both the structure and infill of the building are treated as separate entities in order to optimize the efficiency of building assembly and modification. As depicted in Figure 5, the basic layout can be configured into various plans, simply by partitioning the core space lot or rearranging the location of bathroom and kitchen within the dynamic space lot. In other words, there is no one fixed plan in D3 design system but a flexible plan that houses endless of possibilities. Owning to the use of a number of interchangeable component sub-assemblies, D3 makes possible the transfer of construction process from building to manufacturing, with component manufacturers and end-users playing a much larger role in the design process. For example, the bathroom, kitchen, partition, façade etc. are mass produced which then divergently attached to the building structure (Figure 6). The occupant has wide spectrum of choice with regards to products in the market. Since each system is independently manufactured in a controlled environment, the development entails the use of technology and innovation, without the involvement of excessive site labour, time, and cost. In this sense, D3 comprehends the advances of science and technology over time, leading to a faster production at economical rate.

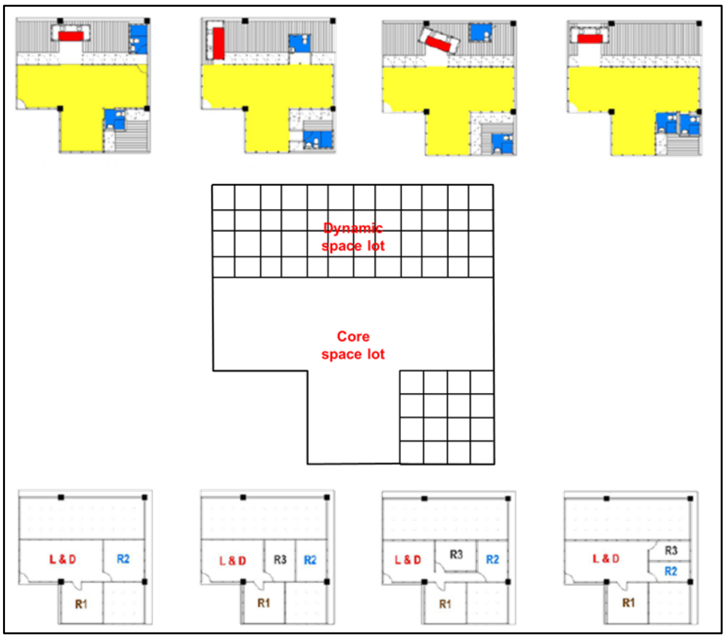

Figure 5: Different variations in the arrangement and partitioning of D3 basic dwelling unit

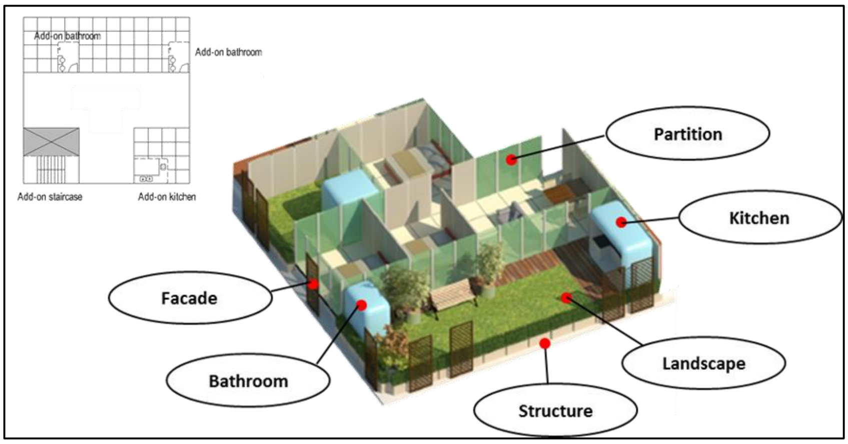

Figure 6: D3 independent building systems

Once the design system is in tandem with serial production and standardization, there will be no bounds for the development of a sustainable community that can accommodate a wide diversity of users and household types. Prospective occupants can choose from a catalogue of available components which are tailored to individual lifestyles and budgets. This enables the occupants to consume only the type and quantity of features they currently require or can afford. For example, a variety of kitchen options that suit a wide range of household lifestyles can be offered by the manufacturers without significant increase of their administrative and operational costs due to the prefabricated nature of kitchen cabinetry. Besides, the variety of configurations available caters to desires for increased work surfaces, space economy, and the inclusion of washer, dryer and recycling facilities within the kitchen. Similarly, the bathroom requirements also vary according to the occupants and their individual scenarios. Normally, two bathrooms will be provided for every affordable house in Malaysia. However, the number of bathroom is not restricted in D3 housing; if the number of occupants and their schedules justify for another bathroom, D3 open plan concept would satisfy this requirement by balancing the size and location of this additional bathroom with the remaining spaces in the dwelling unit. Consequently, the bathroom options offered by D3 housing can range in size from powder rooms to complete bathrooms with shower, bath, toilet, and sink (Figure 7). Since every individual dwelling unit is flexible enough to adapt to the changing needs of both existing families and future users, the combination of these units will enable a variety of sustainable habitual spaces to be processed, which then can constantly renew themselves without becoming obsolete (Figure 8).

Figure 7: Examples of available modular bathroom in the market

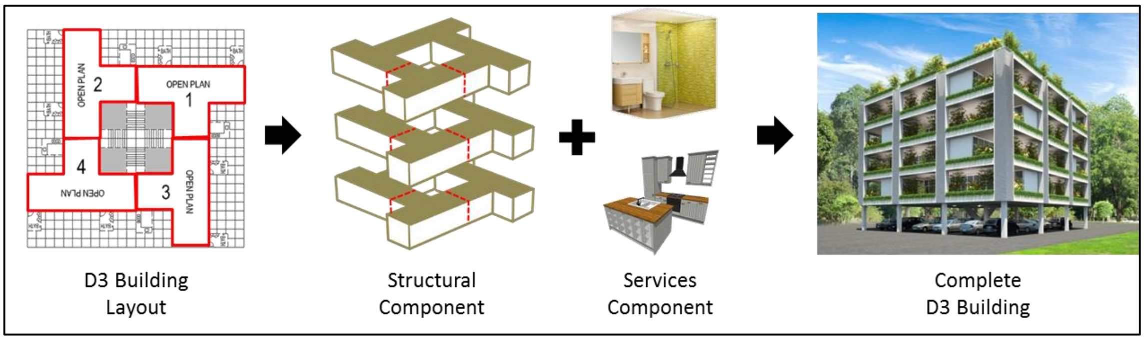

Figure 8: Formation of D3 building through combination of individual flexible dwellings

The principles underlying the design of facades are analogous to those governing the structure and plan: flexibility and individual identity. By positioning the dynamic space lot in the peripheral of the plot, a setback of walls is created where no external walls to be in contact with the outdoor environment. Such setting can be well-adopted in the apartment development, imparting a sense of individual identity and differentiating vertical occupancies or uses, yet avoiding the extremes of monotony and theme park atmospheric elements (Figure 9). One of the most common drawbacks of prefabricated housing is the homogenous and repetitive nature of the development, which is a by-product of the economies of scale. The value of providing a diversity of appearances is that it satisfies the individual user's personal requirement for identity and self-expression, counteracting any potential feeling of anonymity resulting from increased density, and it incorporates – or rather predicts and pre-structures – the inevitable variety caused by change overtime. Residents are able to explore various options in terms of appearance, style, fenestration, and materials used through the participation in conjunction with the builder.

Figure 9: Examples of flexible façade combination

4. Functionality and Liveability through D3 Efficiency

As stated by Barlow (1999), current housing construction situates the industry somewhere between craft forms of production and mass production, which tends to display relatively low quality consistency, measured by the amount of rework required on completion (Figure 10). This strongly contrasts with the car industry which has been pioneering lean production concepts for many years and may be moving towards agile production as customer input into the final product, quality and after-care grow. As a housing design system that seeks to avoid the rigidities of prefabrication and less effectiveness of conventional construction, D3 has the potential to help boost a greater productivity, better quality, and an assurance of a growing and interested housing market. With the delivery of highly customized products at costs comparable with mass production, it is possible to make prevalent the concept of mass customization in the Malaysian construction industry. The following sections are devoted to describe how the housing functionality and liveability is achieved with D3 design system, in terms of construction, space, and energy.

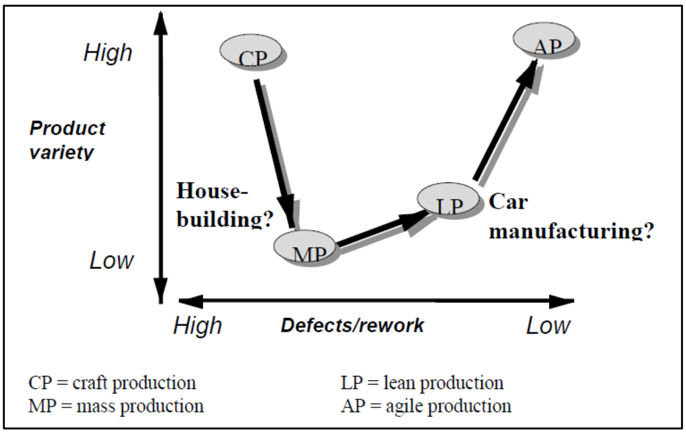

Figure 10: From craft to agile production in the housing and car industries (Baker, 1996)

4.1 Construction Efficiency

Construction efficiency is among the most effective strategies for decreasing the cost of housing construction without reducing its liveability (Feldman and Chowdhury, 2002). In the case of D3 construction, a modular system prevails in an attempt to minimize building costs, as well as to execute simple but accurate construction. The 7.2m x 7.2m module allows for a strong element of flexibility with regard to a variety of building configurations (Figure 11). This unit module with its multiples and subdivisions form the basis of all dimensions of the dwellings. The advantage of the employment of this single unit module is that all locations and sizes of the parts with respect to the whole are precisely identified during the construction process (Figure 12), and thus, no obscure or arbitrarily unrelated measurements are involved in the unit system. This also leads to other advantage, such as the standardization of many building components (prefabricated beam, column, and slab) for mass production in manufacturing. There is usually a cost with the provision of a structure that allows for flexibility and adaptability. In a departure from the conventional mass housing design, however, D3 design system allows planners and builders to incorporate various housing types within a single unit module in order to respond to a diverse range of values, incomes, and households (Figure 13). With such ability, a wide range of housing size is covered under one design plan, be it a 450ft^2 studio type dwelling, 700ft^2 low-cost housing, or 1,000ft^2 affordable housing.

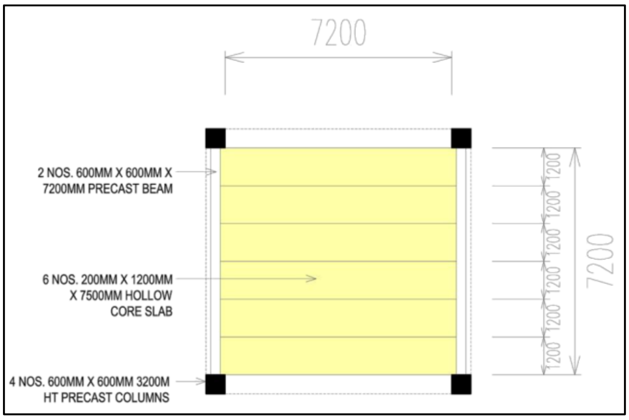

Figure 11: A D3 typical structural unit

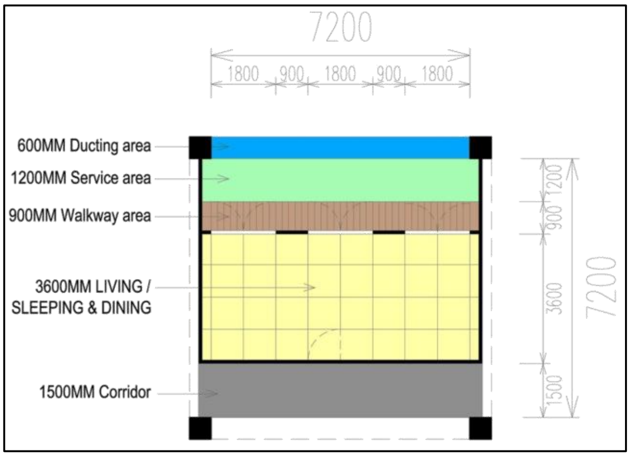

Figure 12: A D3 typical functional unit

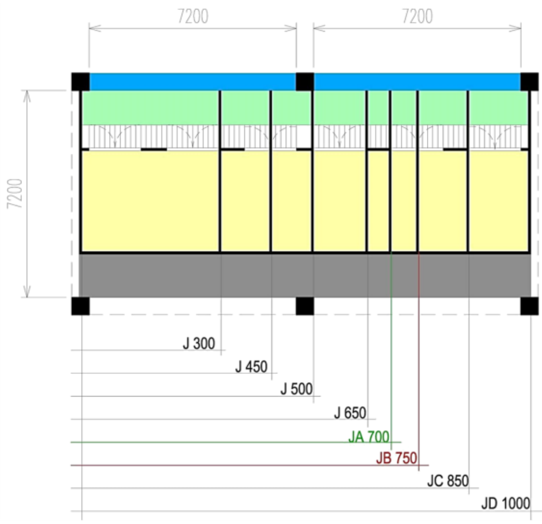

Figure 13: Different types and sizes of D3 housing with a single modular unit

All prefabrication of structural components is made in an off-site factory and is regulated with regard to the single unit module, namely column, beam, and hollow core slab. When all components are delivered on site, they are assembled to become a home (Figure 14). Assemblage of components is easy and simple, where altering or replacing components is much the same. The construction system is a kit-of-parts solution to the affordable housing problem that does not require a highly skilled work force or special machinery. By incorporating IBS into the construction process, a compressed construction schedule is not only cost-saving in and of itself, getting the building into productive use sooner and reducing finance periods, but, especially in times of significant inflation, compressed construction schedules save additional significant sums. Therefore, a building that adopting D3 design system can be constructed at a faster pace and arranged in multiple manners, to achieve high density in the most comfortable spatial design environment (Figure 15).

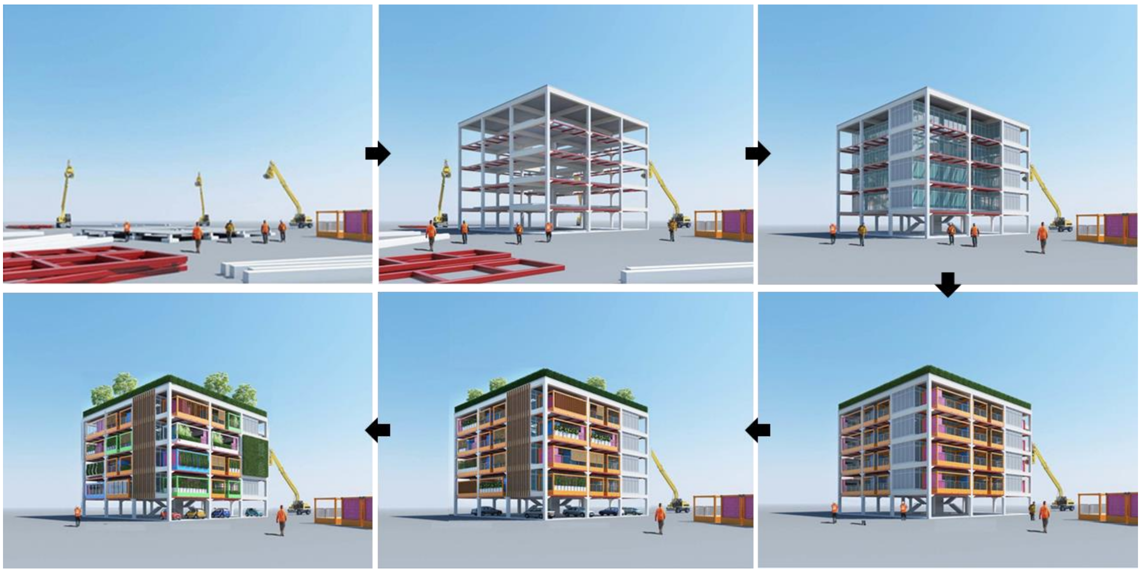

Figure 14: Comparison of trades and time frame between conventional and D3 construction

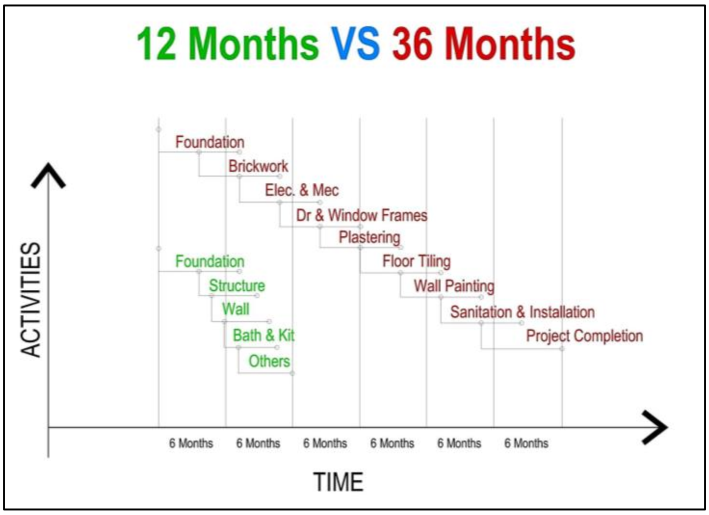

Figure 15: Comparison of trades and time frame between conventional and D3 construction

Besides, the use of 100% machine produced components allows both the cost and structural integrity to be effectively reduced because using modern construction materials, such as lightweight partitions, modular bathroom and kitchen can all save time. In traditional construction, each sequence of construction involves different work crews that lead to the conflict in scheduling. Some trades such as formwork or pouring concrete may even stops or dramatically slow the work of others. The on-site construction of a bathroom, for example, requires nine major steps and the inclusion of more than thirty parts/components (Figure 16); as compared to a modular bathroom which is manufactured in the factory environment and is delivered to site as a complete unit. In addition, the conventional practice for installing the plumbing system involves the cutting and assembly of the various pipelines and fittings. It is obvious that prefabrication of such plumbing installations in a factory is potentially a more efficient and economical procedure, particularly when a number of essentially identical plumbing installations are to be made, as in the case of multiple dwelling, units, hotels, apartment houses, schools, and the like. This is the key of reducing conflict in scheduling, where trades and building parts are greatly reduced by coordinating dimensions and positions instead of improving on site by cutting to size. On top of that, the whole project can also benefit from those intangible benefits, such as site cleanliness, less labour, less material wastage, shorter construction period etc.

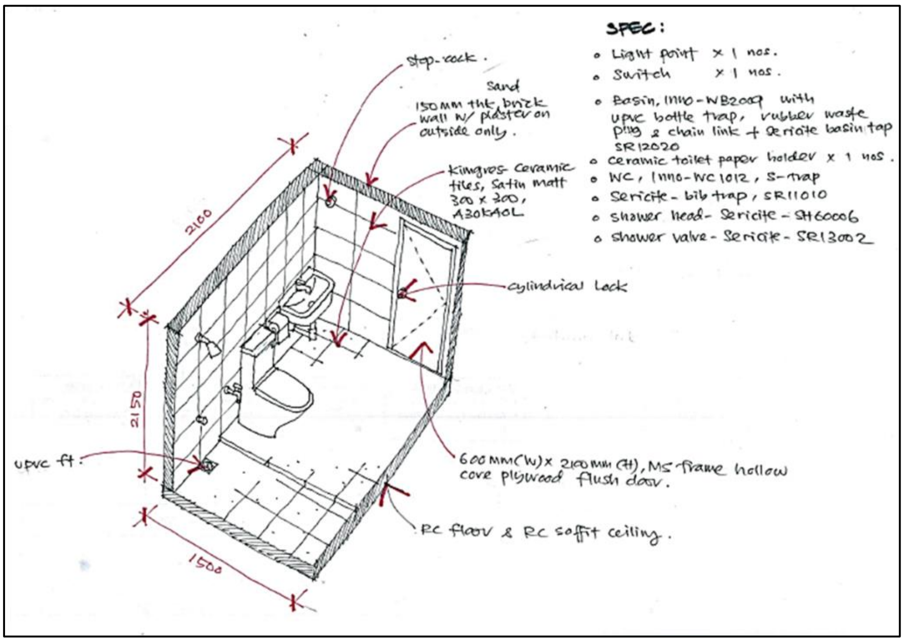

Figure 16: Parts and components of building a conventional bathroom

4.2 Space Efficiency

Structural system, as rigid and unchanging part of the housing unit, dictates the degree of flexibility of spatial unit set (Živković and Jovanović, 2012). The key role of this part of design process for housing unit flexibility is conceivable through the fact that these parts are the most inflexible elements of the unit. The position of technical installations is another basic unchangeable aspect of residential space. The issue of structuring the technical core is, thus, important to be considered and resolved in the initial design phase, so as to give more flexible solution in exploitation. In D3 housing design system, space efficiency is achieved without compromising the dwelling liveability by several approaches. First, all structural elements are located at the exterior of the layout to allow for unlimited unobstructed clear spaces that can be freely arranged over the life of the dwelling unit. The dining room and bedroom are distributed along the core space lot, which is capable of being arranged and modified according to the user's needs (Figure 17). The main entrance to the house is adjacent to the living room. All the living room and bedrooms are made to be accessible to the "landscape area", which also functions as the laundry area or open porch, providing an excellent means of open-air drying.

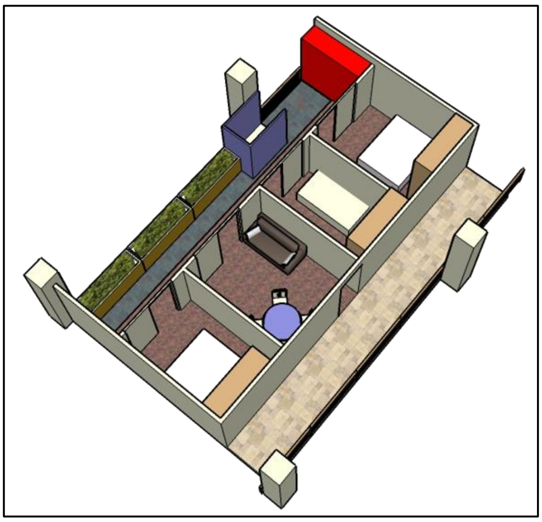

Figure 17: A typical 750ft^2 D3 dwelling unit

The kitchen and bathroom are grouped in the dynamic space lot in order to concentrate the plumbing system, so that economic maintenance and cleaning are possible. This concentrated plumbing system consists of a modular system for routing building utilities. The current practice in many multi-floor buildings is that the distribution ducts for electrical conductor and plumbing are installed inside the concrete walls and floors. The limitation of this setting is that the arrangement of the distribution ducts cannot be changed once it is installed. Also, there are a number of times where moisture is found on the floor due to the condensation and leakages of the ducting system. To overcome the inflexible nature of the technical installations, a modular system for routing the building services connections is introduced, which is an integrated service panel installed along the periphery of the building structure carrying the building services connections including but not limited to the electrical connections, plumbing connections, solid waste transfer connections, gas supply connections, heating, ventilation and air conditioning connections, fire sprinkler piping connections, and other communication services connections associated with a building structure (Figure 18).

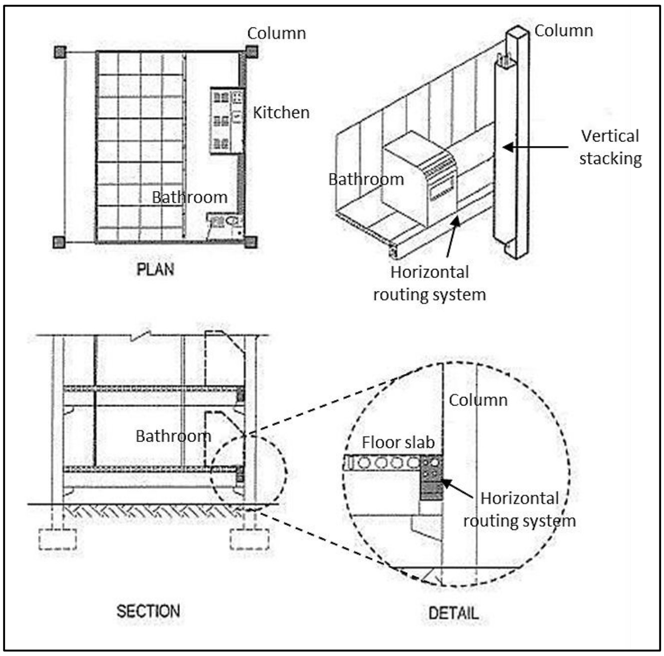

Figure 18: Configuration of building structure installed with the prefabricated integrated service panels

This routing system is easily installed and can be reconfigured whenever desired. It consists of an elongated rigid casing, having a top portion, a bottom portion, a plurality of side surfaces and a pair of ends that are configured for connecting with other rigid casings and other external building services connections (Figure 19). The top portion of the rigid casing is open to connect with the building services connections and for allowing access to the elongated compartments inside the rigid casing. An adjustable top closure means is used for closing the top portion of the rigid casing. The side surfaces of the rigid casing are provided with a number of external connectivity means configured for connecting with the building services connections. The routing system can be installed in a combination of arrangements, either at the subfloor position of the building structure, or to be vertically attached to the walls of the building structure, or even to be attached to the roof of the building structure. The interconnection means of the prefabricated integrated service panels is compatible with existing piping connections and can be installed with existing plumbing and electrical connections and existing interconnecting means for the plumbing and electrical connecting systems.

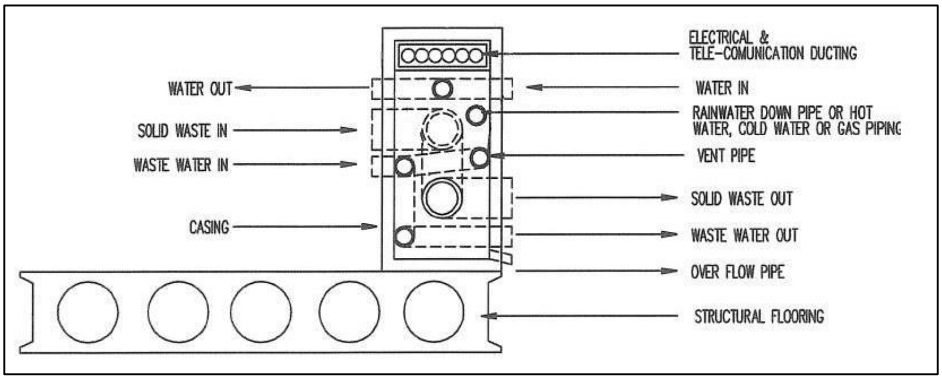

Figure 19: Side view of the integrated panel for routing building utilities

Flexibility in D3 design system is further achieved by using movable partitions. Since common walls within a dwelling unit are non-load-bearing walls, the dwelling unit floor areas can be arranged independent from boundaries to suite the size of any uses. The sustainability initiative here focuses on providing spaces to be used for a variety of purposes over time, be it the changes of household demography or the changes of resident's living satisfaction. Since this kind of functional change can be done by merely switching of the independent units within the configuration through a simple process, the function of the dwelling unit can be cultivated and adapted to the occupant's need whenever it is required. By enabling the floor plan to be adapted to the future users and the changing needs of families, D3 unit plan is able to take into account different family types: (i) dynamic family which is likely to have more children in future, and is thus requires a high degree of space flexibility to cater for continuously changing and increasing needs; (ii) stable family which is not going to have any more children (either the children have left home or are too small to leave home) and thus requires a relatively lower degree of space flexibility; (iii) stagnant family which is expected to live in the same dwelling for a long time and thus has sufficient opportunity to benefit from flexible building elements, which provides for lower life-cycle cost of such elements. Furthermore, a residential space can be converted into a café by just incorporating a larger kitchen and more toilets; a laboratory or playroom or computer room when added with a unit space for teaching can be used as an educational institution. So similarly the kind of unit space or constant space can change its function from residential to commercial, without ever needing to change the basic unit.

4.3 Energy Efficiency

Malaysia is situated in a maritime equatorial area, where the climate is generally the same throughout the year, with uniform temperatures, high humidity, light winds, and heavy rainfall (Hyde, 2008). The very nature of the Malaysian climate necessitates mechanically ventilated or air-conditional interiors, especially in urban areas. However, poor design and indiscriminate use of air conditioning have resulted in huge increases in energy use. Passive and low energy design strategies are too often excluded from the affordable housing projects because they are deemed to add cost to the construction, though they are the solutions for a sustainable future. In fact, it is possible to attain energy efficiencies without incurring additional costs. As pointed out by Feldman and Chowdhury (2002), energy efficient design contributes to environmental sustainability and saves life-cycle costs. D3 directly responds to the fundamental demographic and economic pressure that has heightened the need for a new housing alternative which appropriately integrates affordability and sustainability. To ensure mass housing populations could enjoy eco-housing with affordable price, affordability is designed in at the beginning by adopting a simple design layout, which is flexible enough for adaptation and yet suits to the tropical climatic condition.

The passive design strategies adopted in D3 design system is inspired by numerous features found in the traditional Malay house that area geared towards providing thermal comfort. With a direct dependence on nature for its resources and embodying a deep knowledge of ecological balances, the traditional Malay house is best reflecting the bioclimatic housing, using various ventilation and solar-control devices, and low-thermal-capacity building materials (Figure 20).

Apart from being well adapted to the environment, a very sophisticated addition system was also developed to allow the house to be extended in line with the growing needs of the user. Such an autonomous housing process, which is using self-help and mutual-help approaches, can throw some light on the development of a modern autonomous housing model. In general, the experiences gained from the traditional Malay house evidenced that an appropriate house in tropical country should provide for the following: (i) allow adequate ventilation for cooling and reduction of humidity; (ii) use building materials with low thermal capacity so that little heat is transmitted in to the house; (iii) control direct solar radiation; and (iv) control glare from the open sky and surrounding

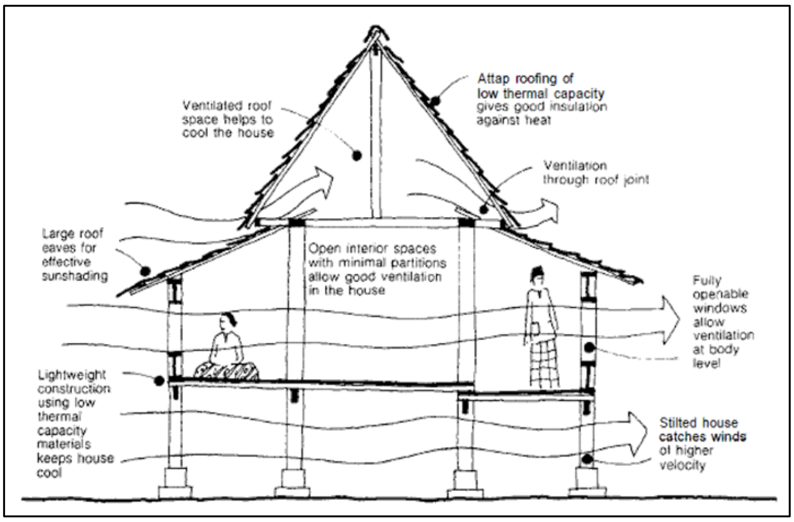

Figure 20: Climatic design of the traditional Malay house

In the case of D3 design system, cross ventilation is optimized by having an elongated dwelling shape together with minimal partitions or interior walls. This is not only allowing for easy passage of air and cross-ventilation, but also encouraging a good lighting of the interiors, as well as the flexible use of space (as described in Section 4.2 – Space Efficiency). Besides, the parallel arrangement of windows and the placement of high louvers on the internal walls of each bedroom also ensure adequate wind from outside flows through the house. By setting back the exterior walls 2.1m from the peripheral of the dwelling, no walls are exposed directly to the outdoor environment. Solar radiation is, thus, effectively controlled with the large thatched upper floor ceiling that acts as the overhang. Together with the installation of adjustable louvres or grilles as building façade, a barrier is created which not only provides good shading and protection against driving rain, but also to some extent maintain the quality of openness for ventilation and outdoor views. The setback also creates an open porch that makes possible the occupants to enjoy the open-air landscape. With careful planting or selection of vertical green, the open porch can function as a buffer corridor that aids in air circulation. The presence of air movement will then enhance the evaporative and convective cooling from the skin and can further increase the occupants' comfort. Glare, which is a major source of stress in the tropical climate, is effectively controlled by using louvres or grilles which break up large bright areas into tiny ones and yet allow the interiors to be lighted up; or by planting less reflective vegetation. Figure 21 illustrates the interior views of the D3 housing.

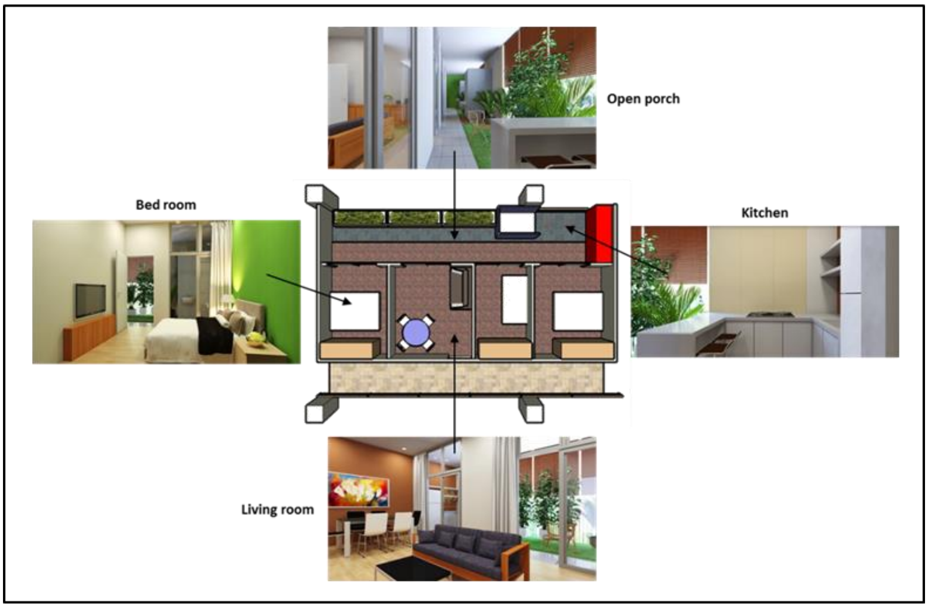

Figure 21: D3 plan and its interior views

The use of reinforced concrete skeleton structure ensures a lot of the qualities that aid flexibility in housing design, which then contribute to the housing affordability and sustainability. First, prefabrication construction allows for the design of flexible internal space layout are variable to accommodate different family structures. The constant improvement in prefabrication technology that supported by the incorporation of lightweight, durable, smooth edged, space efficient, and universally adopted specifications will ensure that mass housings remain affordable and sustainable for the long term. Second, the use of concrete as the main structural material contributes to a wide range of inherent benefits at no extra cost, such as its proven integral fire resistance, high levels of sound insulation, and robust finishes. Through its very nature, concrete provides robust surfaces for walls, partitions, columns, soffits and cladding that are easily sealed and free of ledges or joint details. All these may finally lead to the lower maintenance costs of the building while set in motion an efficient, cost effective and practical method for solving housing needs and overcrowding concerns in urban areas. However, realizing that the concrete industry is responsible for 10% of worldwide CO_2 emissions, the limited use of concrete is also to be considered in D3 design system. For example, complicated wall arrangements are avoided in D3 housing, so that less concrete wall panels are used as internal partition. Within a typical D3 dwelling unit, walls that facing the outdoor environment is eliminated with the installation of aluminium sliding doors. Since the infills of D3 housing are prefabricated materials that are subject to change, lightweight materials that have a low heat storage capacity such as gypsum board and plasterboard with insulation can always be used in replacement of the existing one. In short, flexibility in terms of architectural and construction process is the key strategy of sustainability in D3 housing.

5. Conclusion

Affordable housing in the past has never been designed to last. It was aimed to provide a short-term solution – maximum number of houses in the shortest possible time – to meet the urgent housing demand as if poverty and lack of affordable housing is a short-term problem. Although it is a government effort in providing adequate and affordable housing for the general population, the new contemporary household with its diversity of interior design needs in their consideration of future housing prototypes can no longer be ignored.

D3 design system introduced here can generate a better and cheaper habitat option through the application of existing science, technology and machine production capability. This concept is able to provide a new dimension in the design of comfortable and sustainable housing for the tropical country. The importance of this housing solution is reflected in its ability to solve the housing problems of especially the poor in a manner that is most appropriate to their socio-economic and cultural needs, by using environmental friendly method, contribute to the sustainable development of the construction industry, offers what people demand from a house and that they can live how they want to within it, by taking into account (i) the spatial and functional arrangement, (ii) the potential to expand spaces for increased occupant's usage, (iii) maximizing natural lighting and ventilation, (iv) the continuity of the traditional housing concepts into a modern contemporary residential development. On a much larger scale, D3 can facilitate the shift towards a higher quality housing in the country, and eventually create sustainable dwellings for everyone in anywhere in the country.

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Comprehensive Planning as a Platform for Environmental and Economic Development of Urban and Rural Areas

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Abstract

Urbanization in China is vast. It is foreseen that in the near future 75% of the population lives in the cities while the present share is less than 50%. The rapid urbanization has led to major problems concerning urban development and environment: Unsustainable planning, pollution and severe deterioration of ecosystems and poor quality of buildings, especially housing. Land use rights have been the engine of this development. However, revitalizing the economic model is the key to transformation of the Chinese cities. By adopting new approaches to urban policies can help to change the path China is on. Innovative urban planning and design is one of the key development areas for healthier cities and districts. At the same time it serves for both economic development and environment.

Co-operation between different stakeholders is mandatory in the development in sharing resources and possibilities. ChangJi area in Jilin province locates between two cities, Changchun and Jilin. Both cities have agreed to develop the area according to sustainable planning and design approaches. Re-thinking urban and rural structures, transport, agriculture, industrial development and industry structure and energy services aim at environmentally sound and livable urban areas and prosperous rural villages. The regional development in ChangJi focuses on piloting new methods for comprehensive and master planning and exploring possibilities on low carbon development. Environmental and economic development go hand in hand in the execution of strategies for opening up for international approaches, technological innovation, ecological city, intelligent city, urbanization system, social mode with planning as the platform. The first phase of this development was finalized in August 2015.

Keywords: Urban planning, environment, energy, emissions

1. Introduction

The urban and regional planning processes are tending to draw up optimal solutions. This will too often include solutions that are not correlating with the future reality and will further lead to very unsatisfying results; wrong investments in infrastructures or buildings, failing in function, identity and attraction among others. This can never be fully prevented but it can, however, be reduced by analyzing how the different solutions are dependent on certain circumstances.

Land use planning aims to promote economic community structure and sustainable land use. Goal is to ensure a safe, healthy, pleasant, socially functional living and working environment which provides for the needs of various population groups. China's urbanization is rapid. Roughly 300 million people will move to cities in about 25 years. In the urbanization process the land use planning has served more for the economic growth than for the basic aims of planning. The consequences include poorly planned residential areas, pollution due to increasing energy production and industrial activities, car transport and neglecting the environment sometimes totally.

The rapid urbanization has increased energy demand in China significantly. Energy use in public sector increased by 15% between 2006 and 2010. The increase in energy use in residential sector is estimated 150 – 300 % between 1996 and 2006 (Amecke H et. al., 2013). ChangJi area locates in the severe cold climate zone in North-East China, Figure 1. The annual energy consumption in present residential apartment buildings is estimated 150 – 250 kWh/m^2 and in public buildings 200 – 300 kWh/m^2 (CIUPD, 2015). Co-generated district heat and electricity are mainly produced with natural gas but the main share of electricity still with coal fired condensing power.

Climate Zones	Mean Monthly Temperature	
	Coldest	Hottest
Severe Cold	≤ -10 ^{0}C	≤ 25 ^{0}C
Cold	-10 - 0 ^{0}C	18-28 ^{0}C
HSCW	0- 10 ^{0}C	25 - 30 ^{0}C
HSWW	>10 ^{0}C	25 - 29 ^{0}C
Temperate	0 - 13 ^{0}F	18 - 25 ^{0}C

Figure 1. Climate zones in China (Shui & Li, 2012)

2. ChangJi regional plan

2.1 Planning process

Forests cover approximately 28% of the land area of ChangJiest. The forest areas are saved from construction. Agricultural land and forests together cover more than 50% of the total land area of about 4000 km^2. The population of ChangJi is expected to grow from the present 910 000 up to 5,1 million in less than 30 years. At the same time the widely spread out development with the isolated dwelling and job areas promote private car transport. This development has already contributed to construction of wide roads and huge parking areas; the walking distances are long and implementation of an efficient public transport is problematic.

The ChangJi planning project introduced the Finnish regional planning processes and tools to Chinese planning procedures. A Sino-Finnish group of experts from various planning and design fields analyzed the direct and indirect impacts of the plan. An environmental impact assessment tool was used for cross-evaluation of development themes and targets, Table 1. The aim of the tool is to find the needs for information and possible on-site investigations.

Table 1: Through cross-evaluation of planning themes and priority target areas in planning analyzing the environmental impacts and information were recognized that various fields needed further investigations.

Planning themes / *Planning targets*	*Descriptions for new development*	*Housing and living environment*	*Earth (soil and solid ground), water, air and climate*	*Flora and fauna, biodiversity and natural resources*	*Structure of built environment, infrastructure, energy and traffic*	*Visual image of the whole region cultural heritage, archaeology*	*Source of livelihood*	***Unsure issues and knowledge needs***
Protecting of nature								
Protecting of cultural heritage								
Water management								
Clean energy production								
Transportation network								
Recreational areas and routes								
Structure of built environment								
Further analysis and information needs								

The regional plan provides opportunities for a safe and healthy living environment that considers different population groups. Various provisions certify the protection of the built environment, landscape and natural values; and leave a sufficient number of areas for recreation.

2.2 Planning targets

The ChangJi regional land use plan takes into account the functionality, economy and ecological sustainability of the community structures. The regional land use plan bases on estimated phase-by-phase population growth. The phasing ensures the full utilization of the existing community structures.

The opportunities to re-organize traffic, especially public transport and non-motorized traffic are considered. The use of renewable energy and waste management, sufficient water supply and drainage are implemented in land use in an appropriate manner that is sustainable in terms of the environment, natural resources and economy.

The plan's impact on community structure, the built environment, nature, landscape, arrangement of traffic, especially public transportation, and technical services, economy, health, social circumstances and culture, and any other significant impacts should be analyzed. In ChangJi, the large-scale impact analysis was already carried out but the detailed information is missing. Ground water areas to be saved from construction activities and, e.g., areas with polluted land or noise pollution from road traffic should be mapped before the final regional plan.

Figure 2. The urbanization in ChangJi requires millions of square meters of new housing. New housing areas are often remote and not connected to existing towns. (Photo: Sanukka Lehtiö)

The regional plan of the area bases on development in three phases according to population growth. The 1st phase aims at construction in the existing areas for about 600 000 new inhabitants. The 2nd phase will expand the existing areas, and the 3rd phase brings completely new cities and towns into the development. This way the utilization of existing infrastructure is maximized and the distances stay short. The planning and construction will promote public transportation as the primary transport mode. The areas need to be dense enough with sufficient amount of population to support the public transportation.

A specific target is to plan a new Airport City as a landmark for the area including high-tech businesses, universities, exhibition center and residential areas.

Expansion of the existing areas may start only after the areas of the 1st phase are completed. These areas can expand the structure if the growth needs more land. The practical order of construction has to be evaluated by general planning so that the new construction strengthens the existing structure. As the development is rapid, reduction of environmental consequences gives priority for a well performing public transportation. The general planning aims also at increasing the share of renewable energy or carbon neutral energy, promotion of energy efficient buildings, sustainable use of materials and material savings, and efficient infrastructure. The development should guarantee sufficient basic services for the inhabitants (day care, school, health care, and other daily services).

Sustainable transport allows for the basic access and development needs of individuals, companies and society to be met safely and in a consistent way with regard to human and ecosystem health at the same time as it promotes equity within and between successive generations. Sustainable transport system on a large area requires co-operation with different regional and municipal actors. The ChangJi area includes both regional fast trains and slower local trains which are linked to local transport systems.

The planned sustainable transport system includes all the transport modes that are considered socially and environmentally friendly. This refers to transport modes that have low carbon emissions (close to zero) or are totally emission free. It includes walking, cycling and public transportation, but also environmentally friendly carpooling systems, car share, taxis (if low on CO2 emissions) and vehicles that cause low environmental impacts in use.

The most important route planning of the public transportation system bases on a trunk line system, where the strong public transport links form the root to the system connected to housing, work places and services. Secondly, feeder links are connected to the trunk line system. The level of connectivity depends on the planned population in different areas – the higher the population the better the connectivity. Land use planning connected to transport planning helps for the estimation of successful user levels for the public transportation, but also make the new housing areas more sustainable.

Figure 3 shows part of the regional plan as an example. The markings and symbols on the ChangJi regional plan are implemented from Finnish regional planning and general planning. Figure 4 shows an example of the expansion of existing structure. Areal markings present the various development zones and subareas for further investigation or to emphasize the further detail planning. Intended land use is presented with areal markings. Symbols are used for different sites, nodes and such land use where area need is minor. Line markings and symbols are used for roads, lines and pipes. The plan colors show the development targets (existing areas, new residential, commercial or industrial areas and other intended purpose of use. Dotted arrows show transport system development directions and, e.g., dotted circles urban development areas supported by existing public transport. Different layers in the plan include infrastructures, transportation networks waste management centers with energy production facilities etc.

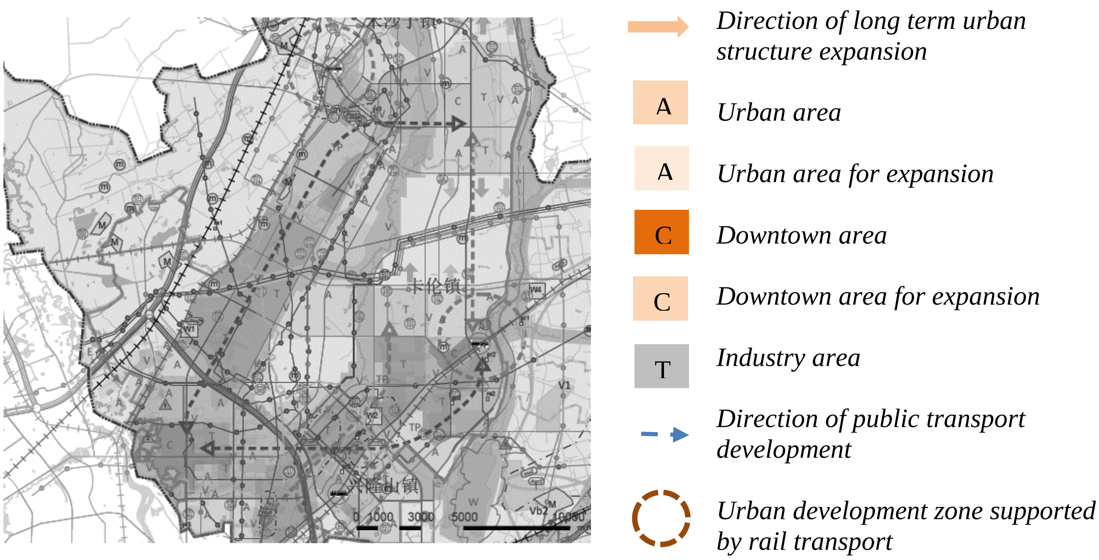

Figure 3. Example of the plan and plan markings (Architect Sanukka Lehtiö)

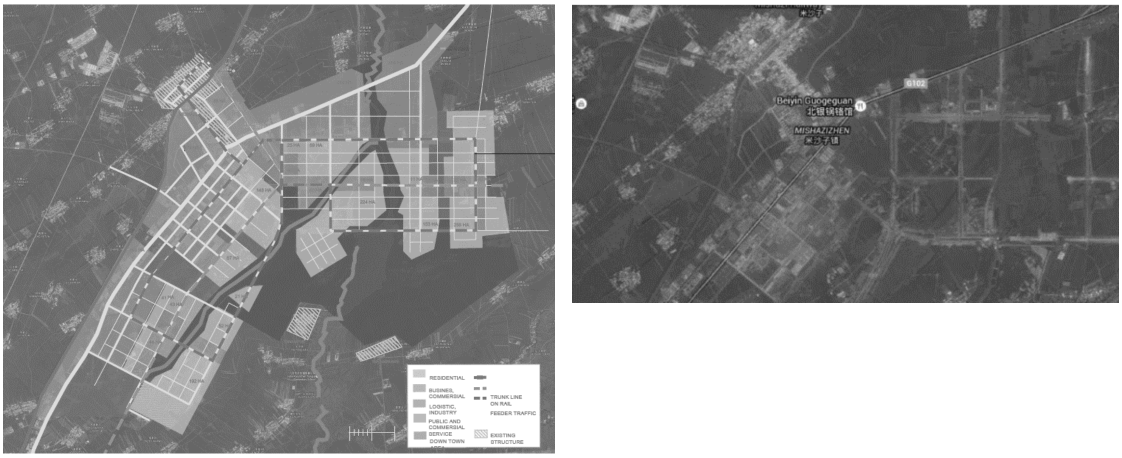

Figure 4. Planned expansion of an existing area (Architect Anna Brunow)

The target of regional level plan of ChangJi area is to be the guideline for the sustainable land use. There is a particular need to rely the strengths of each area or district in developing regional structures, to promote the creation of networks between the areas or regions, to agree on specialization, and to create particular development zones. An efficient utilization of existing structures will also improve the economy. The quality of the living environment is an important issue with a view to ecological sustainability and prevention of significant environmental damage. The volume of traffic and division into different modes of transport, energy consumption and the cost of infrastructure are largely determined by the structure on community in general planning.

3. Sustainable energy

3.1 Energy demand

The energy demand analysis of the whole ChangJi area bases on present population and estimated growth in different development phases. The population growth from 900 000 up to 5,1 million people will altogether require 170 million m^2 new residential buildings and 80 million m^2 commercial, office and public buildings. There is no exact data on building energy use available for North-East China. Therefore, reference information (collected by Paiho et al., 2013) was used for the estimations, Table 2. The energy demand of the ChangJi area excludes energy use in the industrial processes.

Building energy use in China (Paiho et al., 2013).

Energy application	*Building energy use kWh/m^2*
Rural areas	*7,5*
Northern cities for heating	*60 - 130*
Electricity use excluding heating	
• *Residential*	*10 – 30*
• *Typical public buildings*	*26 – 60*
• *Large public buildings*	*70 – 300*
• *Other*	*30*

Hot water heating Changji bases on various technologies. Residential buildings may have an apartment based electrical, natural gas water heater, or solar thermal systems. In office buildings, also separate boiler stations are used.

The total energy use (heating, cooling, electricity) excluding energy use in the industries will rise from the present 5,5 TWh up to 35 TWh. Approximately one third of the total is electricity. As the urbanization continues, household electricity use will increase more in relative terms than heating energy while the heat demand of new buildings is substantially lower than that of the present multi-story buildings. Heating season is fixed and it is presently 167 days per year. The estimate includes phase-by-phase improvement of energy efficiency of buildings and development of passive and solar districts.

Passive house is a voluntary approach to design and build an energy efficient building. There are several different definitions for a passive house in Europe. The original definition comes from Germany. The climate of Germany is quite mild compared to North-East China. The winter climate of ChangJi is comparable to Central Finland although with higher solar potential. The energy demand of a passive district or neighborhood bases on the following assumptions:

- Space heating demand 25 kWh/m^2
- Hot water heating demand 25 kWh/m^2
- Electricity demand 30 kWh/m^2.

3.2 Energy mapping

The energy plan for the district includes implementation of efficient technologies for energy production according to energy demand. There are two key issues in the energy plan: Minimized energy consumption of the district, and efficient renewable or carbon neutral production for clean energy. The energy plan includes all the energy that is needed in the district. Key element in an energy plan is energy mapping to define feasible local energy sources. The energy mapping supports the entire city design and usage process. Figure 5 shows the energy resources that can be utilized in ChangJi development.

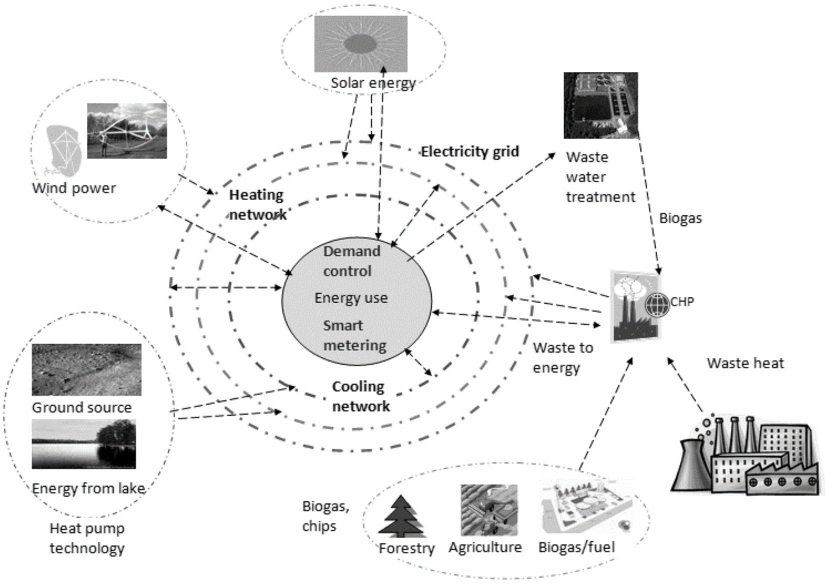

Figure 5. Feasible energy sources for ChangJi

The ChangJi energy map shows the potential sources to cover the energy demand. Basically the energy services depend on the location of the energy use, Figure 6. Rural villages and small towns are optimal for distributed energy sources whereas cities can utilize both centralized and distributed systems. The ChangJi area lacks a proper waste management system. Waste incineration is one feasible system for large-scale CHP production.

The energy services are planned for multi-source mixed energy production. The energy production scheme depends on the population of the planning area and the possibility to combine areas under a common energy system. The systems are centralised, mixed or distributed systems.

Figure 6. Energy production schemes.

3.3 Energy services

Centralised energy production bases on co-generated heat and power CHP. Environmental consequences of the production need to be reduced by renewable or low carbon fuels. In large-scale facilities, the potential fuels are municipal waste and natural gas. Natural gas is used for co-fuel in the beginning of the burning process and for improving the energy efficiency of the process. The fuels for the reference waste incineration CHP plant in Vantaa, Finland, are 44% natural gas and 56% municipal waste for production efficiency of 95%.

The potential of waste to energy for the whole Changji area is approximately 10 - 20% of the total energy demand. The share can be increased by better energy efficiency of the buildings, more efficient waste collection especially from shops and service buildings and utilization of agricultural waste. However, agricultural waste is more suitable for micro CHP systems for villages.

Waste to energy facilities can be built in the 8 waste management centres in the area. Natural gas with existing delivery infrastructure is the primary alternative and more environmentally friendly fuel as coal. Coal fired condensing boiler power plants are the most inefficient power production facilities. These production facilities have efficiencies between 30 and 40%. CO2 emissions from the old Chinese production plants vary from 800 kg/MWh up to 1600 kg/MWh. The typical existing Chinese CHP facilities have efficiencies between 60 and 80%. A modern waste to energy CHP has an efficiency of 90 – 95% and thus would reduce emissions from energy production drastically.

The purpose of mixed energy production is to utilize multiple sources of energy in addition to large-scale production facilities. These combinations are suitable for towns and villages for improvement of energy infrastructure or for small villages to cover the whole energy demand. Such systems include:

- MicroCHP for power and heat
- Ground source energy for heating and cooling
- Water source energy for heating and cooling
- Solar power for electricity
- Solar thermal as stand-alone systems or integrated to district heating
- Wind power

The wind conditions in the region do not support large-scale wind power. Therefore, only local systems with capacities below 10 kW are feasible.

There is a wide range of microCHP systems with capacities for 3 – 3000 kW electricity and 15 – 12000 kW heat. Typical agricultural wastes in the region are corn stalk, straw and husk with an average energy content of 4 – 5 kWh/kg. Total amount of the residues for energy production is estimated 400000 – 500000 tonnes.

Ground source energy can be used for single buildings, group of buildings or as local district heating and cooling system. Typically, the system runs with heat pumps but it can serve as an energy storage as well. Figure 6 shows a principle of heat pump heating and cooling system for an apartment building. There are six heat well bored down to 200 m in the ground. The heat wells are located with 15 m distances for to prevent disturbance between the wells.

Water source or combined water and ground source system are feasible as well, Figures 7 and 8. Heat exchangers either at the bottom of a lake or on the ground can be used in water source. Water filled abandoned coalmine shafts can be used for heat storage and water source heating and cooling.

Solar power (PV) system varies from Building integrated PV to large solar power plants. Solar power can serve as distributed system for all developments. It are especially usable for cooling, as the load match is perfect.

Figure 7. Heat pump heating and cooling

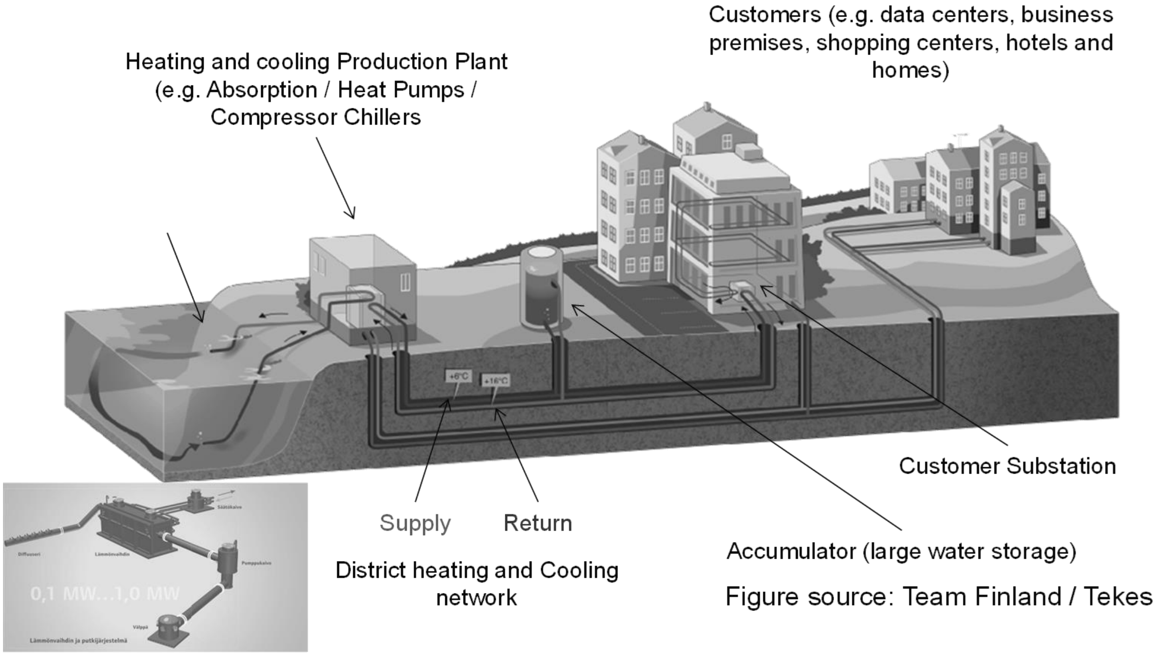

Figure 8. Water source heat pump heating and cooling

4. Conclusions

The first phase of the project produced models for further development. The environmental and economic targets set for the region are high surpassing the requirements set by the legislation and typical planning projects. Especially the to be planned Airport City can serve as a world-class example of Chinese ways and means to develop sustainable cities.

The risks involved in the development is the typical Chinese scheduling of projects and lacking knowhow in implementation of the various technologies. The hard-pressed progress may bypass the targets. It also inevitable that the city planners need to connect with technology providers and specialists to avoid misinterpretation in implementation of technologies.

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How can Sound Absorbing Tiles Make your Stairways Sound Better?

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Abstract

As many of us live in apartment buildings, we all know that the stairways are noisy and reverberant thus disturbing the residents. Currently, no study is available to show how the amount and positioning of attenuating material in stairways impacts on the acoustic environment of apartment blocks. This study demonstrates the effect of a two stage acoustic treatment carried out in a four-storey apartment building. Measurements and sound samples were taken at three separate stages to describe the development of acoustics: before, stage one and stage two. Before: no absorption. Stage one: A-Class sound absorption material was installed on the ceilings. Stage two: sound absorption tiles were added to the underside of the staircases. Measurements tell about very significant improvements in the stairway: Reverberation time (T20) shortened by 3 seconds from 3.6 to 0.6, Speech Transmission Index (STI) increased from 0.47 to 0.81 and Sound Pressure Level decreased by 10 dB. Additionally, the sound samples recorded at each stage revealed a huge change. From these results we can conclude, that this acoustical treatment was really worth doing. The stairway is now more peaceful, harmonious and makes the residents` lives feel a bit more luxurious.

Keywords: Acoustics, room acoustics, sound absorption, stairway noise, apartment building

1. Introduction

Many of us live in apartment buildings knowing, that the stairways are noisy and reverberant thus disturbing the residents. Currently, no study is available to show how the amount and positioning of absorption material in stairways impacts the acoustic environment of apartment blocks.

The purpose of this study, with acoustical measurements and sound samples, is to give useful information to housing companies and builders, how to make noisy stairways quieter and the residents satisfied. Furthermore, the measurements taken at three separate stages, tell us also how the sound absorption material affected the acoustical parameters.

This study and acoustical measurements were carried out in a housing cooperative Hakanmetsä, in Helsinki at 2014.

2. Measurements and sound samples

Measurements and sound samples were taken at three separate stages:

- before (no absorption)
- stage 1 (absorption on the ceilings)
- stage 2 (absorption tiles were added also to the underside of the staircases)

At stage 1 and 2 the room acoustical parameters were measured on two separate floors. The measurements were taken according to SFS-EN ISO 3382 [1-3] and IEC 60268-16 [4] standard.

At stage 1 (Figure 1) 28 m2 (which was also the entire surface area) of impact resistant A-Class sound absorption material (Ecophon Super G 35 mm) was installed on the ceilings of each landing. The ceiling was installed with suspension of 100 mm (overall depth of system, ods).

At stage 2 (Figure 1) the sound absorption tiles (Ecophon Super G 35 mm) were added 12 m2 (the entire surface area was 18 m2) to the underside of the staircases.

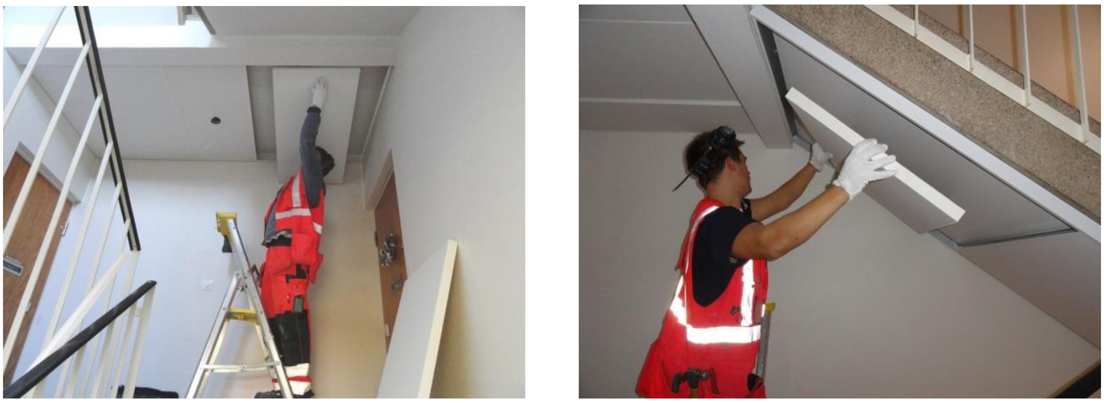

Figure 1: At stage 1 A-Class sound absorption material was installed on the ceilings (left) and at stage 2 sound absorption tiles were added to the underside of the staircases (right).

The measurements were performed by using impulse response method (test signal log-sweep, 10 s, 2 source and 6 microphone positions at each floor). The following acoustical parameters were calculated in octave bands (63 Hz – 8000 Hz) from measured impulse responses:

- Reverberation Time, T20(s)
- Sound Pressure Level, LAeq (dB)

- Speech Transmission Index, STI (values between 0 -1)

Speech Transmission Index value of 1 means that speech is perfectly intelligible. The closer the STI value approaches zero, the more information is lost.

In addition the Sound Pressure Level passing through the door from the stairway into the apartment, was measured at each stage by using reference noise (pink noise, LwA= 92,0 dB).

The sound samples in the stairway were digitally recorded (Olympus LS-5). Recorded samples were typical sounds in everyday life such as noisy children and a woman coming downstairs with high heel boots on. Additionally one sample was recorded by using a short sentence which was recorded earlier in an anechoic chamber. Then that sentence was played back in the stairway with Genelec 6010A loudspeaker and recorded at each stage like all sound samples were.

3. Measurement results

Figures 2 and 3 describe Reverberation Time T20 (s), figure 4 shows Speech Transmission Index (STI) and tables 1, 2 and 3 describe Sound Pressure Levels in different microphone positions. The stairway`s background noise level during measurements varied between LAeq = 30 – 35 dB.

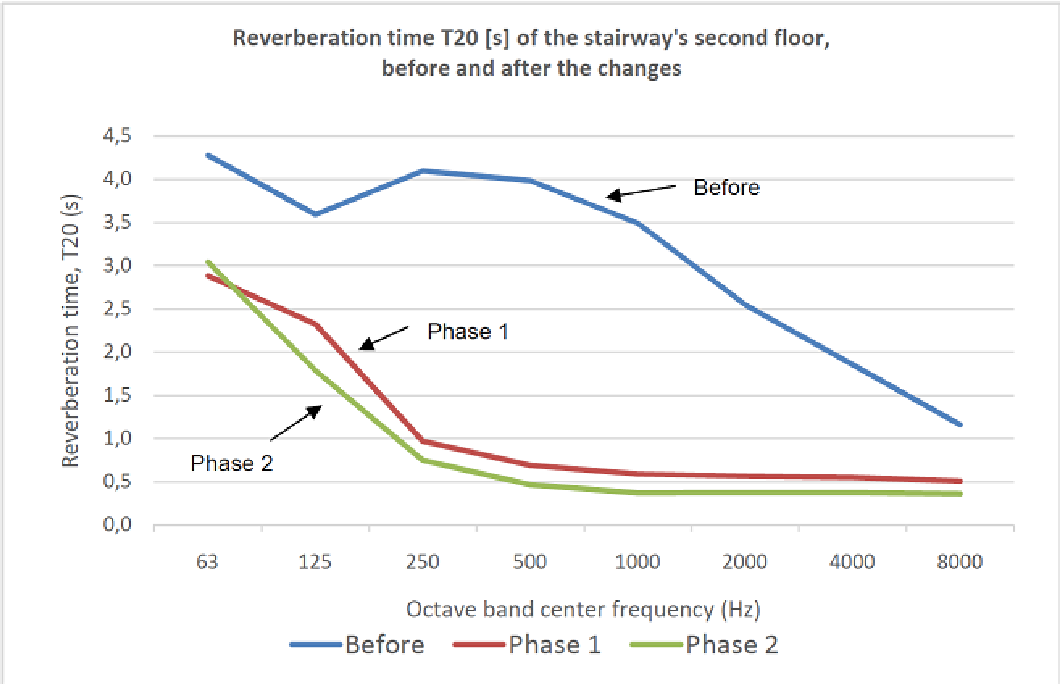

Figure 2. Reverberation Time T20 (s), (63 Hz – 8000 Hz) before and after each stage.

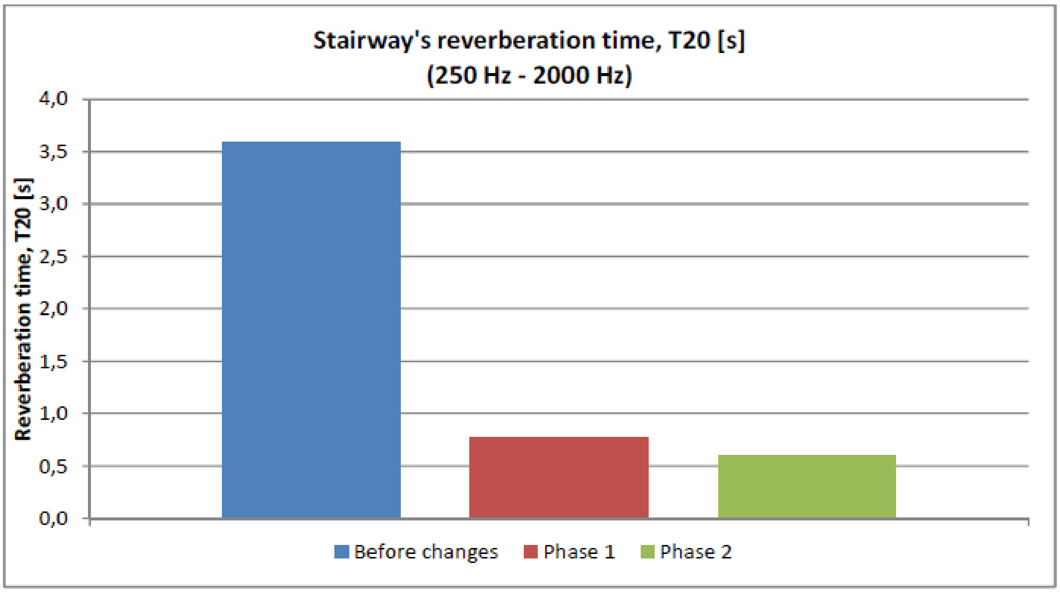

Figure 3. Reverberation Time T20 (s), (250 Hz – 2000 Hz) before and after.

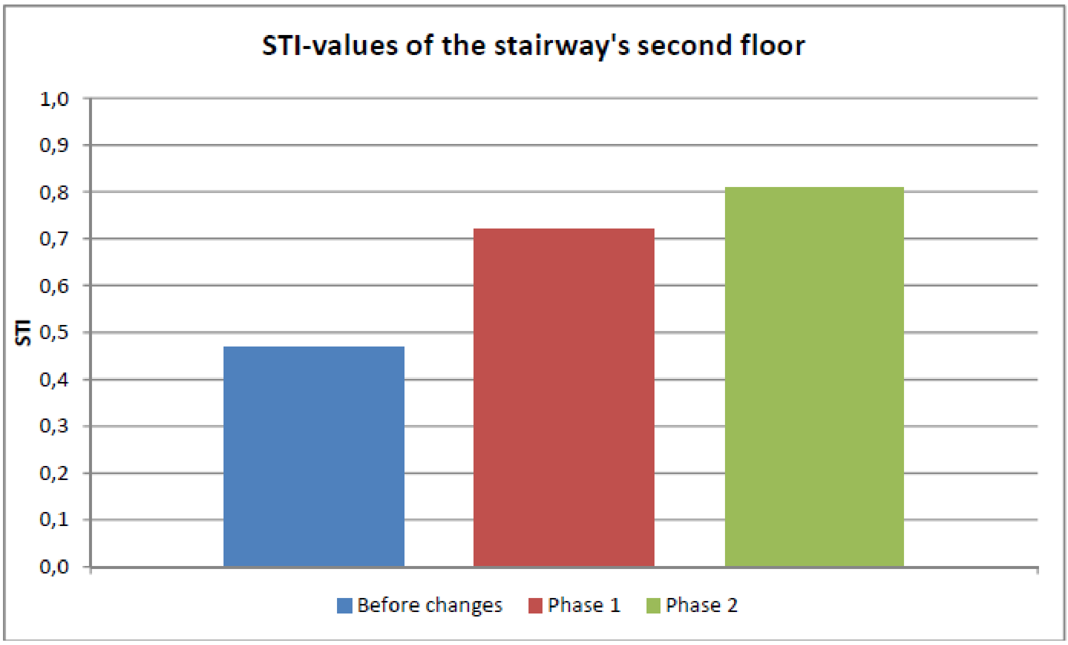

Figure 4. STI - values before and after.

Microphone position	Sound pressure level, $L_{A,eq}$ [dB]		
	Before	Phase 1	Phase 2
Floor 1.5	90	83	81
Floor 2.5	90	83	80

Table 1. Sound pressure levels of the reference noise (LwA = 92 dB). Loudspeaker is on the 2nd floor.

Microphone position	Sound pressure level, $L_{A,eq}$ [dB]		
	Before	Phase 1	Phase 2
Floor 4	80	63	57

Table 2. Sound pressure levels of the reference noise (LwA = 92 dB) at the top floor, when loudspeaker was on the ground floor.

Microphone position	Sound pressure level, $L_{A,eq}$ [dB]		
	Before	Phase 1	Phase 2
Floor 3	91	81	81
Floor 4	93	84	83
Inside an apartment (2nd floor), outer door closed, inner door open	61	48	45

Table 3. Sound pressure levels of the reference noise (LwA = 92 dB). Loudspeaker is on the 3.5 floor.

Space	Reverberation time, see tables 1-3 and 5-7	The National Building Code of Finland, part C1:1998 requirement (500Hz - 4000Hz)
Stairway, before	Does not fulfill the requirements	≤ 1.3 s
Stairway, phase 1	Fulfills the requirements	≤ 1.3 s
Stairway, phase 2	Fulfills the requirements	≤ 1.3 s

Table 4. The measured reverberation times are compared to the requirements of the National Building Code of Finland, part C1:1998 [5].

4. Discussion

In figures 3 and 4 we can see the biggest change occurred in phase 1. Before changes the Reverberation time was 3.6 seconds, after Phase 1 it was 0.8 s. and after Phase 2 it was 0.6 s. Owing to dramatically shortened Reverberation Time, whenever noise comes up in the stairway, it will almost immediately fade out as well.

Figure 4 diagram prooves out that adding absorption enhances also the STI-value. This means improved speech clarity. Thanks to that, whenever people meet in the stairway, they start to talk with a lower sound level than they did earlier. And as a consequence, talking in the stairway is hardly audible anymore inside the apartment.

Table 1 demonstrates that after phase 1 the sound pressure level decreased 7 dB and after phase 2 it dropped 3 dB more, altogether 10 dB. This is such a big reduction, that people experience the sound strength only as half what it was earlier.

From Table 2 we can see that after phase 1 the sound pressure level from ground floor to floor 4 decreased 17 dB, which is really huge reduction. After phase 2 the sound pressure level dropped still 6 dB more, so the total reduction was as much as 23 dB.

Table 3 shows clearly, that absorption material decreases effectively the sounds coming from the stairway inside the apartment. After phase 2 the sound pressure level dropped even 16 dB.

In table 4 we can see that the reverberation time meets the requirements of the National Building Code of Finland already after phase 1.

5. Conclusions

From these results we can conclude, that this acoustical treatment was really worth doing and meets the requirements of Finnish National Building Code, C1:1998 even after stage 1. The sound absorption, which was installed on the ceilings of each landing, already gave the residents good protection from noise coming from stairways. But undoubtedly, adding the sound absorption tiles also under the staircases decreased the noise disturbance even more, thus making living in the apartment flats even more peaceful.

The stairway is now more comfortable, harmonious and makes the residents` lives feel a bit more luxurious in this noisy world we are living in.

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[4] IEC 60268-16: Sound system equipment – Part 16: Objective rating of speech intelligibility by speech transmission index.

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The Development of a Generic Design for Primary Healthcare Facilities in South Africa

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Abstract

Primary healthcare (PHC) service delivery is severely hampered by lack of, and poor quality infrastructure. In many cases the physical infrastructure at clinics is old, inadequate and in some cases not suitable for use. The provision of services (water, sanitation and electricity) is in many cases not adequate, especially in rural areas. This study developed a generic design for modular conventional clinics and for rapid deployment clinics. Researched, patient-centric service delivery and workflow have been used as major drivers for design configuration. Clinics have been organised to accommodate three patient streams: namely chronic services, acute services, preventive and promotive services. An optimal patient flow pattern was determined and the infrastructure norms and standard guidelines developed by the South African National Department of Health were considered. The space requirements were derived from the design terms of reference and the PHC norms and standards. Two methods of construction were assumed, i.e. traditional brick and mortar, and Innovative Building Technology (IBT) system with the latter being an insulated panelised system. A conceptual design for a generic, basic clinic for use in South Africa is developed. The conceptual design is modular based and allows for additional functions to be added as and when required. The design is both flexible and adaptable. It is highly likely that the clinic may function off-grid under certain circumstances.

Keywords: health infrastructure, basic clinic, building services

1. Introduction

Recognising that historical funding models have entrenched inequity and undermined affordability of healthcare services in South Africa, the South African National Department of Health has introduced the National Health Insurance (NHI) scheme to integrate healthcare services. This requires a "re-engineered approach to providing primary health care (PHC) using a population based approach for the delivery of PHC outreach service to the uninsured population of South Africa" (NDoH 2011:2). Major implications, such as shifting to increased community outreach services (as opposed to facility-based services), and emerging requirements for information networks (for NHI management) are foreseen. As infrastructure is integral to the delivery of healthcare services, these organisational transformations provide an extraordinary opportunity for science, engineering and technology input across the life cycle of primary healthcare facilities.

Primary healthcare (PHC) service delivery is severely hampered by lack of, and poor quality infrastructure. In many cases the physical infrastructure at clinics is old, inadequate and in some cases not suitable for use. The provision of services (water, sanitation and electricity) is in many cases not adequate, especially in rural areas. In addition to this, no standardised clinic design and lifecycle management tools currently exist. This results in poor infrastructural investment decision making, problematic procurement processes and practices and poor maintenance of existing facilities. Re-engineering of primary healthcare as the main mechanism of healthcare service delivery requires urgent intervention at the infrastructure level.

This study developed a generic design for modular conventional clinics and for rapid deployment clinics. The study does not evaluate materials that could be used or undertake a comparative analysis between materials. This study focuses on the components underlined in Chapter 3.

2. Research approach and methodology

Designers of buildings are often unable to explain how they arrived at a design solution beyond "that his or her reason for making a particular design decision is based on a 'feeling' or 'intuition'" (Wiggins 1989:1). However, increasing building complexity and sustainability imperatives require a "new decision model" (Mendler and Odell 2000:19; CIB 2009:4). Mendler and Odell (2009:24) argue that this new approach "requires some focused research time" and that sustainable design "requires the design team to consider a larger number of issues in the decision-making process" with "supplemental research to understand the environmental impacts associated with design options and to identify preferred approaches". It can be argued that what is being proposed is the use of grounded theory being "a set of rigorous research procedures leading to the emergence of conceptual categories" which may make use of both quantitative and qualitative data (GTI 2015).

The research approach to the study was based on the South African Institute of Architects (SAIA) *Plan of Work* as proposed in their Practice Manual (SAIA 1.1211:3). The Plan of Work consists of five work stages namely:

Stage 0 – Inception briefing and appointment of consultants
Stage 1 – Appraisal and definition of the project
Stage 2 – Design concept
Stage 3 – Design development
Stage 4 – Technical documentation and approvals
Stage 5 – Contract and administration and inspections

This study includes only Stages 1 and 2.

A reading of the practice manual Plan of Work may suggest that the two work stages actually imply a research-based approach to design: however the text is biased towards meeting the programmatic goals of the client rather than researching the full range of performance requirements of the building project.

The research method used by the study is Ernst Neufert: Architects' Data (ed. Herz, 1970) as it suggests a methodology closer to research-based design and uses qualitative and quantitative research data. In the section appropriately titled 'Design Method' (Herz, 1970:30) it is recommended that the “work starts with the preparation of an exhaustive brief” and lists information that must be known before planning begins. The required information includes site (location, environment, size, levels, services, fixtures); space requirements (areas, heights, positioning and relationship); dimensions of existing furniture; finance (site acquisition, legal fees, mortgages, etc.,); proposed method of construction (brick, frame construction, sloping roof, flat roof); and all the legal facts. A questionnaire is included in this approach which includes questions relating to the client, fees and agreements, persons and firms connected with the project, general, project, basic design factors, technical fact finding, records and preliminary investigations, preliminaries, and activities and events. The question is a combination of quantitative data (e.g., type of topsoil) and qualitative (e.g., what is the attitude of the town planning officer towards architecture).

It then recommends that the individual units are analysed, drawn to scale and put provisionally into groups. The relationships of rooms to each other and to the sun are analysed (Herz 1970:30). What follows is critical: ‘at this stage an “idea” in 3-dimensions will emerge’ and ‘instead of starting to design at this stage, explore the various means of access, the prevailing wind, tree growth, contours, aspect, neighbourhood, then finalise the positioning of your building, relating it to tentative landscaping, etc.’ Finally, it recommends that one ‘try out several solutions to explore all possibilities and use their pros and cons for searching examination.’ Based on the foregoing it argues that the ‘idea now becomes clearer and the real picture of the building emerges’.

What is described in Neufert’s text is grounded theory, a research method that aims to allow the theory (in this case the idea) to emerge from the research. In fact, an early attempt to ‘design’ is discouraged to allow theory testing to be done from which a ‘design’ emerges. Further evidence to support this theory is found later: Neufert recommends that after the completion of the preliminary design a pause is taken to ‘help get rid of preconceived ideas and undigested brain-waves, and to allow time for other short-comings of the design to be revealed not least in discussions with staff and client’ (Herz 1970:30).

To further aid this research method Barry’s Introduction to Construction of Buildings (Emmitt and Gorse, 2005) is used to construct a useful methodology for considering the construction of buildings by breaking the construction process down into five basic components, namely; sub-structure, super-structure, roof assembly, services, and finishes. Each of these components can be further sub-divided into sub-components such as windows and doors for super-structure. This approach has been used with some success in previous experimental studies undertaken by the CSIR at its Innovation Site in Pretoria (van Wyk, 2009; de Villiers 2011).

3. Research question and sub-questions

The primary research question is the following:

How and in what way can Science, Engineering and Technology (SET) give input into the development of a <u>standardised design terms of reference</u>, based on a <u>modular approach</u>, for a basic clinic that will comply with primary healthcare (PHC) <u>norms and standards</u> while delivering improvements in indoor environmental quality, reductions in <u>non-renewable resource use</u>, improved construction quality, reduced construction time, reduced construction cost, and support resilient human settlements in a sustainable and economical manner?

In order to answer the primary research question, a number of sub-questions must be answered. Not all of these sub-questions are addressed in this paper: the sub-questions addressed in this paper are underlined in the primary research question.

4. Standardised design terms of reference

Researched, patient-centric service delivery and workflow have been used as major drivers for design configuration. Clinics have been organised to accommodate three patient streams: namely chronic services, acute services, preventive and promotive services. Care is taken to provide general zoning which allows for future expansion, particularly for specialised services, community outreach services, and the patient streams, where greatest future growth is anticipated.

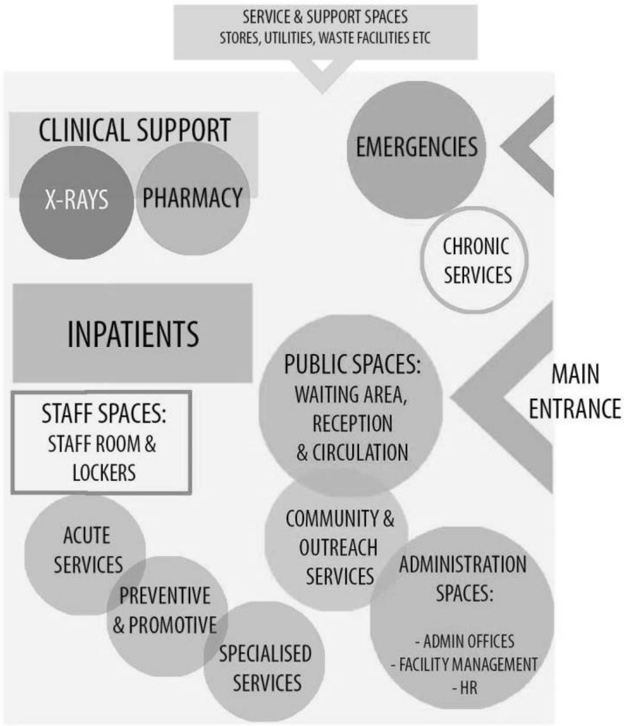

Figure 1: General zoning

4.1 General ambulant patients

Patients enter the clinic site through a controlled entrance at the security guardhouse. From here they proceed to the front entrance of the clinic building. Upon entering, patients are triaged and except for emergency cases, register at the front reception desk. Thereafter they remain in the main waiting area until called by the nurse who, where necessary, takes the patients' details, blood pressure and possibly their weight. Patients required to give a urine sample for testing will use the universally accessible ablution facility adjacent to the sample room. Having been attended to by the nurse, patients are directed to wait in the sub waiting area before proceeding to the relevant room. After consultation or counselling, patients either go to the treatment room for further assistance, collect medication from the dispensary or leave the building.

4.2 Emergency patients

Patients requiring urgent care are triaged on arrival and are immediately directed to the emergency room where they are attended to by the nurse who may arrange to transfer the patient to a referral hospital.

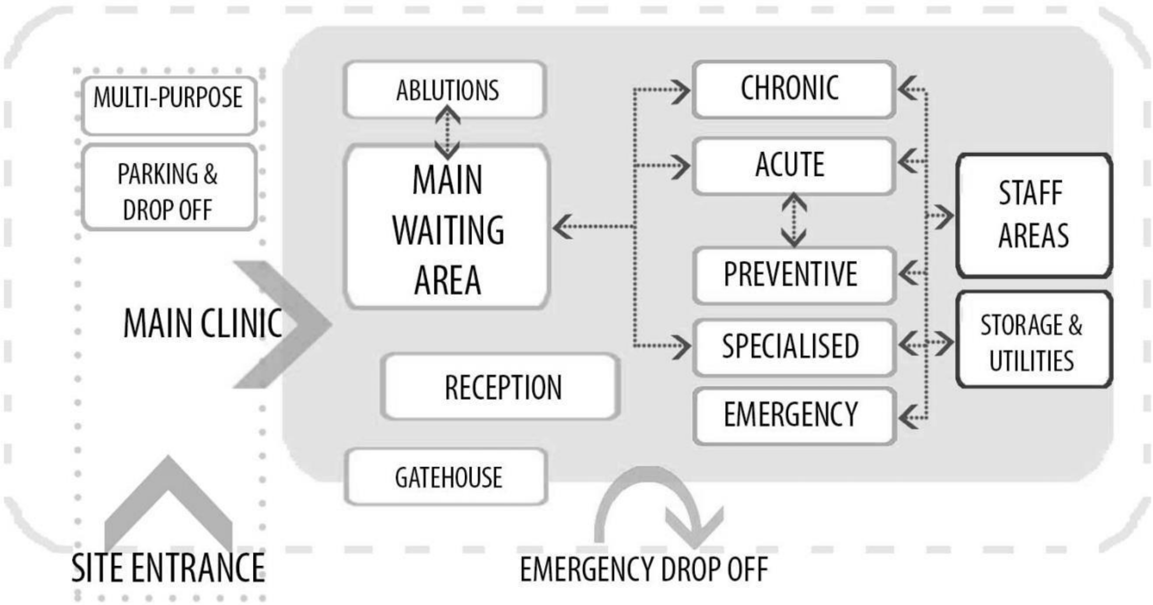

Figure 2: Functional Relationships for Basic Clinic

5. Norms and Standards

The development of guidelines, norms and standards formed part of a National Department of Health project called Infrastructure Unit Systems Support (IUSS Project). IUSS was a structured collaboration between the National Department of Health (NDoH), the Development Bank of Southern Africa (DBSA), the Council for Scientific and Industrial Research (CSIR), and other stakeholders with the shared objective of optimizing the acquisition and management of South Africa’s public healthcare infrastructure throughout the infrastructure’s lifecycle.

The development of guidelines, norms and standards has been structured into work package sets and 45 work packages including facilities and departments, regulations, engineering services, infection prevention and control, equipment, sustainability and environment, tomorrow’s healthcare environments, have been identified. A development programme has been initiated providing for input focused workshops and output focused task groups developing new draft documents.

The draft norms and standards developed for the IUSS Project have been used to prepare the concept design.

6. Modular requirements

The intention is to develop a generic basic clinic design that can be constructed using either conventional building technology (brick and mortar) or innovative building technologies (IBTs).

In both instances use has been made of a modular approach based on a modular dimension (modules of 300 mm) creating a standardised unit capable of being fitted out to serve the specific function, and have interchangeable components (doors, windows, etc.). This approach was taken to ensure that the clinic was flexible enough to adapt to local conditions and could be scaled-up to meet local needs over time. The modular approach was also applied to the design and selection of off-grid utility services, especially electricity generation (solar and wind) and sanitation.

Having regard for the patient flow and norms and standards a modular dimension of 4.2m x 3.0m created the most flexibility. In the conventional building technology application the foundations will be conventional concrete foundations and slab: for the IBT application a steel chassis will be constructed with steel supporting super-structure and roof. The IBT module will be manufactured in the factory and transported to the site where it will be placed on supporting stub columns (brick or concrete).

In both IBT cases the interior can be equipped according to its intended use either off-site, or on-site, depending on the circumstances of the specific project.

7. Non-renewable resource reduction

Buildings and their operations depend on the continued supply of services such as water, sanitation and electricity. However, service delivery failures do occur whether due to design and operational factors such as regular maintenance or system failure. An assessment of infrastructure in South Africa in 2011 noted that “the quality and reliability of basic infrastructure serving the majority of our citizens is poor and, in many places, getting worse” (SAICE 2011:5). Of the three services targeted in the study namely, electricity, water and sanitation, the infrastructure report card finds that there has been “further deterioration in the ageing bulk water infrastructure portfolio as a result of insufficient maintenance and neglect of ongoing capital renewal” with water quality identified as “a serious problem, especially outside metros” (SAICE 2011:6), “serious problems with management of many waste water (sewage) treatment works” including “waste water leakage and spillage, especially into major rivers” and that the backlog in sanitation “increasing owing to unsustainable infrastructure”, and with regard to electricity that “in many areas infrastructure is ageing and/or overloaded” with municipal infrastructure in particular described as “below standard and poorly maintained (SAICE 2011:8).

Critical services such as primary healthcare rely on a stable service provision especially with regard to water, sanitation, electricity and the proper storage of drugs. Innovative infrastructure service technologies are technologies that can be implemented to provide alternative methods for securing a stable infrastructure service.

One of the strategies that can be employed to ensure an uninterrupted service is to reduce the building’s exposure to municipal services through the use of innovative infrastructure technologies. This has a number of benefits: first, it assists the building to adapt to major perturbations and events without a disruption in service delivery; second, reducing the building’s dependence on municipal services also reduces the operational costs of the building; and third, innovative infrastructure technologies are less resource intensive, especially with regard to the water/energy nexus, as they operate at the site of use, thereby reducing the requirement to move bulk services around.

7.1 Energy

It is intended that all the power required to operate the building should be generated on site allowing the building to function off-grid. As the building is to be used primarily as a clinic facility, the design demand should be calculated on maximum demand when the building is being fully utilised. Based on an analysis of the expected demand for electricity, a load profile was generated using the expected utilisation of appliances. The daily average power consumption of the clinic was calculated as 19,8kWh/day, i.e., an electricity generation system that is sized to produce 20kWh/day is required. The cost of a 20 kWh/day PV system for a sunny but wind poor location such as CSIR Pretoria campus ranges from R291,718.00 to R319,000.00 inclusive of VAT and requires 48m^2 of PV panels. The cost of a 20 kWh/day wind system for a windy location such as the East London Industrial Development Zone is R287,854.56 inclusive of VAT and requires 2 x 3kW wind turbines. Preliminary investigations indicate that a wind system is slightly cheaper than a PV only system, but is site dependent on the availability of wind and solar resources.

The following three options were recommended, each one capable of being up-scaled using the modular approach, for the clinic to function off-grid:

- Photovoltaic (PV) based system for the generation of electricity for sunny but wind free sites such as CSIR Pretoria campus.
- Wind based system for the generation of electricity for windy sites such as the East London Industrial Development Zone.
- Liquid Petroleum Gas (LPG) for heating and cooking.

7.2 Water

Standard setting for water and sanitation at clinics takes place within specific dimensions of quality - acceptability, accessibility, appropriateness, continuity, effectiveness, efficiency, equity, interpersonal relations, technical competence and safety. Different kinds of facilities will be required to provide the same services in different situations, for example services to clinics in remote rural areas will be provided through different facilities compared to polyclinics in high-density urban areas. Therefore national standards about facilities and staffing norms for clinics are not set. The National Department of Health defines what services and facilities are required to best meet the health needs of the nation, i.e. a clinic must have a supply of electricity, running potable water and proper sanitation, which means adequate number of toilets for staff and users in working order and accessible to wheelchairs, but do not specify how the services are to be provided and at what level the standards should be met.

Clinics, especially in rural areas, tend to become a social gathering point for the communities, mainly because of the general lack of infrastructure (electricity, water sanitation, roads, transport, etc) compared to clinics in urban areas. The person-load per day of rural clinics is therefore generally higher than that of urban clinics, as patients normally have the responsibility of caring for a number of children/family, or are too old, or disabled, to visit the clinic by themselves and need assistance, and as transport services are infrequent, long waiting periods.

Water conservation includes rainwater harvesting and treatment, and waste water recycling systems. Rainwater harvesting, in its essence, is the collection, conveyance and storage of rainwater. The scope, method, technologies, system complexity, purpose and end use vary from rain barrels for garden irrigation in urban areas, to large-scale collection of rainwater for all domestic uses.

In the case of this clinic design, rainwater is collected and stored in rainwater tanks: the tank or tanks can either be positioned on the ground close to the downpipes or in a single more ideally situated location, or buried in the ground as a subterranean tank. The number of people being served at the proposed clinic estimated at 1400 per month. The recommended water allowance per person per day use as recommended in the World Health Organization guidelines is 2 to 6l/d (WHO 2011:9.2). The water demand per month will range between a lower limit (1400 x 2 x 22 = 61600) and the upper limit (1400 x 6 x 22 = 184800). No provision is made for urinals and the water closets (wc's) are based on closed-system units described more fully under sanitation. Using Pretoria as the location of the clinic, and given the area of the building (300 m^2) and the annual rainfall (732mm) (Climatemps 2015) the expected maximum annual harvested water supply will be 219600 liters which is insufficient to meet the needs of the clinic. Additional water sources will be required including sustainable urban drainage systems (SUDS) which will be very site-specific.

7.3 Sanitation

Lack of sanitation in healthcare facilities appears to be a more serious matter than lack of water supply. Many factors influence the choice of sanitation technology that meets the requirements for adequate sanitation at clinics, and these include:

- Cost effective provision of services and accessible to maintenance and servicing of the toilet by local community members.
- Management - The choice of system that is sustainable over the years.
- Use of the local contractors targeting youth and women.
- Sustainability of employment for the operation and maintenance.
- Improvements to health.

If a water supply is available, a conventional water-borne system can be selected, but many rural clinics have an erratic water supply that is inappropriate for the provision of water-borne sewage systems. In the case of insufficient water supply the choice of sanitation facility is usually limited to a dry on-site system, whether a VIP or waterless system, or a closed-loop recycling system. On-site, close-loop system, flush toilet waterborne sanitation systems are available from a number of companies and manufacturers in South Africa. They are ideal sanitation solutions in cases where only dry sanitation was an option. Generally in these systems naturally-occurring micro-organisms (bacteria) are selected as a biological additive to the digester tank. The biological process occurring in the digester tank converts raw sewage into re-usable filtered water, ready for re-use to the toilet cistern for flushing. A solar panel is installed to power the recycle pump in the digester unit. The product can be supplied as a pre-assembled unit or it can be supplied in a kit form to be assembled on site. This makes the transport of the unit much easier and no heavy equipment is needed for installation. The parts can easily be handled and carried by hand.

8. Concept design

From the above data a concept design was generated. Using the design approach advocated by Neufert (Herz 1970:30), the design commenced by the preparation of an "exhaustive brief". This was obtained from the patient flows and the PHC norms and standards. No specific site was identified so the assumption was made that the site is accessible on all sides, is flat, and is north orientated. It was assumed that no services are available. The space requirements were derived from the design terms of reference and the PHC norms and standards. It was assumed that finance would be made available from Government. Two methods of construction were assumed, i.e. traditional brick and mortar, and Innovative Building Technology (IBT) system with the latter being an insulated panelised system.

The second phase of the concept design analysed all the individual units, drew these to scale, and arranged them in groups (see the plan sketch in Figure 3). From the 2-dimensional floor plan a section was generated (see section in Figure 2). This was the outcome of a number of “solutions to explore all possibilities and use their pros and cons for searching examination” (Herz 1970:30). A number of assumptions were used to generate the section. First, the building is raised to enable displacement ventilation to occur. An overarching roof was generated to provide additional shade to the rooms below, and to enable the extraction of air from the rooms. Preliminary ideas around the fitting of photovoltaic panels and solar water heaters are explored, as well the fitting of a rainwater harvesting system. The potential to open and shut the rooms is also explored to aid ventilation and security after hours. The section was the first attempt of a “real picture of the building emerging”. From the plan and the section a 3-dimensional sketch could be generated (see Figure 3).

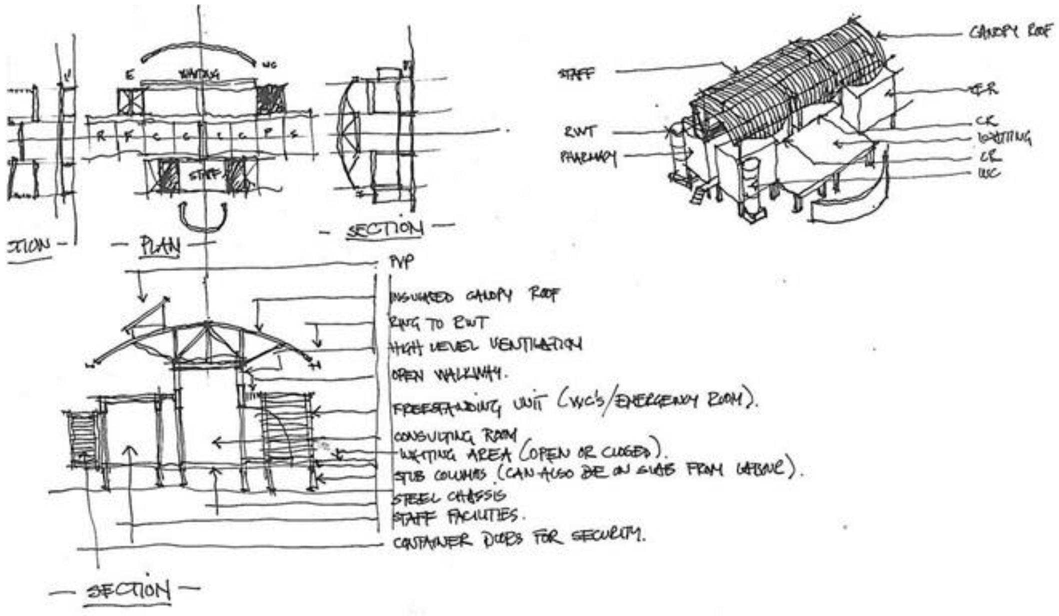

Figure 3: Design sketch

As already indicated above, this sketch was the outcome of a number of iterations. Further to Neufert, “a pause is taken to help rid of preconceived ideas and undigested brain-waves, and to allow time for other short-comings of the design to be revealed not least in discussions with staff and client (Hertz 1970:30).

The outcome of this period of reflection was the further development of the design as shown in Figure 4.

Figure 4: Conceptual design for basic clinic

9. Conclusion

The study developed the basis for a generic basic clinic for application in South Africa. The conceptual design is modular based and could be constructed using either conventional building technologies (brick and mortar) or Innovative Building Technologies (IBTs). The conceptual design also allows for additional functions and its supporting infrastructure to be added as and when required. The design is therefore both flexible (the modularity allows rooms to be used for different functions should the requirements and needs change) and adaptable (may be extended in a number of ways).

The research finds that it is highly likely that the clinic may function off-grid under certain circumstances with the exception of water where approximately half of the required demand can be met off-grid. These circumstances relate to climatic conditions, topography of the site, location of the site, ground conditions, and the extent of the site.

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Modelling the Process of Innovation in Construction: Framework and Research Agenda

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Abstract

Increasing demand and expectations from clients coupled with the need to compete necessitate that Construction firms innovate to gain competitive advantage. Despite the labelling of the construction industry as less innovative by a number of reviews and comparative studies, innovation in the industry occurs at a high rate often hidden on projects. A better understanding of such innovation processes could be crucial for the management and implementation of innovations. However, current innovation literature in construction is focused on adoption and diffusion of innovations sourced from manufacturers and leading suppliers. Attempts at innovation processes have often come from generic models of how innovation occurs in construction based on theoretical speculation rather than empirical observation of the processes of specific innovations. This has resulted in a lack of understanding of the dynamics and processes by which innovation occurs in construction and an inadequate process theory for construction innovation. This paper presents a framework and agenda for exploring the trajectory of innovations in construction adapting concepts from the Minnesota innovation studies framework (MISF). The MISF suggests that the process of innovation involve five concepts: ideas, people, transactions, context, process and outcomes. The paper also draws on organizational ambidexterity theory and the intellectual capital based view, proposing a framework that is an adaptation of MISF. The proposed framework focuses on innovative ideas as being explorative or exploitative; people in terms of human capital; transactions shaped by social capital and context as organizational capital; the process as the sequence or stages of innovation generation or adoption for implementation and outcomes as the consequences of the innovation process for projects and firms. The paper draws on an ongoing research that aims to develop process theory for construction innovation, which can potentially provide a model of the innovation process in construction based on real examples of how processes of specific innovations unfold.

Keywords: Innovation Process, Construction Innovation, exploration, exploitation

1. Introduction

The construction industry has been described as an important sector contributing significantly to the socio-economic development of nations. However, the industry has been criticized for its poor performance (Harty, 2008; Winch, 1998). The answer to the industry's challenges is considered to lie in the development of a stronger innovative culture to improve the rate and quality of innovation across the industry (Harty, 2008; Manley, 2008). The unique nature of projects necessitates that construction firms explore new innovative solutions or exploit existing capabilities to solve problems. However, knowledge of the processes of exploration and exploitation of innovative ideas in construction is limited. Most studies on exploration and exploitation have been conducted in high technology intensive industries (e.g. He & Wong, 2004; Katila & Ahuja, 2002) with a few exceptions (e.g. Liu et al., 2012) that have investigated project based firms or project settings.

Mainstream innovation researchers have proposed numerous stage-based models to represent the innovation process as a sequence of discrete steps or stages (e.g. Rogers, 1983; Zaltman et al., 1973). These models, however, lack an empirical basis and there have been a few attempts to test the ability of such models to reflect how innovations develop in real situations. The innovation process has been described to be very much fluid than such stage models suggests, and in the project based environment can be very interactive and dynamic with feedback loops (Manley, 2008). Similarly, current literature on construction innovation processes is mostly generic models (e.g. Gann & Salter, 2000; Slaughter, 2000; Winch, 1998) of how innovation occurs in construction. These are based on theoretical speculation rather than empirical observation of the processes of specific innovations. This has resulted in a lack of understanding of the dynamics and processes by which innovations occur in construction and an inadequate process theory to help better manage the innovation process.

Among the central problems in the management of innovation according to Van de Ven (1986) is the process involved in the management of ideas into good currency to ensure implementation. Innovation efforts in the industry are considered to be disproportionately oriented towards enhancing products rather than process improvements. This is exacerbated by the poor state of knowledge in research into innovation processes (c.f. Winch, 1998). Harty (2008) points out the dearth of studies that investigate the processes of innovation implementation in construction. In a recent review of the state of the science in innovation, Anderson et al., (2014) observed a move away from process research which has led to a limited understanding of the processes of innovation. They call for more process research, to make the notion of process and interaction the point of departure. An innovation process study will help gain a deeper understanding of how and why innovation unfolds over time in construction and increase understanding of the processes and behaviours that are necessary for effective development and implementation of innovations. A process theory will not only provide an insight into the transformation of an idea but will also produce a model of innovation process for construction which can serve as a roadmap to managers of innovation, depicting paths that result in success or failure of an innovative idea.

2. Innovation defined

Various attempts have been made to define innovation. According to West and Farr (1990), innovation as a term has been used in many ways and the variance appears systematic with the level of analysis used, and is often very much varied and vague the more macro the approach becomes. Sexton and Lu (2012) suggests the need to adopt a view of innovation that is suited for particular contexts. Zaltman et al., (1973, p. 10) consider innovation as “any idea, practice or material artefact perceived to be new to the unit of adoption” whilst Van de Ven (1986, p. 604) emphasized the transactional nature of innovation and defined innovation as “the development and implementation of new ideas by people who over time engage in transactions with others within an institutional context”. In the construction management literature, Slaughter (1998) defines innovation as “the actual use of a nontrivial change and improvement in the process, product or system that is novel to the institution developing the change”. This paper adopts a more comprehensive definition of innovation proposed by the OSLO manual (OECD, 2005) that consider an innovation as “the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organizational method in business practices, workplace organization or external relations"

3. The nature of construction innovation

Construction innovation can take a number of different forms regardless of the type of innovation involved. Tatum (1987) proffers four ways by which technological innovation occurs in construction: adoption of new approaches from external sources; modification and adaptation of existing technologies; incremental improvement of existing technologies; and the development of new technologies. The source of these ideas may be from research and development processes, leaders in the industry, leading suppliers and product manufacturers from other industries, competitors adopted or developed technologies or from experienced clients. Various typologies of innovation have been put forward. A popular typology is that of Slaughter (1998) who categorize construction innovation into incremental, modular, architectural, system and radical. Much of the innovations in construction according to Koskela and Vrijhoef (2001) fall into the incremental and modular categories of Slaughter's classification.

Construction innovation occurs at the sector, business and project levels (Abbott et al., 2007). Innovation on construction projects include process, product and organizational innovations which can be established innovations in the industry or custom developed for specific projects with opportunities to be diffused on future projects. Construction innovation is described as hidden on projects occurring within teams and often developmental through interaction between stakeholders on site. NESTA (2007) in its report on hidden innovations presents four categories of hidden innovations that include locally-developed, small-scale incremental innovations that take place 'under the radar'. At the business level innovation is much more about developing resources and capabilities: research and development (R&D) and organizational development. Whilst R&D focusses on the development of new materials or improvement on existing ones, organizational innovation involves the generation of new or enhancement of existing supply chain arrangements, strategies relating to human resource management, business processes and practices (Abbott et al., 2007; NESTA, 2007) or health and safety policy (Sexton & Barrett, 2003). Innovation at the sector level also takes two forms: through regulations and standards that prescribe new material attributes or behaviours which forces innovation, and the drive of innovation by client's that are dominant enough to drive innovation in the sector or rather for their specific needs (Abbott et al., 2007).

4. Theoretical framework

A number of models and frameworks have been proposed for the study of the process of innovation in organizations. Such models, often from product development perspective propose frameworks or models that are linear and generic (e.g. Zaltman et al., 1973). Some construction management researchers have also proposed similar generic models of the innovation process in construction organizations (e.g. Gann & Salter, 2000; Winch, 1998). Researchers in the Minnesota innovation study programme proposed a comprehensive but succinct framework for the study of the innovation process that doesn't only look at the process itself but concepts that feed into, drive or result from the innovation process. Van de Venn and Angle,(2000) rather summarize these concepts in the framework that: "from a managerial perspective, the process of innovation consists of motivating and coordinating people to develop and implement new ideas by engaging in transactions (or relationships) with others and making the adaptations needed to achieve desired outcomes within changing institutional and organizational contexts". The framework for their study of innovation process involves six concepts: ideas, people, transactions, process, context and outcomes. Changes in these concepts constitute an event which is mapped over the period of development and implementation of the innovation.

4.1 Innovation Ideas

Innovative ideas can be of different forms and from a myriad of sources. Ideas might be a recombination of old or existing ideas, something new that challenges the status quo or something new to the people involved (Van de Ven & Angle, 2000). Innovations are often a combination of emergent processes, adopted and adapted procedures often in use elsewhere and ideas that become refined over time through realistic organizational limitations (West, 2002). Therefore, the newness characteristics tell whether the innovation is new to the world or to a given context. Rogers (1983, p11) put forward that innovation involves products or services that are considered new to a social system with little emphasis on whether the newness of the idea is objectively assessed as by the time lapse since the first use of the product or service. Gopalakrishnan and Damanpour (1997) for instance consider newness as a function of the field's unit of analysis which goes to determine whether the innovation is new to an individual, group or team, an organization, industry or society in general. This degree of newness separates, or can be used as the basis to distinguish innovation generation from its adoption, and newness has often been considered as an empirical question for experts or executives of firms to address (Damanpour and Wischnevsky, 2006).

4.2 Individual engagement in innovation process

The role of individuals in the innovation process in organizations has been reiterated by researchers in the creativity and organizational behaviour literature. Early attempts to study the role of individuals in the innovation process in organizations focused on creativity, considered the first stage of the innovation process (e.g. Amabile, 1988). Winch (1998) made the point that operational personnel are the sources of ideas in many work environments, often captured through suggestion systems and quality circles. This can be through their own experiences and knowledge or through what can be referred to as practitioner research. Yuan and Woodman (2010) give examples of such behaviours to include the search for new technologies, exploring and suggesting new ways to achieve objectives, adoption of new and improved methods of working as well as the investigation and securing the needed resources to implement new ideas. Individual engagement in innovative behaviours has been described in relation to idea generation, idea promotion (championing or coalition building) and idea implementation (Holman et al., 2012).

4.3 Transactions

Transactions are necessary is examining how relationships develop in the management of innovation. Such transactions according to Van de Ven and Angle (2000) could be in relationships among peers (team-member exchange) or hierarchical relationships between superiors and their subordinates (leader-member exchange) regarding their engagement in the development of innovations. It could also be about proposals and commitments regarding the search and allocation of resources or any arrangement with parties to undertake tasks needed for the innovation development. Transactions are deemed to be a dynamic process that consists of three stages: negotiations, agreements and administration (Commons, 1950; cited in Van de Ven & Angle, 2000). How transactions go can be contingent on the novelty of the innovative idea. Much more novel and radical ideas require more trial and error with repeated or renewed cycles of negotiation, commitment and administration (Fernandez, 2001; Ring and Van de Ven, 2000). Transactions in construction could be with clients, consultants or other units or teams in the firm that play a role in the development and implementation of the innovation.

4.4 Context for innovation

Innovation has often been described as context specific. Context has been described by Andriopoulos and Lewis (2009) as a set of pressures and stimuli that shape the behaviour of individuals and groups. Van de Ven and Angle (2000) consider context as the setting or institutional environment within which an idea is developed and implemented through transactions among people. Thus, context can be described as the environment within which innovation occurs and can be within a team, project, firm, network, industry or even a nation. The structures, practices and procedures of an organization can be crucial to creating the necessary infrastructure for the successful development/adoption and implementation of innovations. Van de Ven and Angle (2000) suggest that for technological innovation such context variables include institutional norms, basic scientific knowledge, financing and human resources.

4.5 Innovation outcomes

The outcomes of innovation are realized after their development/adoption and implementation. Scholars have often drawn attention to the positive bias that anything innovation is good. Innovation is considered to be new to the unit of adoption and with the anticipation to reap benefits from its usage or the changes that it brings to the organization (West & Anderson, 1996). As Van de Ven and Angle (2000) point out innovation is often seen as good as a new idea must be useful; being possibly profitable or to solve problems and often ideas that are not successful characterized as mistakes. The process through which teams or organizations achieve innovation, however, results in either positive or negative consequences. Janssen et al., (2004) put forward both benefits (e.g. successful innovation, cohesion, effectiveness and efficiency) and downside (e.g. failure of the innovation, less cohesion, ineffectiveness and resistance to future innovations) to innovation in teams. Effectiveness judgements can also be made during the process of innovation development and implementation and can change during the process of implementation depending on the judgement of stakeholders or their perception of how well the innovation is meeting their expectations (Van de Ven & Angle, 2000). These changes result from changes in targets and expectations often coinciding with some unanticipated problems and setbacks or shifts in organizational priorities. Perceived in process judgement of innovation outcomes according to Van de Ven and Angle (2000) is a consequence of actions as well as a predictor of future actions but rather often incomplete explanations of actions.

4.6 The process of innovation in organizations

The innovation process is considered to be much more complex than the decision to adopt/develop and implement change. For instance, King and Anderson (2002) opine that a lot of activities are required before the decision to adopt is taken which can include fact finding, politics and manoeuvres, negotiations as well as formal and informal discussions. Process models can be deemed to belong to either the rational or behavioural schools of thought. The rational school is considered to be the most dominant view that underpins construction literature as far as innovation process is concerned (c.f. Barrett & Sexton, 2006). King and Anderson (2002) suggests that existing rational models are based on theoretical speculation, are normative, and give descriptions of the process as a sequence of stages. These models often prescribe linear and often predictable stages of innovation which Sexton and Barrett (2003) regard as depicting the innovation process as rigid, multistage and linear in nature. The stages, however, could be dependent on the nature of innovation, source and context within which the innovation is implemented. For instance, innovations that are adopted for implementation are often considered to be much simple and linear whilst innovations that are developed or originate from the implementing organization can follow much more complex, iterative, and non-sequential trajectories (Wolfe, 1994), consistent with the description of the innovation process by Quinn (1985) as a controlled chaos.

5. Proposed framework and research agenda

Despite the comprehensive nature of the concepts in the Minnesota innovation studies framework, it is generic and lacks a strong theoretical grounding and focus. To address this is to introduce a new adapted framework that is rooted in theories that will give the findings much more focus. Therefore, a framework that adapts the Minnesota innovation studies framework is proposed **(fig.1.)** which is rooted in the theories of ambidexterity and intellectual capital. In presenting an input-process-output model of ambidexterity, Simsek (2009) conceptualize exploration and exploitation as the components of the process with inputs that drive such processes existing at different levels of an organization. This input-process-output model can be adapted to investigate the process of explorative and exploitative innovations and their inputs at different levels of organizations that underlie the process of such explorative and or exploitative endeavours. Such inputs occurring at different levels of the firm can be intellectual capital: human capital, individual characteristics and individual engagement in the process; social capital and transactions between stakeholders; organizational capital that reflects the context within which the innovation occurs can be explored in terms of its facilitative ability or otherwise in explorative and exploitative innovative processes which are either adopted or generated. The output following Simsek's model would be the possible consequences of innovation processes at different levels which could at the individual, team, project or firm depending on whether the innovation is bottom up or top down. In the context of construction, the output of innovation could mainly be the consequences for the project as well as for the firm involved. Again the Minnesota framework is silent on the incentive or motivation as all innovations require that before they are initiated and is required before any innovation process commences.

5.1 Motivation or trigger for specific innovations

This is what Van de Ven (1991) describe as shocks that trigger innovation which can be opportunities for improvement, identified problems or competition from the environment. Individuals often go through the cognitive process to come up with novel solutions to problems or as opportunities for improvement (Holman et al., 2012) often with the identification of a problem that needs solving, a threat requiring urgent attention, an opportunity to improve current or existing conditions. Drucker (1985) identified sources of innovation opportunity to include: new knowledge, industrial changes as well as unexpected success or failure. Motivation or the trigger from sources both within and outside the organization sets the stage for concrete actions to pursue or undertake specific innovations regardless of the availability of the appropriate organizational climate (Van de Ven, 1991).

5.2 Explorative and exploitative innovative ideas

Part of the definition of an innovative idea is its characterization into different typologies and one such classification is whether the innovation idea constitutes an explorative or exploitative innovation (He & Wong, 2004; Jansen et al., 2006). Exploratory innovations offer new designs and create new markets requiring new knowledge (Benner & Tushman, 2003; Jansen et al., 2006). Exploitative innovations rather tend to improve and expand on existing knowledge and skills, brings improvement in efficiency and builds on existing structures and processes (Benner & Tushman, 2003). Whilst some researchers equate exploration and exploitation respectively to incremental and radical innovation, others have moved away from such classification for less technology intensive firms where there are less research and development activity (e.g. He and Wong, 2004) and firms undertake problem-solving activity using new knowledge, methods and techniques or refine and reuse existing knowledge, technologies and methods. Both forms of innovations entail knowledge combinations where one utilizes the existing and well-understood ways with the other leveraging knowledge that is varied and dispersed. Exploitative innovation demands efficiency and convergent thinking to be able to harness existing capabilities to improve products and services on a continual basis whilst explorative innovation involves efforts to generate novel recombination of knowledge, technologies and methods through search and experimentation (Andriopoulos & Lewis, 2009).

5.3 Human capital and individual role in innovation

The ability of an individual to actively be involved in the innovation process in organizations could be attributed to their innovation competency. Innovation competency according to Cerinsek and Dolinsek (2009) is to "act and react in an innovative manner in order to deal with different critical incidents, problems or tasks that demand innovative thinking and reactions, and which can occur in a certain context". This competency might also be underlain by factors as creative ability, education, training and experience which constitute human capital and is a source of knowledge and a resource for firms. Individuals association with the innovation unit according to Van de Ven and Angle (2000) is dependent on their skills, background, the frame of reference, experiences and activities that occupy their attention. Amabile (1988) suggests that the individual's creative behaviour is shaped by expertise, creative thinking skills and intrinsic task motivation. As Van de Venn and Angle caution, people as creators or facilitators of innovation must be balanced with people as inhibitors. This is against the backdrop of the fact that human beings have limited capacity in dealing with complexity and tend to adapt unconsciously to incremental changes often conforming to the group and organizational norms. This raises the question of how individuals can become invested in the development of new ideas given the tendency to focus on and protect existing practices (Van de Venn and Angle, 2000).

5.4 Social capital and transactions

Transactions and relationships might require internal and external social capital to be successful. Social capital is considered to be the network of interrelationships that aids knowledge exchange and integration within a firm. Adler and Kwon (2002) propose three dimensions of social capital: structural, cognitive and affective social capital. These complement each other in creating opportunity, motivation and ability to exchange knowledge. Social capital facilitates the exchange of knowledge, insights and mental models, improving the richness of exchange of information and iteration (Subramaniam & Youndt, 2005) which is relevant in transactions among parties involved in the innovation process. Social capital can be described as either cooperative or entrepreneurial. According to Kang et al., (2007) these two configurations of social capital can be identified especially in their alignment with exploration and exploitation. Cooperative social capital represents a social system that is tightly coupled with strong and dense networks of inter-connections. Entrepreneurial social capital, on the other hand, is characterized by weak redundant relational networks where members share a common component knowledge which is a reflection of their shared technical and professional knowledge (Kang and Snell, 2009). In effect cooperative social capital involves the existence of strong ties for the efficient sharing of knowledge whilst entrepreneurial social capital is about having access to a myriad of contacts from whom knowledge and expertise can be accessed when needed without necessarily having a close social relationship.

5.5 Organizational capital

Innovation in firms is developed in a context that can be reflected in the organizational capital. Organizational capital depicts the knowledge in processes, systems, structures as well as behaviour, norms, mental maps, core competencies and culture and is often context specific relating to the internal structure and organization of a firm. Organizational capital also consists of codified experiences and institutionalized knowledge that remain in the firm and used through databases, to preserve knowledge and to create routines, processes, structures and systems for continuous usage (Youndt et al., 2004). Organizational capital has been identified in two forms; mechanistic and organic (Kang & Snell, 2009). Whilst the mechanistic archetype involves detailing routines the organic type of organizational capital is about flexible or simple routines, priorities, vision and boundaries within which individuals and teams must work. This is more of a culture of conformity versus the encouragement of proactivity and creative thinking that can be associated with the empowerment or autonomy to be able to shape or challenge established norms (Kang & Snell, 2009). Thus, mechanistic archetype is where there are structures in place for coordination and control of activities and processes whilst the organic provides the flexibility to accommodate unexpected events and allow problem-solving through innovative thinking. The context can also relate to what Amabile (1988) refers to as an organization's motivation for innovation manifest in a number of ways either positive or negative to encourage or discourage innovative efforts in the organization.

5.6 Innovation generation and adoption processes

Damanpour and Wischnevsky (2006) argue that the process of innovation differ for innovation generation and innovation adoption and therefore how such innovations occur in organizations cannot be explained by the same theories of innovation. Generation is more of a creative process involving exploration of ideas, emergent and inherently characterized by variation and experimentation (March, 1991). Adoption, on the other hand, involves the adaptation of existing ideas and is more exploitative, planned and characterized by selection, refinement and implementation (Damanpour & Wischnevsky, 2006; March, 1991). Damanpour and Wischnevsky (2006) argue that such distinction between generation and adoption has often been overlooked by innovation researchers often referring to both as the innovation process. The requirement for success in innovation may, however, vary from one case to another or between innovations in different industries. Construction, for instance, provides a different context within which innovations are often adopted for implementation as compared to other high technology industries like manufacturing. This warrants a differentiation of innovation processes depending on whether innovations are adopted or generated for implementation and more so for contexts such as construction where the incidence of innovation might include both adoption and or generation.

5.7 Project and organizational outcomes

Outcomes of innovation in construction could be cost and time reduction in the execution of an operation, improvement of safety on site, reduction in environmental impact or improvement in the performance of the completed facility (Slaughter, 2000). Such effects ultimately impact the success of not only operations but projects and among a portfolio of projects affects the firm's performance and competitiveness. This reinforces the fact that innovation in construction not only benefits projects they are implemented on but also the parent organizations of the teams involved. Innovations developed on-site can help increase the capability of firms for innovation through learning and diffusion on future projects (Gann & Salter, 2000; Winch, 1998). Not all innovations are however successful, and failed innovations can have cost, time and quality implications. Failed innovations can as well impact relationships between parties or the image of the organization involved.

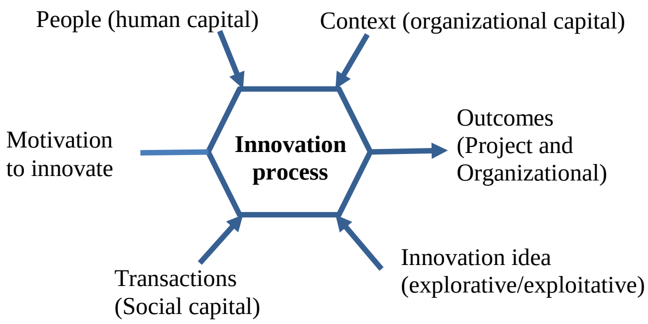

Figure 1: Conceptual framework for process of specific innovations

The forgoing discussion proposes a theory-driven framework and provides an agenda for exploring the process of innovations in the context of project-based firms where innovation is considered hidden and where the unique characteristics of the context and organizing have consequences for the innovation process. Therefore, it will be worth exploring or finding answers to the following questions: How are innovations adopted/developed and implemented by construction firms? How does the process of specific innovations differ depending on the innovation's attributes? What is the motivation for construction innovations and what roles do individual stakeholders play in the process? How does intellectual capital facilitate the process of innovation development/adoption and implementation by construction firms? And what are the consequences of the innovation processes for projects and organizations involved?

The above forms part of an ongoing research aimed at creating a process theory of innovation in construction. Data is to be collected through case studies using mixed methods: retrospective interviews, ethnographic interviews and observation. The critical incident technique is to be adopted in the interviews to focus on critical or significant moments and events that define the innovation process. Case study firms and innovations are to be carefully selected to consist of firms of different sizes as well as innovations of varied attributes. Cluster analysis could be used to distinguish innovation processes by type or attributes in an attempt at creating a differentiation theory by identifying patterns within and across clusters.

6. Conclusion

The framework presented here departs from the Minnesota innovation studies framework and existing process studies by including intellectual capital and ambidexterity theory. The nature of construction being a project based industry suggests that the nature of innovative ideas, multifunctional personnel and contexts differ from that of permanent organizations that have been the contexts for many innovation process studies. A study of innovation process as proposed in the advanced framework will be one of the first few attempts to provide an innovation process theory for construction and project based firms based on empirical studies of specific innovations. This proposed study will also help create a differentiation theory on innovation process not only for explorative or exploitative innovations but also whether innovations are bottom up or top down, product or process etc. Finally, the paper presents how intellectual capital can facilitate innovation through individuals (human capital), social capital in transactions and organizational capital in providing the appropriate context for innovation. Such a study will help point out the criticality of human, social and organizational capital in facilitating the innovation process of specific innovations adopted/developed and implemented by construction firms. It will also potentially provide a model for innovation process in construction that can help managers better manage intellectual capital to enhance the innovation process and its outcomes.

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Design and Prototyping of a Curtain Wall System With Wooden Load-bearing Structure and Glass Infill Panels

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Abstract

The sector of architectural envelope is at the moment one of the most developed, both in terms of technological innovation and design experimentation. The whole construction industry knows that the curtain wall performances are essential to reduce the impact of buildings in the environment, in terms of greenhouse gases emissions and energy consumption. At the same time, a positive trend for the buildings with wooden load-bearing structure has developed and it is proved by a growing number of projects in geographic areas where historically no-one used this material. The wood is highly appreciated in the field of construction industry because of its good mechanical resistance, its good thermal insulation and sound-proof, the ease it can be worked, the tactile heat that transmits and the message of environmental eco-friendly improvements it can be associated with. After a meticulous observation of these trends, the Università Iuav di Venezia has decided to develop a specific research project: it has prefigured that a work in synergy between the two sectors can offer a fertile ground to develop technical and planning know-how. The aim is to develop prototypes of innovative curtain walls with wooden load-bearing structure and glass infill panels. A market survey has shown that wood curtain walls are almost absent, that's the reason why it has been chosen to analyse and develop this kind of product with the partnership of Simco Tecnocovering (nowadays Simeon S.r.l.), an Italian company specialized in aluminium curtain wall systems. It has been decided to set aluminium systems with wooden envelopes and a mixture of aluminium and wooden structures made by the most important competitors against a façade system only made of wood. The paper presents the final results of the research, underlining the problems observed and the solutions that have been found.

Keywords: Architectural envelopes, curtain wall, wooden structure, glass infills, sustainability

1. Introduction

The development of a curtain wall system with wooden load-bearing structure and glass infill panels was the goal of this experience. The project included also activities evaluation, as well as the technical and technological aspects, about the "patentability" of the system.

A curtain wall (according to EN 13830:2015 "Curtain walling – Product standard") consists of *"a part of the building envelope made of a framework usually consisting of horizontal and vertical profiles, connected together and anchored to the supporting structure of the building, and containing fixed and/or openable infills, which provides all the required functions of an internal or external wall or part thereof, but does not contribute to the load bearing or the stability of the structure of the building. Curtain walling is designed as a self-supporting construction which transmits dead-loads, imposed loads, environmental load (wind, snow, etc.) and seismic load to the main building structure"*, and it is normally made with an aluminium structure.

Despite the excellent technical and performance characteristics of the aluminium, using wood as a structural material brings undoubted positive effects in terms of environment preservation, in addition to satisfying a market sector that requires aesthetic standards related to the use of natural materials. Instead of aluminium, in fact, the use of wood would mean fewer problems of thermal bridge, the use of a material with a lower embodied energy (the amount of energy required to produce a unit of material starting from the raw material), in addition the obvious advantages of static (it is lighter). In a territory, also, as we have been seen, particularly receptive for the development and production of envelope systems.

Goal of the project was therefore the development of a patent system of bloc curtain wall made in wood/glass, based on the know-how of the producer in a first and recent application "pilot" of this system on a building in France.

2. Description of the research project

The research project was born from the participation of Veneto Region, during the period 2007-2013, to the European Social Fund program that is part of the European Community strategic guidelines focused to strength economic and social cohesion of the European Union by reducing economic, social and territorial disparities among Member States and the regions of the Union. This was achieved through the European "Regional Competitiveness and Employment Objective" which established the strategy, the priorities and objectives of the European Social Fund (ESF) in every specific regional area. In this context, in 2013 the Veneto Region has supported and funded a program called "ESF – Axis Human Capital – Research Grants" for the presentation of postgraduate research projects that include cooperation between a university and a company based in Veneto Region (called "operating partner"), with the target to train and employee young researchers. In this context, 127 research grants – 49 assigned to the Università Iuav di Venezia – started, with a total funding of more than 6 million euro.

The Università Iuav di Venezia in collaboration with Simco Tecnovering S.r.l. (company specialized in curtain wall systems) as operating partners developed a research project. The role played by Simco Tecnovering was a technical support during the design phase of a new curtain wall system in wood and glass. The level of involvement of the operating partner was comprehensive, because it took place during most of the period of research project. The operating partner was the main promoter of the research project, having identified the market potential and, thanks to the experience developed in this industrial sector, having the specific technical skills to develop the prototype. The position of the operating partner in the regional, national and international market also allows to directly focus in the dissemination of results.

The research project takes place in the building envelope and curtain wall area, particularly in wooden doors and windows sector, of great importance both nationally and regionally. According to the available data at the time of the research project, the Italian market of windows and architectural envelope was about 5 billion Euros worth (2011, Studies and Research Service of the Chamber of Commerce of Verona, data InfoCamere), where the curtain walls sub-sector amounted to nearly 500 million euro (2012, Uncsaal/ISTAT data). Particularly, concerning wooden window frames, the market reached the billion and a half total turnover (2011 data, Studies and Research Service of the Chamber of Commerce of Verona, data InfoCamere).

The Veneto Region is particularly important concerning energy saving measures: almost all – about 95% – of works carried out on buildings in 2011 was the replacement of windows. Concerning the replacement of windows, 10.2% of the total amount of work in Italy took place in Veneto, ranked fourth after Lombardia, Piemonte and Emilia Romagna. Veneto is in fourth position in Italy also as total surface installed, with over 250,000 square meters. (2011 data, Enea Annual Report – Tax deductions of 55% for the energy upgrading of existing buildings).

All across Europe the awareness that the wood can become a key material for the construction industry, not only for small private buildings but also for large structures, is constantly growing. In Berlin new residential houses will totally made of wood; in Sweden skyscrapers are designed also in wood, while in France the government announced that the construction will be stimulated by new tall buildings with wooden frame, together with a policy development of forests supported by the Ministry of Agriculture.

Architectural envelope prefabrication allows to reduce waste, to control the quality of the product, to test its real performance, to inspect the equipment on site and to speed up the assembly stages. Systems of mixed wood-aluminium façade are present on the market, but no system is completely made of wood; moreover, they are usable for several types of buildings (residential, office, school, etc.). This was the main focus of the research, being also a development opportunity for the Veneto Region.

3. Organization and methodology

The research, which took place from March 2014 to March 2015, was divided into four phases. The first phase was focused on the collection and analysis of information related to the research project, with particular reference to the technical aspects of the building envelope and windows. It covered a period of about two months and was carried out mainly in the Università Iuav di Venezia. The first phase included five additional sub-phases:

1. The analysis of classification systems for building envelopes according to UNI 8290-1: 1981 + A122: 1983: *Edilizia residenziale. Sistema tecnologico. Classificazione e terminologia*;
2. The analysis of the main systems of building envelopes, in particular those related to the UNI EN 13830: 2005 *Curtain walling. Product standard* (still current at the time of the research project, now substituted by EN 13830:2015 *Curtain walling. Product standard*);
3. The analysis of the physical/technical (thermal, light, sound, fire safety, etc.) factors involved and of the performance levels of the main types of architectural envelopes currently available;
4. The analysis of the main types of wood species currently used for architectural envelopes;
5. The analysis of the physical/technical (thermal, light, sound, fire safety, etc.) factors involved and of the performance levels of the main types of the glazing systems currently available on the market.

The first phase allowed to get a comprehensive state-of-the-art of curtain wall and architectural envelopes sector, updated to the most recent technical solutions. This phase prepared a solid background for the research, before starting the true design process.

The second phase focused the methodology of design and production of curtain walls. It covered a period of about three months and was carried out between the Università Iuav di Venezia and the corporate headquarters. It included four additional sub-phases:

1. The analysis the dynamics of the curtain wall industrial sector and of the operating partner organization, of its technical/economic departments and business function, of its production facilities, of the commercial network, of systems and products already on the market;
2. The analysis of the UNI norms concerning curtain walls systems;
3. The analysis of laboratory tests and tests aimed to design and produce a curtain wall;
4. The collection of information about similar existing wooden structure systems, with glazed infill panels, and the analysis of their characteristic.

The second phase allowed to better understand the operational partner and its industrial organization; moreover, the second phase allowed to collect information about similar products already on the market, in order to focus the design process in a better way.

The third phase included the design and prototyping of the curtain wall system in wood/glass. It covered a period of about six months and was carried out between the Università Iuav di Venezia and the corporate headquarters. It included two further sub-phases:

1. Study of a curtain wall system with wooden frame and glazed infill panels;
2. Mock-up of the system itself.

The third phase was the true design phase, when all the information collected during the previous phases were put together in order to prepare a mock-up to be later verified in its formal and technical aspects.

The fourth and final phase, which lasts about a month, took place between the Università Iuav di Venezia and the corporate headquarters, included the making of a video of the whole process and the preparation of a book with the technical/performance characteristics of the system.

4. Phases of analysis, design and prototyping

Based on the information gathered during the analysis phase, we found that in the market there aren't systems of wooden facade entirely of wood, but there are always metal elements especially for the connection between the carrier and plugging.

We considered the multiple needs related to marketing, to engineering, production, installation and maintenance of the same during the design phase of the system. For this reason we developed a process of continual review, but at the same time the result is a product more in line with actual needs of future customers.

The system is a curtain wall, female-female typology: this solution allows to optimize the number of profiles, to facilitates the industrialized production of the modules and to do a faster assembly of the element. It is available in two versions:

- With external caps: the fixing of the glass takes place with a mechanical system;
- Full glass structural version: the fixing of the glass takes place using particular adhesives.

System with external caps
A great potential of the system is linked to the possibility to product particular forms, customized shape for the structure of the façade (mullion and transom) and the outer cover. Contrary to the extruded aluminium, which features production must maintain a constant shape, wood is malleable and can be modelled.

Full glass structural version
This version of the system is studied to obtain a full-glass aspect. The bonding of the glass to the structure was made with a particular adhesive. The supplier of the adhesive tested this fixing system and the process of certification of the product is just started. This product is applied in

wooden support after that it is cleaned and treated with the primer. The tightness is immediate so that the block can be immediately moved with glass suckers. The maximum tightness is achieved after 60 hours after the application. This system minimizes the strips that we should normally have with the use of structural silicone, speeds up the production process and guarantees high performance.

One of the crucial problems to be solved was the system of engagement and disengagement of the elements of connection between the main frame and the glass panel. We thought about maintenance methodology.

In the course of the useful life of the building in fact it is possible that some glasses break due to accident, breakage due to nickel sulphide in tempered glass (also with HST) and the replacement of these collisions is often not a simple operation. In Francophone countries, the main market for the company, if the structural glazed infill breaks, it can not be replaced directly on the jobsite, but, as opposed, it is necessary to remove the sub-frame and proceed with the replacement in the factory or in a protected and dedicated area. These solutions are already been broadly applied for aluminium facades or for mullions and transoms curtain wall, but there aren't many application in wooden façade. The main difficulties concerning the needs to ensure adequate mechanical strength, to contain the width of the profile and to minimize the use of metallic materials, both for thermal reasons, both for evaluations on the life cycle of the product. We overcome these aspects proposing a punctual anchor that allows the replacement of vision modules from the inside and the replacement of shadow box part from the outside. The method of replacement is safe and easy: we can also keep some replacement element already glazed in the building, ready for use. During the study of the system we considered various types of openings (bottom hung, top hung, pantograph) and we studied accessories of hardware ad hoc, due to the size and of the loads involved. We can integrate the bloc with different types of internal and external solar screening: screening curtains, brisesoleil, blinds, architectural louvers, mobile systems. Also claddings can be different: glass (monolithic, double glazing, triple glazing) or opaque (enamelled glass, wood, plastic or metal sheet). The basic system is in laminated wood. We can also use microlamellar to increase performance static. Wood species can be chosen by the architect. You can also choose the wood finish. You can use the natural wood (accepting the uncontrolled maturation and reaction to weather), treated with paint (that make it stable over time but it will reduce the natural variability) or earlier aged (the change is more controlled and the material is more stable).

Figure 1: the two prototypes of the wood/glass façade.

5. Discussion

One of the most important point of discussion is the introduction of a wooden frame as substitute of aluminium as structural material for curtain wall. Since aluminium is largely considered as the main structural material in curtain wall industry, one of the targets in the following steps will probably be spreading the results to convince potential architects, clients and users of the possible applications of this façade system. Actually, considering the characteristics of the system, we can state that:

- Static performance are satisfactory: the system is dimensioned to respond to a wind pressure of 1250Pa (a pressure which is normally used for mid-rise towers, about 14 floors). We can review this performance according to different needs by changing the size of the profile or type of wood;
- The thermal and acoustic performance are very good being the wood a naturally insulating material;
- The embodied energy is less than traditional aluminium systems;
- It's possible to disposal the envelope after its phase of life. It is disposable and recyclable since the system is composed by a single material or different materials easily divided into the various elements and it will not become hardly disposed.

The following picture can, at a glance, summarise and compare the different characteristics of an aluminium and a wooden frame curtain wall.

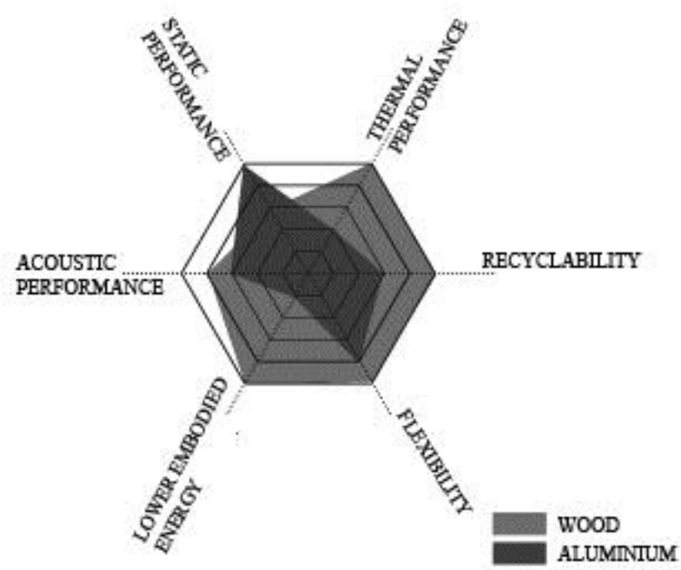

Figure 2: comparison between aluminium and wooden frame curtain wall.

Wooden frame can represent a valid alternative to aluminium façades, especially considering its lower embodied energy and the thermal performances. We can also consider wood like a sustainable material if we develop correct reforestation policies with the aim of increasing our forest resources. In this way we can obtain more natural resources, a reduction of emission, a increment of the use of recyclable materials.

Moreover, since one the most important targets of the Veneto Region "ESF – Axis Human Capital – Research Grants" program was to supported the occupation, the introduction into the construction building materials and products market of a brand new façade system, potentially usable in several different building typologies, can have the impact to push other companies to develop similar systems, with the consequent impact of new possible work assumptions. In fact, the design, prototyping, engineering, production and installation of a new façade system by a specialist company, able to carry out research applied, is in fact one of the motors which allows, subsequently, other operators to propose their own solution, triggering a virtuous circle that can bring, as well as a new market and a benefit in terms of employment.

6. Conclusions

The industrial nature of the Veneto region and of the whole Italy is particular fruitful for closures and the window frame sector. This research that aimed at the development of an innovative system of closure with wooden frame and glass curtain, virtually absent from the market certainly brought advantages to operating partner, but also to their suppliers and to the business world linked in similar activities. The design of a new system involved the use of resources and an initial investment that will to return in economic, commercial, image, etc. positive effects.

Architectural envelope, and especially façades and curtain wall, that represent one of the most important sectors in construction industry, both from formal and technical point of view, are highly important in the energy balance of a building, since thermal performances of the envelope deeply influence the internal comfort and energy consumptions. Also, the use of wood as structural material can be a valid alternative to more common aluminium structures, that can be used various building typologies (residential, directional, commercial, etc.). Moreover, this type of curtain wall can be largely used both in new and refurbishment projects.

Considering the objectives of the research and the prototype characteristics, the final results can be considered largely satisfying. The prototype represents a good example of a new system that is quite absent from the façade market and has some peculiarities that can satisfy designers' and users' needs.

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Lean Project Management during the Construction Phase of South African Public Sector Projects

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Abstract

In construction, the progress of the project is driven primarily by the construction project programme or schedule and the Construction Project Manager (CPM). The project programme sets out the bases for monitoring and controlling the project by the CPM. Many construction projects in the public sector are subject to late completion, cost overruns and poor quality arguably as a result of inadequate programme management. During the construction phase of projects, there are many opportunities for the CPM to implement lean tools and techniques that will have a positive impact on the project from a programming perspective. This study investigated the impacts of implementing lean project management (LPM) tools and techniques during the construction phase of public sector projects on the successful delivery of the programme. A sample of 234 registered CPM's were surveyed to determine whether they were aware of LPM and identify how often they used LPM tools and techniques under the nine project management areas of expertise to achieve the successful delivery of the programme. Seventy two responded to the survey questionnaire. It was found that CPM's are aware of LPM and are utilising these principles under the nine project management areas as an initiative towards improving the delivery of the programme during the construction phase of public sector projects. It is evident that there is consensus between LPM principles used often to always under the nine project management areas. The data did however, identify that not all of the LPM principles are equally implemented under each area of expertise. This study was limited to professionally registered CPM's involved in the public sector based within the KwaZulu-Natal province of South Africa.

Keywords: Construction Phase, Construction Project Managers, Lean Project Management, Project Programme, Public Sector.

1. Introduction

A key stimulator of economic growth is the construction industry (National Treasury, 2015). This stimulation is accomplished by increasing the productive capacity of the economy through the provision of infrastructure to both private and public sectors. One of the fundamental challenges of the South African government is service delivery in the construction sector. Some of these challenges are highlighted by the South African Government New Agency Report (2015) as, delays and disruptions during construction, poor site management, time and cost variations, skills and competence issues, lack of quality improvement processes and lack of worker participation.

There are numerous performance indicators regarding service delivery in the construction industry (Chan and Ada, 2004). Time is one of the most important factors taken into consideration regarding the successful delivery of construction projects in the industry. Time is monitored and measured against the construction programme on public sector construction projects during the construction phase. The construction programme as defined by the Project Management Book of Knowledge (PMBOK) (2004) includes the processes required to accomplish timely completion of the project.

Construction usually involves the interpretation of the Client's brief into a design and then translation into reality. This translation requires a design or consultant team selected by the Client/ Employer. Construction Project Management is defined by the South African Council for the Project and Construction Management Profession (SACPCMP) in terms of the Project and Construction Management Professions Act (2000) as the management of projects within the built environment from conception to completion, including the management of related professional services. The CPM is the single point of responsibility in this regard. More specifically this study makes reference to CPM's appointed by the Public Sector to manage and deliver successful construction programmes during the construction phase of projects in the industry.

Truman and King (2013) note that the successful delivery of construction projects in the public sector are hindered by poor programme management. These are failure to adequately programme the work and properly execute the programme, failure to provide adequate qualified human resources to manage the programme, failure to develop an efficient programme and to effectively maintain the programme throughout the project execution and failure to control cost changes that impact the programme throughout the execution of the project.

Lean project management as defined by Pfeiffer and Weiβ (1994) is a system for organising and managing all aspects of a project function by creating principles, practices and tools in order to develop goods and services with higher quality and fewer defects. The general outcome is to do this by using less effort, space, capital and time. In construction, lean project management is delivering more value with less waste in a project context.

A study conducted by Rust and Koen (2011) revealed that the South African construction industry is renowned for low levels of innovation towards stimulating technological solutions to provide and maintain future growth of the industry. As a result, the research conducted in this study aims to identify and highlight lean project management and its implementation as an innovative initiative towards the successful delivery of the project programme. The study aims to achieve the following objectives, to determine whether CPM's are aware of LPM and to identify how often CPM's use LPM tools and techniques under the nine project management areas of expertise towards the successful delivery of the programme.

2. Literature Review

2.1 Lean Project Management

Lean thinking is a philosophy based on the concepts of lean production (Koskela, 1992; Koskela, 2000). Alternatively, the first consideration of the ideas of lean production for use within construction is attributed to Koskela (1992) (Garnett, *et al.*, 1998; Mossman, 2009). Lean construction is a different project management approach because it has a clear set of objectives for the delivery process, is aimed at maximising performance for the customer at the project level, designs concurrently product and process, and applies production control throughout the life of the product from design to delivery (Howell, 1999).

Lean project management builds on the understanding that no other project has been or will be exactly the same as the one you are currently working or preparing to work on. It takes a practical approach with simple steps to demonstrate how to complete projects in half the time, all the time. LPM assists project managers taking on more projects, wanting to complete them faster with less team stress (Leach, 2006). LPM is the inclusive adoption of other lean concepts such as lean construction, lean manufacturing and lean thinking into the project management context. LPM has numerous ideas in common with other lean concepts. However, the fundamental principle of LPM is delivering more value with less waste in the project context. LPM has many techniques for implementation to projects and one of the main methods is standardisation (Leach, 2006).

2.2 The Public Sector

One of the fundamental challenges of the South African government is service delivery in the construction sector. In recent report presented by Public Enterprises Minister in 2015, it was highlighted that although the government considers the public sector to be part of the country's economic fibre, the sector is confronted with major delivery challenges. Some of these challenges faced during the course of executing construction projects include: delays and disruptions, poor site management, time and cost variations, skills and competence issues, lack of quality improvement processes and a lack of worker participation. As a result, there is no doubt that substantial improvements in quality and efficiency are needed and are possible (South African Government News Agency, 2015).

Project risks further highlighted by the Price Waterhouse Coopers (PWC) report: SA Construction (2014) includes project execution, noting the challenges as: the competitive nature of the market as well as skill shortages which places pressure on companies to deliver projects. This then poses a risk to companies' ability to start projects efficiently, manage changes in projects, manage limited resources and complete and handover projects. The report further identifies the proposed actions required by the industry as: Implementation and monitoring of project management procedures and policies over the life cycle of a project; and assignment of accountability is imperative in mitigating the risk posed to project execution. This reinforced the initiative proposed by the research regarding the implementation of LPM during the construction phase of public sector projects as an initiative towards the successful delivery of the programme.

2.3 The CPM Profession

Construction project management is project management applicable to the construction industry which is aimed at meeting the client's requirements in order to produce a functional, feasible and financially viable project. The CPM's roles involve overall planning, co-ordination and control of a construction project from initiation to completion (Burke, 2003). More specifically this research makes reference to CPM's appointed by the Public Sector to manage and deliver successful construction programmes during the construction phase of projects in the industry. In construction, the selection of the CPM is a key appointment which can influence the success or failure of the project. As the single point of responsibility, it is the CPM who integrates and co-ordinates all the contributions and guides them to successfully complete the project (Burke, 2003).

2.4 The Construction Phase and Project Programme

The progress and success rate of the project is driven primarily by the programme and the CPM. The project programme sets out the grounding upon which the project is monitored and controlled by the CPM (Truman and King, 2013). Determining what work must be done, what resources including human resources are to be used, together with the identification of equipment, facilities and funds needed for projects reinforces the need and importance of having a sound project programme to manage these deliverables. The aim of the programme is to provide a plan that is well thought out and realistic which can be achieved.

Many construction projects in the public sector are subject to late completion, cost overruns and poor quality as a result of inadequate/poor programme management (Truman and King, 2013). During the construction phase of projects, there are many opportunities for the CPM to implement lean tools and techniques that will have a positive impact on the project from a programming perspective. Watt (2014) further notes that during the construction or implementation phase, the project plan is put into motion and the work of the project is performed. Progress is continuously monitored and appropriate adjustments are made and recorded as variances from the original plan. The programme is updated and communicated on a regular basis. In any project, a project manager spends most of the time in this phase.

2.5 The Relationship between LPM, the Public Sector, the CPM Profession, the Construction Phase and the Project Programme

Evidence of the use of lean thinking has shown that there are many benefits to be made from applying lean principles to construction. These benefits claimed include, improved productivity, increased reliability, improved quality, more client satisfaction, increased predictability, shortened schedules, less waste, reduced cost, enhanced buildability improvements to design and improved safety (Lehman & Reister, 2004; Mossman, 2009).

Government, industry and clients are all seeking to bring about a change in the construction industry to improve quality, competitiveness and profitability, and to increase value to clients. Where the emphasis has traditionally been on the need to manage the interface between the project and the client's organisation, it is now shifting towards the need to manage the flow of activities through the whole life cycle of the project, concentrating on those activities that actually add value (Matheu, 2005). The South African construction industry plays a major role in contributing towards the gross domestic product (GDP), highlighting its major role of adding towards the growth and development of the country. It has been identified that the construction management profession in the industry is one of the key roles and is the single point of contact between other consultant professionals on a project and the client. As a result, the success of the project ultimately rides on the unique management skills of the CPM.

The successful completion of construction projects are achieved when they are completed within budgeted cost, specified quality, stipulated time and delivered safely. One of the key tools identified in order to aid CPM's towards achieving this goal is the project programme. The application of sound project management principles on a project is not only the means to the projects ends, but aids in guiding and managing the project towards its successful completion while meeting the client's needs within the defined budget (Truman and King, 2013). This highlights the ability of CPM's to provide the public sector with the unique management skills they require such as LPM to assist in improving the delivery of the project programme. One of the key management areas highlighted that can be implemented by CPM's is LPM. CPM's need to implement LPM tools and techniques during the construction phase of public sector projects as an initiative towards improving the delivery of the project programme.

3. Research Methodology

In order to achieve these research aims, the research approaches adopted involved, conducting a comprehensive literature review which investigated the concepts of LPM, the public sector, the CPM profession, the construction phase and the project programme and the relationship between these areas of concern.

The study involved targeting all CPM's professionally registered with the SACPCMP in the province of KwaZulu-Natal (KZN). These registered CPM's were identified from the Professions and Projects Register (2015). This register lists 234 registered CPM's in KZN. Out of the 234 registered CPM's, 72 responded to the survey questionnaire. This represents a 31 per cent response rate.

The sample was surveyed to determine whether they were aware of LPM and to identify how often they used LPM tools and techniques under the nine project management areas of expertise to achieve the successful delivery of the programme. The data was analysed using SPSS version

23. Finally, conclusions were drawn from the research findings and recommendations for implementation are presented.

4. Findings and Discussion

CPM's were presented with the fifteen principles underpinning LPM and asked on a scale of 1 to 5, where 1 = never and 5 = always, to confirm how often they used these principles under the nine project management areas of expertise during the construction phase of public sector projects towards improving the management and delivery of the programme. The CPM's responses were ranked according to the mean scores presented in Table 1.

Table 1: LPM comparison with the Nine Project Management Areas of Expertise

Lean Principles and Techniques	Mean and Rank	Nine Project Management Areas of Expertise								
		Cost Management	Communication Management	Integration Management	Procurement Management	Human Resource Management	Risk Management	Scope Management	Time Management	Quality Management
1. Improving planning and communication	Mean	4.29	4.16	4.12	4.12	4.08	4.08	4.04	3.95	3.93
	Rank	**1**	**2**	**3**	**3**	**5**	**5**	**7**	**8**	**9**
		(1)	**(1)**	**(4)**	**(3)**	**(4)**	**(8)**	**(5)**	**(10)**	**(9)**
2. Eliminating waste and errors	Mean	3.97	3.98	3.54	3.48	4.08	4.09	4.25	4.18	4.01
	Rank	**7**	**6**	**8**	**9**	**4**	**3**	**1**	**2**	**5**
		(6)	**(8)**	**(15)**	**(14)**	**(4)**	**(6)**	**(2)**	**(3)**	**(6)**
3. Direct intervention to drive immediate and apparent change	Mean	3.95	3.86	4.26	3.75	3.90	3.75	4.54	3.66	3.95
	Rank	**3**	**6**	**2**	**7**	**5**	**7**	**1**	**9**	**3**
		(8)	**(11)**	**(2)**	**(9)**	**(9)**	**(13)**	**(1)**	**(15)**	**(8)**
4. Improving work planning and forward scheduling	Mean	3.56	3.70	3.79	3.84	4.18	3.97	4.04	3.98	4.27
	Rank	**9**	**8**	**7**	**6**	**2**	**5**	**3**	**4**	**1**
		(15)	**(15)**	**(13)**	**(7)**	**(1)**	**(10)**	**(5)**	**(8)**	**(1)**

Table 1: LPM comparison with the Nine Project Management Areas of Expertise (Continued)

Lean Principles and Techniques	Mean and Rank	Cost Management	Communication Management	Integration Management	Procurement Management	Human Resource Management	Risk Management	Scope Management	Time Management	Quality Management
		Nine Project Management Areas of Expertise								
5. Direct intervention to drive immediate and apparent change	Mean	3.95	3.86	4.26	3.75	3.90	3.75	4.54	3.66	3.95
	Rank	**3**	**6**	**2**	**7**	**5**	**7**	**1**	**9**	**3**
		(8)	**(11)**	**(2)**	**(9)**	**(9)**	**(13)**	**(1)**	**(15)**	**(8)**
6. Improving work planning and forward scheduling	Mean	3.56	3.70	3.79	3.84	4.18	3.97	4.04	3.98	4.27
	Rank	**9**	**8**	**7**	**6**	**2**	**5**	**3**	**4**	**1**
		(15)	**(15)**	**(13)**	**(7)**	**(1)**	**(10)**	**(5)**	**(8)**	**(1)**
7. Specifying value from the perspective of the customer/ client	Mean	4.06	3.83	4.08	4.01	3.72	4.13	3.94	4.09	4.16
	Rank	**5**	**8**	**4**	**6**	**9**	**2**	**7**	**3**	**1**
		(4)	**(12)**	**(5)**	**(4)**	**(13)**	**(4)**	**(12)**	**(6)**	**(3)**
8. Eliminating activities that do not add value	Mean	4.22	4.16	3.80	3.65	4.00	4.09	4.01	4.13	3.81
	Rank	**1**	**2**	**8**	**9**	**6**	**4**	**5**	**3**	**7**
		(2)	**(1)**	**(12)**	**(11)**	**(7)**	**(6)**	**(8)**	**(5)**	**(13)**
9. Ensuring the work environment is clean, safe and efficient	Mean	3.93	4.01	4.23	3.68	3.90	4.33	4.06	3.79	3.97
	Rank	**6**	**4**	**2**	**9**	**7**	**1**	**3**	**8**	**5**
		(9)	**(7)**	**(3)**	**(10)**	**(9)**	**(2)**	**(4)**	**(12)**	**(7)**
10. Implementing critical path analysis and programme management	Mean	3.90	3.70	3.75	3.97	3.72	4.00	4.04	4.22	3.88
	Rank	**5**	**9**	**7**	**4**	**8**	**3**	**2**	**1**	**6**
		(11)	**(15)**	**(14)**	**(6)**	**(13)**	**(9)**	**(5)**	**(1)**	**(11)**
11. Reduce lead time	Mean	3.93	4.09	4.01	4.87	3.89	4.13	4.01	4.18	3.72
	Rank	**7**	**4**	**5**	**1**	**8**	**3**	**5**	**2**	**9**
		(9)	**(4)**	**(8)**	**(1)**	**(11)**	**(4)**	**(8)**	**(3)**	**(15)**
12. Reduce total costs	Mean	3.84	3.73	3.86	3.79	3.79	3.95	4.00	4.08	3.93
	Rank	**6**	**9**	**5**	**7**	**7**	**3**	**2**	**1**	**4**
		(12)	**(13)**	**(11)**	**(8)**	**(12)**	**(11)**	**(11)**	**(7)**	**(9)**

Table 1: LPM comparison with the Nine Project Management Areas of Expertise (Continued)

Lean Principles and Techniques	Mean and Rank	Nine Project Management Areas of Expertise								
		Cost Management	**Communication Management**	**Integration Management**	**Procurement Management**	**Human Resource Management**	**Risk Management**	**Scope Management**	**Time Management**	**Quality Management**
13. Maximising workflow, minimising the performance variation rather than focusing on speed only	Mean	4.04	3.94	3.94	4.00	4.09	3.94	3.93	4.22	4.04
	Rank	**3**	**6**	**6**	**5**	**2**	**6**	**9**	**1**	**3**
		(5)	**(9)**	**(9)**	**(5)**	**(3)**	**(12)**	**(13)**	**(1)**	**(5)**
14. Value management techniques	Mean	3.97	4.09	4.02	3.41	4.08	4.20	4.09	3.75	3.88
	Rank	**6**	**2**	**5**	**9**	**4**	**1**	**2**	**8**	**7**
		(6)	**(4)**	**(7)**	**(15)**	**(4)**	**(3)**	**(3)**	**(13)**	**(11)**
15. Benchmarking techniques including the use of key performance indicators	Mean	4.16	4.02	4.36	3.59	3.50	3.34	3.88	3.98	3.75
	Rank	**2**	**3**	**1**	**7**	**8**	**9**	**5**	**4**	**6**
		(3)	**(6)**	**(1)**	**(12)**	**(15)**	**(15)**	**(15)**	**(8)**	**(14)**
16. Risk management techniques	Mean	3.72	3.90	4.05	4.34	3.94	4.34	3.93	3.68	4.27
	Rank	**8**	**7**	**4**	**1**	**5**	**1**	**6**	**9**	**3**
		(14)	**(10)**	**(6)**	**(2)**	**(8)**	**(1)**	**(13)**	**(14)**	**(1)**
17. Implementing continuous improvement from one project to another	Mean	3.75	4.12	3.93	3.52	4.15	3.73	4.01	3.88	4.11
	Rank	**7**	**2**	**5**	**9**	**1**	**8**	**4**	**6**	**3**
		(13)	**(3)**	**(10)**	**(13)**	**(2)**	**(14)**	**(8)**	**(11)**	**(4)**

(Note: Ranking in brackets refers to the LPM principles as used within each project management area).

Table 1 presented the means of responses to the frequency of the use of 15 LPM principles in each of the nine project management areas of expertise, highlighting where each principle was most frequently used. The following was noted regarding the principles critical to the successful delivery of the programme:

- Improving planning and communication was most often to always used under cost management, suggesting that planning and communication important towards ensuring the cost management is adhered to;

- Eliminating waste and errors was used often to always under scope management, indicating that it was important for CPM's not to deviate from the scope, as the primary objective towards completing the programme is to achieve the planned scope;

- Improving work planning and forward scheduling was used often to always under quality (1^{st}) and human resource (2^{nd}) management. This suggests that competent human resource selection including the quality of the works being executed was key towards ensuring that planning and scheduling is implemented efficiently;

- CPM's highlighted that eliminating activities that do not add value were most often to always used under cost management, indicating that by not deviating from the scope and adhering to the approved budget the primary objective of completing the programme timeously can be achieved;

- CPM's felt that implementing critical path analysis and programme management was used most often to always under Time (1st), scope (2nd) management, suggesting that completing the project on time and as per the approved scope was important to the successful delivery of the programme;

- Reduce lead time was used often to always under procurement management, suggesting that the procurement and delivery of materials in relation to the programmed deliverables were key towards the successful completion of the programme;

- Maximising workflow, minimising the performance variation rather than focusing on speed only, was used often to always under time management, indicating that completing as many work activities as possible, the right way, the first time around timeously was important towards achieving the target milestones governed by the programmed;

- Risk management techniques was ranked 1st under both risk and procurement management suggesting that CPM's find procurement a critical area that has to be managed towards ensuring that the procurement and delivery of materials coincide with the milestones highlighted in the programme;

- Implementing continuous improvement from one project to another was used often to always under human resource management (1st) suggesting that CPM's see the need to ensure that implementing continuous improvement from one project to another is carried out through human resource team on the project.

In comparison, Table 1 then presented the means of responses to the frequency of use of the nine project management areas of expertise in each of the 15 LPM principles highlighting were each area of expertise was most frequently used. The following was noted:

1. Cost management was used often to always under improving planning and communication, suggesting that improper planning and communication will have a negative impact on cost management for the project.

2. Communication management was used often to always under improving planning and communication suggesting that there is consensus with improving communication under communication management as highlighted by CPM's.

3. Integration management ranked 1st under benching marking techniques including the use of key performance indicators, highlighting that CPM's are tracking their performance by integrating benchmarking techniques and key performance indicators during the construction phase of the project.

4. Procurement management was used often to always under reduce lead time, suggesting that reducing the lead time under procurement management plays a vital role towards ensuring that delays in the programme are avoided as long lead items must be ordered timeously so that they are delivered and installed in alignment with the programme.

5. Human resource management ranked 1st under improving work planning and forward scheduling, indicating that CPM's prioritise improving the team's work planning and forward scheduling so that any anticipated delays or hold points can be identified prior towards eliminating possible delays so that the programme is delivered on time.

6. Risk management ranked 1st under risk management techniques highlighting that there is consensus between the application of the principle under the respective area of expertise.

7. Scope management was used often to always under direct intervention to drive immediate and apparent change, suggesting that CPM's ensure any changes to the scope that may impact the programme is driven immediately towards understanding the nature of the change, its impact on the programme and then determining the way forward.

8. Time management ranked 1st under implementing critical path analysis and programme management and maximising work flow, minimising the performance variation rather than focusing on speed only. This suggests CPM's ensure the management of the programme including the execution of the critical path is monitored closely during the delivery of the programme so that the project is delivered on time. In addition, it is also indicative that CPM's focus on maximising the workflow towards ensuring more work is executed and completed rather than increasing speed and minimising performance. As a result, progress of the works is capitalised on towards ensuring the successful and timeous delivery of the programme.

9. Quality management was used often to always under improving work planning and forward scheduling including risk management. This indicates that detailed planning of the programme including execution of same was seen as critical by CPM's towards ensuring that risks are mitigated and controlled so that quality is not compromised by abortive work being redone due to poor quality workmanship. This ensures that the programme is delivered on time but at a quality level that is acceptable and satisfactory.

The mean scores and rankings presented in Table 1 bring to light that CPM's are aware of LPM and are utilising these principles under the nine project management areas as an initiative towards improving the delivery of the programme during the construction phase of public sector projects. It is evident that there is consensus between LPM principles used often to always under the nine project management areas. The data did however, identify that not all of the LPM principles are equally implemented under each area of expertise.

5. Conclusions and Recommendations

Having reviewed the concepts of LPM, the public sector, the CPM profession, the construction phase and project programme including the relationship between these areas of concern and taking into consideration the results of the survey, this study comes to the following conclusions: It is evident that CPM's were implementing most of the LPM principles under the nine project management areas of expertise as an initiative towards improving the delivery of the programme during the construction phase of public sector projects. While other principles were only used seldom to sometimes, suggesting that there is room for improvement regarding the equal implementation of all principles under the nine project management areas. It was therefore concluded that CPM's are aware of LPM and are using these principles and techniques during construction projects towards improving the delivery of the project programme.

As a key role player on construction projects, CPMs were identified to be in an opportune position to drive the implementation of LPM on public sector projects. CPM's may consider partnering with the public sector to eliminate/ minimise challenges with implementing LPM principles under the nine project management areas during the construction phase towards improving the management and delivery of the programme. This could be facilitated through regular workshops and programming meetings being held with the public sector and CPM's during the projects life cycle, whereby the problems/ drawbacks are identified and listed, so that control measures are put in place such as risk management plans in order to monitor and avoid identified problems/ drawbacks including dealing with them immediately as they occur.

It was also found that CPM's were using LPM on an ad-hoc basis. LPM was being implemented where CPM's felt it needed to be applied and not as a requirement under all areas of expertise. Hence, it is suggested that the public sector promotes the implementation of LPM though the development of a policy for LPM implementation on their construction projects which will make room for LPM to be applied in a structured manner throughout the construction phase of public sector projects.

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3 Step Site Layout Planning

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Abstract

This paper proposes a method named "3 Step Site Layout Planning" in order to define construction site organization. The designer is supposed to go, one after another, through three activities, that are: construction sequencing definition; transportation system choice; and site layout definition. The method is the nowadays version of an attempt of the authors to propose a useful tool to help construction managers to design their sites. A first approach was proposed, some years ago, based on the literature about the theme. After several uses in real construction cases, it was improved until the present status that is considered to fill manager needs. This method was used, by the authors, for as much as 50 real construction projects. In order to better explain the commented 3 steps, this paper describes one example of each step.

Keywords: Site layout, construction planning, construction design.

1. Introduction

Any industrial production description demands three types of design that are related to: the product being produced; the adopted process; and the factory that hold all the activities.

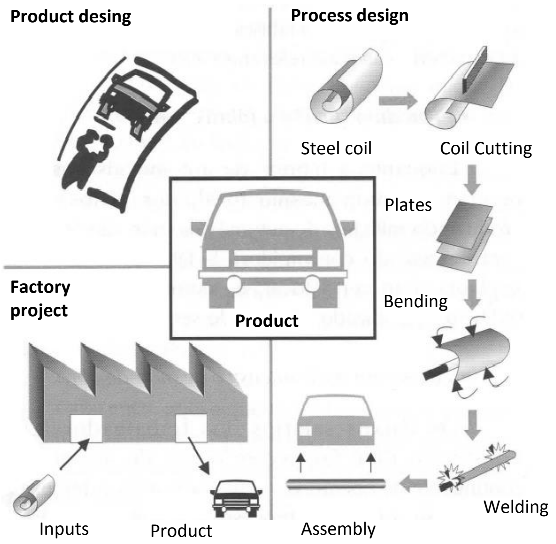


Figure 1: Industrial production of a car (Souza 2000)

Building construction industry should proceed the same way. But it is very common, in Brazil and in several parts of the world, to face very poor representations of production sites. One can point out several reasons to justify this situation: product stays in, and factory moves out; each workday is different from the others; etc. But the variability of the construction products and processes, leading to a very large range of production efficiency, safety, and quality indexes, can be pointed out as stronger reasons to justify spending technical efforts in deeper discussing construction sites. In this context, the authors have been working in both developing and implementing a method to be used for such a purpose.

Building construction sites usually hold a very large amount of workers and materials. One square meter of construction can demand from for about 5 to 100 work hours; such a construction labour productivity, associated to tight schedules, can lead to a very large crew (many times hundreds of workers) to be hosted in the site. Bathrooms, dressing rooms etc. should be available; and also organized work areas should be there to provide good work conditions to guarantee work efficiency and safety. One square meter of a building weights for about one thousand kg; then, the amount of materials to be stocked and moved along the site, and the ways to do that, are special topics to be addressed by construction managers.

The authors, concerned with the necessity of improving labor productivity, material transportation logistics and workers safety in the site, and based on their personal experience and literature about the theme available at that time, proposed a method to deal with site layout planning. During several years a textbook presenting the method was adopted in several construction management disciplines in Brazil as the basic approach to discuss site layout. The author's professional experience, along the last years and more than 50 construction sites studied, lead them to propose the application of such a method stressing three main discussions: construction phases; transportation systems; and site layout. The improved approach has been used in several construction cases and it is been useful to help discussions about improvement of labor productivity, logistics and safety construction (Figure 2)

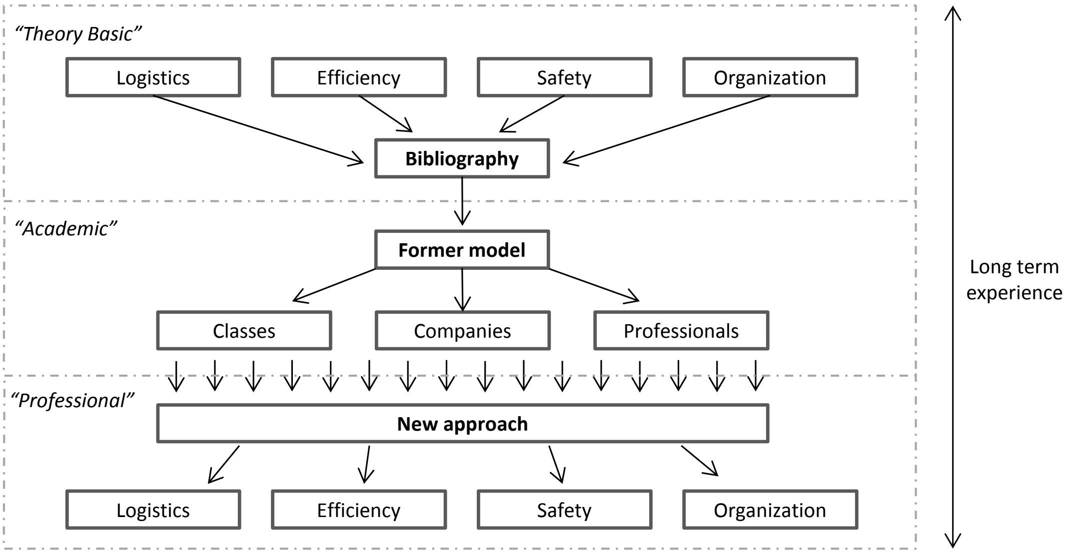


Figure 2: Author's experience and new approach

2. Theory about site layout

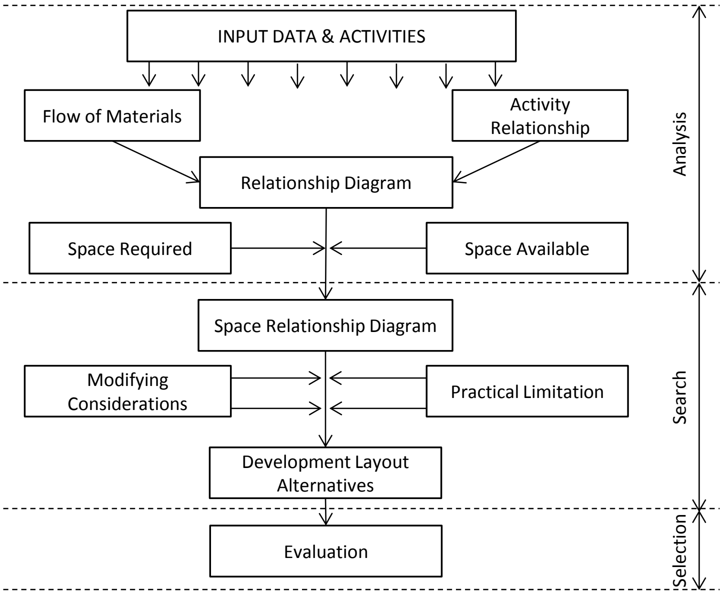
Table 1 presents the authors understanding about how to deal with site layout planning. Unfortunately, to deeply discuss building construction conception, differently from other design subjects, is still new for the contractors in Brazil.

Table 1: Site layout planning approaches (adapted from Souza 2000)

Questions about the design process	***Incorrect posture***	***Correct posture***
How to design?	*From personal criteria*	*From pre-set criteria*
When to do it?	*When you need*	*Preferably, before the work start*
Who designs?	*Who is around when the decision has to be made*	*Set of people that reflects the ideas of both the management and the workers*

Authors first experience in trying to establish directions to design construction sites was based on the ideas proposed by Muther (1973) in his book. Muther proposes several tools to help conceive a factory layout. For example, Figure 3 presents a diagram to define the factory areas to be closer to each other.

Figure 3: Defining area relative proximity importance (Muther 1973)



The steps related to the project process, such as, preliminary information and definitions regarding the process technology and demands for physical resources and spaces inside the construction site, have already been exploited enough by other authors, such as Parker & Oglesby (1978), Peurifoy & Ledbetter (1985), Souza (1993), and more recently, Andayesh & Sadeghpour (2014) who did comparative study of different approaches for finding the shortest Path on construction sites.

During his academic work, the main author of this article also contributed to the studies on construction site guiding some thesis dealing with site layout planning. Birbojn (2001), for example, listed all the site "elements" (parts) one site design should address presenting criteria to orient designers to choose among several alternatives they have to define each element. Table 2 shows the site elements classified according to Birbojn.

Table 2: Site elements types (adapted from Birbojn 2001)

Site elements	***Examples***
Related with production	*Central procession unit, production site…*
Support of production	*stocks, warehouse…*
Transportation system	*lifts, tower cranes…*
Administrative support	*offices, reception…*
Living space	*sanitary facilities, canteen, ambulatory…*

In such a context, authors like Handa & Lang (1988) described sampling elements considered necessary for the operation on construction sites and, through observation of these elements, developed a checklist for the projects evaluation containing weights for each item to be evaluated.

Another research advised by Souza, Maia (2003) considers a site designer goes through different phases in the conception processes and indicates that some of them demand more a mathematical work than a creative effort. He also proposes some directions to help the creative phase of the site layout planning. Figure 4 summarizes some of his directions.

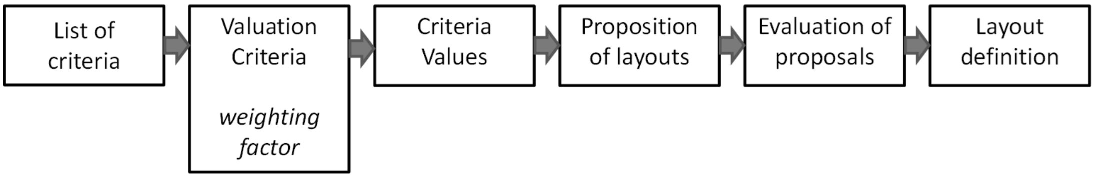


Figure 4: Direction to help creative job in designing site layout (Maia, 2003)

The compatibility between the phases of construction can be done with adjustments to positioning of elements, or changes of schedules, as Zouein & Tommelein (1992) did, aiming at reducing changes in the physical arrangement.

In order to help improving site layout planning implementation, Souza (2000) proposed a step by step method for new site designers. Figure 5 shows a flowchart discussed by Souza in his book.

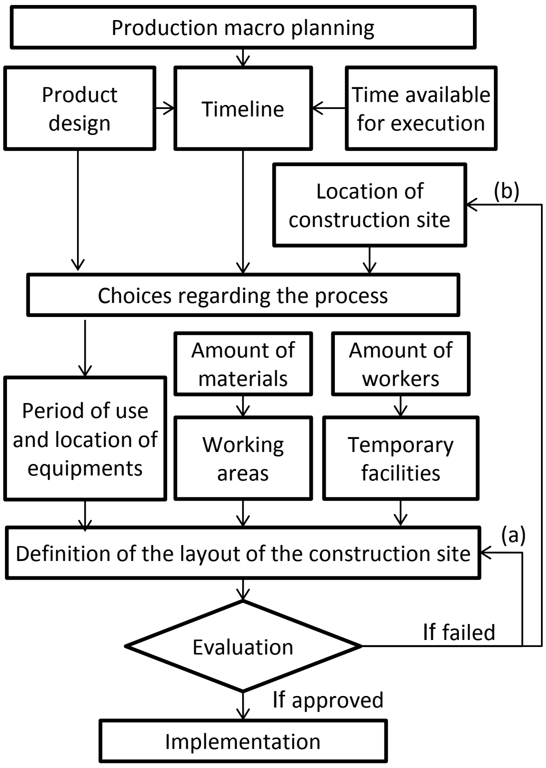


Figure 5: Sequence of site layout planning activities (Souza 2000)

Ideas proposed by Souza (2000) were used in several courses dealing with Construction Management, both for undergraduates and graduates. Some Brazilian researchers, as De Freitas & Santos (2009), tried to facilitate the use of these (and other) ideas leading to the site layout designing "by offering computer resources to help in their decisions making process and to visualize the spatial distribution of the elements in the construction site". Other countries researchers also tried to help stablishing a routine to design site layout in a similar way. Tam & Leug (2002) uses TI to import data to be used in the decisions and believes 3D visualization is very useful in discussing layout. The same authors and also Khalafallah & El-Rayes (2006) also presents algorithms to help some decisions, as for example to evaluate materials transportation cost.

The authors believe TI can help a lot not only with site layout planning but also in several others areas of construction management. But they also believe all these tools just can really be implemented if the process as a whole in defining site layout is understood. Based on the ideas one can see in Figure 5, the authors participate in real site layout planning activities during several years. In their professional experience, they have success whenever a representative group of the construction managers of the site being designed were able to participate in a process where 3 main issues (named "steps") were discussed and decisions were taken about them. These three needed decisions are described in the next item. But the authors believe that: 1) sequence of activities to produce one building extremely influences site layout best solution; 2) materials transportation is an issue to be addressed but there is more than one good solution to provide transportation, and to find the best choice demands interactions with the other 2 steps; 3) locating the several elements (working and nonworking areas) is something that demands more than architectural skills, for example to take into account manager can even change technology or supply politics to help finding better solutions for layout.

3. Proposed method

3.1. General description

The method was created based in a long term research and implementation effort, in a "back and forth" experience type. The academic studies and the opportunity to implement them in several real cases molded the nowadays method. In a very simple description, the new method uses the old ideas (see Figure 5) with an emphasis on the 3 commented aspects steps: construction phases understanding in terms of site demands; using mathematical models to determine the best transportation system for each case; and approaching architectural prescriptions both for working areas and temporary facilities to be built. Although a strong interaction among them occurs, the 3 aspects can be seen as 3 steps to reach the main goal, that is, discuss site layout before the construction activities begin.

Then, the main steps (Figure 6) to face a new project production conception are named: a) construction phases definition; b) macro logistics; c) site layout.

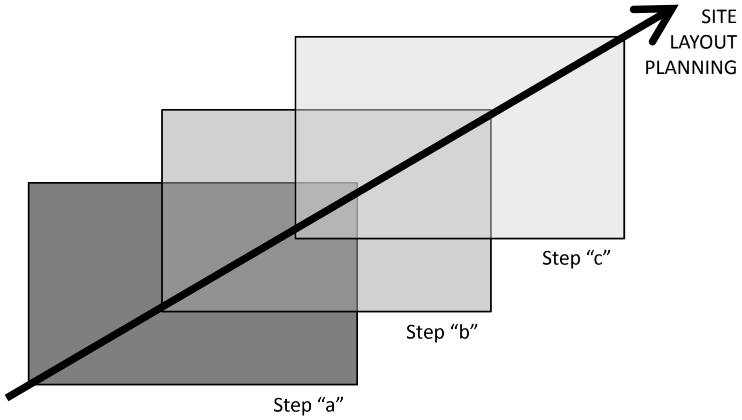


Figure 6: The three steps of the new approach to design site layout.

In step "a" the product as a whole is broken into parts to be produced in a certain schedule; each part is described in terms of its demands in terms of workers, materials and space. In step "b" the transportation systems (a group of machines/tools, varying in terms of type, quantity, location, and process of use) are defined, varying for each phase of the construction schedule. Step "c" is the one where creativity is more present; different architectural solutions are proposed to face resources demands and transportation prescriptions, both in terms of working areas and workers facilities.

3.2. Examples of the steps

3.2.1. Step “a” – Production Macro Planning

Considering the construction of a single building, Figure 7 exemplifies different plans of production that can be followed. One can plan to produce the tower as a whole before dealing with periphery; the opposite can also be planned; and a mix of the two approaches may constitute the plan to be chosen.

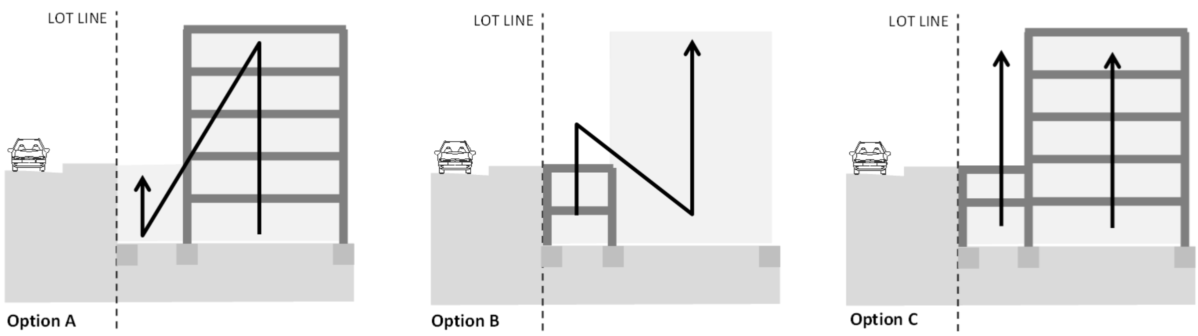


Figure 7: Example of distinct production macro plans for the same building to be built: a) tower before; b) periphery before; c) tower and periphery simultaneously.

Figure 8 presents a real example where plan “b” was adopted instead of plan “a” (to excavate from the back to the front portion of the site; and the same in order to latter produce foundation, steel reinforced concrete structure etc.) which is usually adopted by construction planners. The project holds three towers located in a relatively narrow site with just an only access (a very crowed by cars avenue near tower 1). Plan "b" allows the area of tower 2 to temporarily host the rebar working area avoiding material stocking crash.

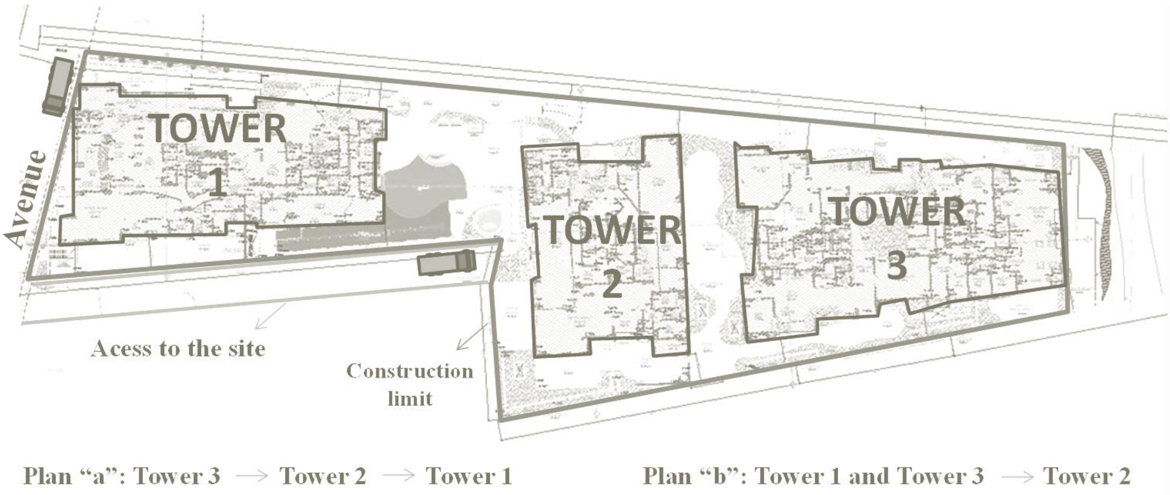


Figure 8: Project with three fifteen-story apartment buildings in Rio de Janeiro state- Brazil

3.2.2. Step "b" – Transportation System Definition

Material moving usually evolves several repetitions of a cycle, described as showed in Figure 9, with 4 parts: beginning, going, finishing, and return. The total time to completely move an amount of materials is defined once one knows the total amount to be moved, the quantity it is moved each cycle and the time of one cycle. More than this simple model, delays should be considered to calculate the capacity of a certain transportation system.

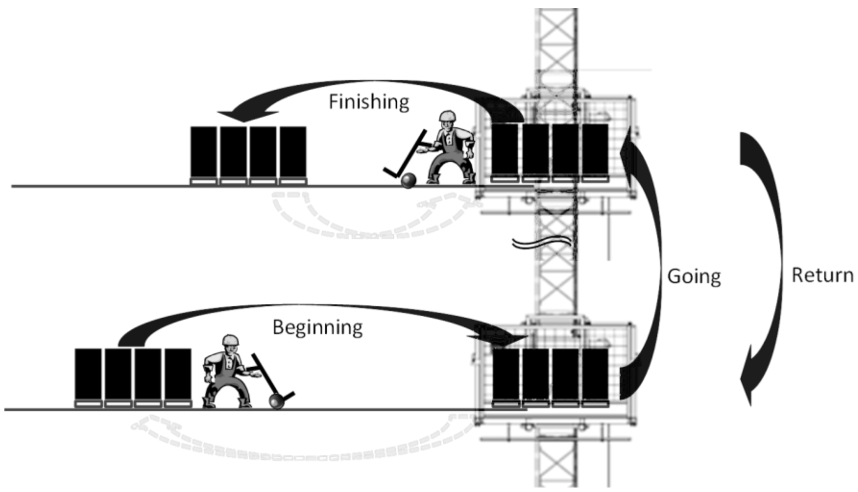


Figure 9: Cycle of materials transportation.

Once one knows the quantity and type of transportation equipment to face calculated demands, it is necessary to provide an appropriated location for them in the site. Figure 10 shows tower cranes (fixed and mobile) location in a multiuse (shopping mall and corporative office building) project in São Paulo – Brazil.

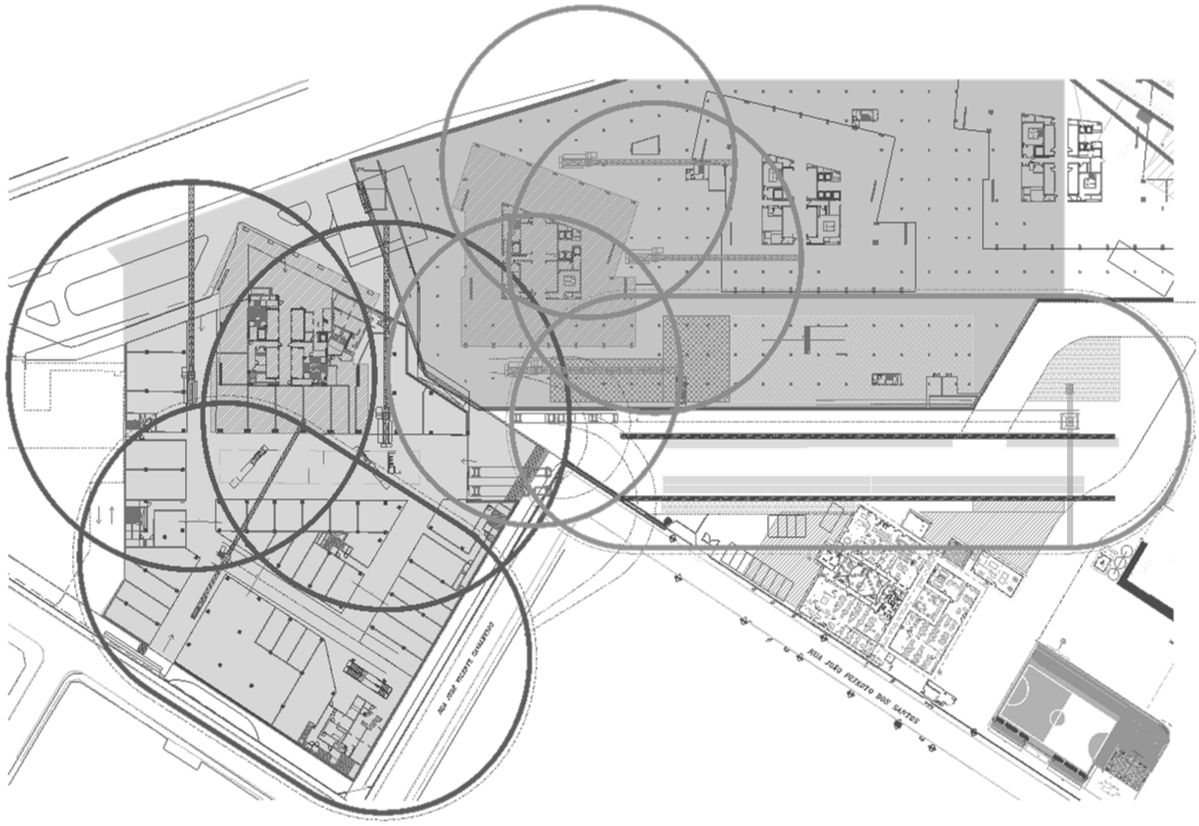


Figure 10: Location of the demanded tower cranes in a multiuse project site in São Paulo state.

3.2.3. Step “c” – Site Layout Drawing

Once site layout varies almost continuously (accordingly to the construction phases), some drawings are necessary to represent it. The drawings should both represent the working areas and temporary facilities for the workers. Each area can be represented as a “piece in the whole design” (“overview” of the site elements) but also it can be showed in detail.

Figure 11 presents an overview, in the beginning phase, for a residential two tower project where one can see the representation of several working areas, but also the access for trucks and even the place used to sell apartments.

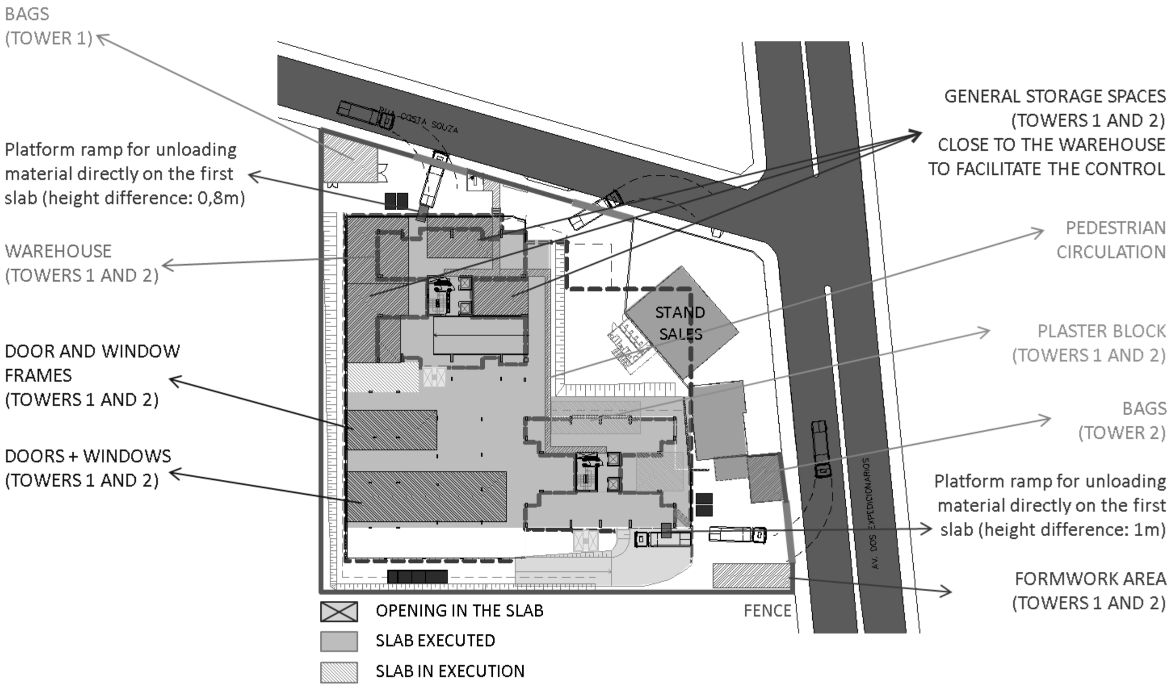


Figure 11: Overview site drawing, in the job first phase, for a residential project in Ceará state – Brazil.

4. Conclusions

This paper summarized a method that has been used in several Brazilian projects. The ideas here described were firstly defined in some academic researches; later, these ideas were used in real cases and there was a kind of improvement, both simplifying and fulfilling the directions to help designing the sites. Simplifying the steps to discuss site layout planning allowed more site managers participation what, in the authors opinion, increase de number of construction projects working with site layout designing. The method has being successfully used in a varied type of projects; from an unique house construction to a very huge multiuse group of high rise buildings. In terms of demanded research, the authors believe TI can help, but they recommend an emphasis in improving methods tools that gather together decision related to the 3 described steps.

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Application of the Domain Theory to Warehouse Concept Development: A Case Study

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Abstract

The need to manage and coordinate design has been recognized in different industries, including construction. However, teams need to have a shared language, which requires a design framework or in other words ontology, providing a terminology, principles and methods. Systems thinking approaches have been used in variety of design ontologies, here we have focused on the Domain Theory (DT). The purpose of this work is to understand how a common design framework aids the design inquiry and management. For that the DT is outlined, its implications to construction are reviewed and a case study as a main method is carried out to illustrate the effectiveness of this design theory for practice. The DT provided the common framework for studying end users, their needs and requirements based on their business operations. Also, the DT supported the design team in understanding the purpose of verification and validation. Results indicate that the common theory reinforced focusing on key parameters, issues and design requirements. However, outcomes also illustrate that system approaches tend to be resource intensive, requiring a more thorough analysis up-front.

Keywords: Domain Theory, design domains, technical activities, organs, structure

1. Introduction

The need to manage and coordinate design has been recognized for some time in industrial product (artefact) development (Farr, 1966), mechanical engineering (Andreasen, 1980), architecture (Emmitt, 2010) and also in engineering design for construction (Ballard and Koskela, 1998). The main reason for these developments is the division/disintegration of master builder into dedicated disciplines as the body of engineering design knowledge and expectations to efficacy have rapidly increased throughout the last three centuries (Kranakis, 1997, Reed, 2009). This has increased the complexity of construction projects and thus, the need for more thorough cooperation, coordination and management of engineering design processes thorough effective communication (Kleinsmann, 2006).

For the latter, design teams need a common language, such as a Domain Theory (DT) (Andreasen et al., 2014). Andreasen (2011) defined 'domains' as a set of dedicated views onto a product:

activities, organs and parts. These are used as the skeleton of a procedure for the product development/design. Domains consist of entities; e.g. the activity domain is determined by the user's application of the product, which together with the user experience and usability, to satisfy the initially unsatisfied need. Thus, the DT is an ontology, a common modelling framework, providing the viewpoints and vocabulary to represent the knowledge needed in product development.

An explicit and common modelling language allows transforming mental models into explicit models that can be shared among designers (Erden et al., 2008). Defining the domains, entities and the types of relationships can serve the purpose of developing a theoretical and conceptual model for engineering design coordination and management. Moreover, a consistent ontology supports the development of computing technologies and helps avoiding mistakes due to the neglect of some domains (Gielingh, 1990).

The aim of this research is to understand how formal design framework aids the design inquiry and management. More particularly, here we review the Domain Theory and its implications into practice (Andreasen et al., 2014, Howard and Andreasen, 2013). In the first part of this paper, a theoretical framework of DT is outlined; in the second part, the implications to construction industry are summarized; and finally, a case study, informed by the DT, is compiled to illustrate the importance of design theories.

2. Methods

The purpose of this study is to understand the implications of a common design framework (Domain Theory) to design practice. Thus, this research aims to answer to the following questions: How does the common design framework aid the conceptualization of design solution from users' perspective? What implications does the framework have on design team and process? For that a qualitative case study method is used to acquire context-dependent knowledge (Fellows and Liu, 2009). The lead author of this article participated in the development of new warehouse concept for small and medium sized businesses dealing with wholesale, retails sales, services or combination of these. This work focuses on the early stages of design and processes for developing a new concept for warehousing.

3. Engineering Design Terms and Frameworks

Across industries, several design researchers have tried to propose a unified definition for engineering design. Here, we start with the definition proposed by Evbuomwan et al. (1996):

> "The process of establishing requirements based on human needs, transforming them into performance specification and functions, which are then mapped and converted (subject to constraints) into design solutions (using creativity, scientific principles and technical knowledge) that can be economically manufactured and produced."

This definition succinctly illustrates the subject and the content of engineering design and three aspects are clearly visible. First, designers work on a variety of aspects during design process:

needs (voice of the customer), performance requirements (required, expected and actual behavior), functional descriptions, structural descriptions, and production/manufacturing processes. Secondly, engineering design can be viewed as a process, using different modes of reasoning, including regressive vs. deductive (backward and forward), decomposition vs. composition (breaking down and putting together) and transformation (transferring problems between abstract and particular) (Koskela et al., 2014). Thirdly, design is between thought and object (Bucciarelli, 2002), aligning three aspects of facilities, including user needs and requirements, design solutions and production processes.

3.1 Domain Theory

Several engineering design frameworks have been developed based on the systems thinking approach, such as the DT by Andreasen et al. (2014). DT consists of several models and concepts for understanding and researching design practices. The basic domains in DT include: technical activity, organ and part (structure). Andreasen et al. (2015) define the technical activity as the user's application of the product (use functions) for fulfilling the unsatisfied need. A use function is an activity of the user to utilize the product for performing certain action. Chen et al. (2015) define a need as a subjective desire of a person to change a problematic conceptual environment into a desirable one. The organ domain is the set of functions, the means of a product, displaying a mode of action (realization of function) and its behavior (properties). Part domain consists of components as an elementary material system, making-up an organ, realizing the organ's mode of action by the part's physical states and interactions. Thus, an artefact is defined by its structure, describing the anatomy of components, properties and relationships.

Properties of the systems and components are divided into two categories, describing the product structural characteristics (form, material, dimensions and surfaces) and behavior (derived from structural characteristics) (Andreasen et al., 2014). Characteristics are a class of properties of an object that define the means by which the object's behavioral properties are realized (Albers and Wintergerst, 2014). The behavior reveals when product is deployed by the user(s) in its context for use purpose and processes. In engineering design literature, behavior is characterized by successive states, including manifestations and value of the properties of the system in response to its environment and the received stimuli (Albers and Wintergerst, 2014).

When a product is deployed it contributes to the transformation of operands such as material, energy, information and/or biological objects. The properties of use functions in relation to the operands are described by their input and output states; the necessary effects from the operators, their nature, their state and how they lead into contact with the operands; and the active environment (Andreasen et al., 2014). The organs are based upon physical, chemical or biological phenomena. When stimuli act on the organ in its context, it delivers an effect. In other words, organs are also called *wirk* functions (Hubka and Eder, 1996, Albers and Wintergerst, 2014), which is a statement about what the product does when in operation (Howard and Andreasen, 2013).

Also the structure and its components are active and interact with each other through their assembly interfaces (Howard and Andreasen, 2013). Components are related to the *wirk* functions, which are based on natural (physical, chemical and biological) phenomena. A part interfaces with other parts and its surroundings, creating the effects of the part. Therefore, the DT defines the domains, its entities and relationships to describe the practice of engineering design.

Andreasen et al. (2015) have also described the engineering design process as a progression throughout the domains in DT. They define the engineering design process as a causal chain: user need > use activity result > determination of use activity > determination of the product's effects and functions > determination of organs and organ structure > determination of parts and part structure. However, in practice, design is not a linear process from needs to structure, it is rather a top-down and bottom-up approach simultaneously (March, 1984), meaning that problem and solution are coevolving throughout the design process.

3.2 Summary of the Domain Theory

The DT, initially developed based on the Hubka's Theory of Technical Systems, distinguishes between use functions (e.g. write text) and *wirk* functions (e.g. deposition of graphite onto the paper by means of pressure and friction) (Howard and Andreasen, 2013). This shows that designers do not only designate a product's behavior or mode of action but also the use activity of the end user. Secondly, the DT differentiates two types of properties, static structural characteristics as means for realizing the objectives and behavior (state variables) corresponding to the stimuli and changes in the environment. Thirdly, design is a process, moving from the need to the description of a structure (part domain) for delivering the expected effects (behaviors). Thus, design is a modelling process for establishing the network of connections between entities in different domains through the expected behaviors to be actualized.

4. Conceptualization of an Engineering Design Framework for Construction

Essentially, buildings are designed to facilitate users' personal or business operations. Space as the functional unit facilitates the satisfaction of user needs. In this work we consider the activity, organ and part domains of DT as a common denominator for design processes and disciplines. In following sections, the content of these domains are discussed in detail.

4.1 Activity Domain: Deployment of Facilities for Value Creation

As in the theory of domains (Andreasen et al., 2015) or proposed by Pennanen (2004), the first domain to be considered is the user process domain. This is an activity-based approach for decomposing client processes (personal or business) into user activities/sub-activities and their properties that realize the client's goals and thus are value-adding. For example, in office building the activity 'meetings' can have these properties: type of an meeting, types of participants, number of participants and usage of equipment (projectors, tables, chairs etc.). Currently, this tends to be considered only informally in the design process (Pikas et al., 2015). Thus, in the activity domain, use functions are defined as interaction with the artefact.

4.2 Organ Domain: Space as a Functional Unit

The user activities, their nature and resource requirements become the basis for defining the environment and its facility centric functional organs to be decomposed into sub-functions. This is typically articulated in the project brief, including information about the area (unit of area per room/person), dimensions (e.g. ceiling height), indoor climate (e.g. temperature, air exchange type and volume, air movement speed, cooling, heating and control of indoor climate), acoustics, lighting, electricity, water supply, sewage and use of equipment. It describes the facility consisting of functional spaces and its sub-functions, some required as resource for activity and others determined by the design decisions (Pennanen et al., 2005).

However, the articulation of spaces in the project brief is a complex activity, where form and use function of the building play the main role in determining how spaces should function, laid out and utilized. Required spaces affect many different aspects of the building, including its form, layout, utilization and spatial planning (Mayouf et al., 2014). Moreover, in a building program, expected behaviors of functions and structures are determined (e.g. air exchange rate). Thus, the completed building program, even though still subject to changes in later stages, is the basis for engineering design process. Koga (2010) defined functional decomposition as value engineering in Integrated Project Delivery, or in other words functional analysis.

4.3 Part Domain: Linking Functional Requirements to Structural Description

Design theoreticians have considered this as the kernel of the design process (Andreasen et al., 2015, Suh, 1998, Kroes, 2002). In schematic design, architect analyses the user needs and translates these into functional requirements (spaces and its sub-functions) and expected behaviors (temperature level to be maintained) as a basis for design conceptualization, and syntheses of the form based on selected technologies and materials required for meeting the client needs. The form defines the internal and external spaces, a composition plan for the totality and the details (relationships), social and economic issues, and a framework for human interactions (Andreasen et al., 2014). According to Hubka and Eder (1996), form can be interpreted and modelled as geometry. Other main structural characteristics include the materials, technologies and dimensions, determined to meet the expected behaviors of the structure. The outcome is the design concept describing the system architecture and its division (structure, HVAC, MEP etc.). Each system consists of a number of components designated during the embodiment of functions and expected behaviors, and its configurations and connections (Ullman, 2009). Particularly, it is the selection of components and their physical characteristics that determine the actual behavior of a system and the best fit with the requirements of the project brief. For example, the architect can link a ventilation unit to the requirement of minimum air exchange rate in a space.

5. Case Study for Illustrating the Implications of Domain Theory

In this section, a case study is compiled to illustrate the importance of domains and their entities; particularly, how the design ontology informs the design process. One of the largest Estonian companies, in the field of logistics parks and warehousing services, is looking for new opportunities for expanding their business services. Until now they have focused on large logistics parks, but they are planning to start providing warehousing services to small and medium sized vendors, service providers and trade companies. They were interested in developing a new warehouse concept that can be detailed for a specific parcel. In this sense, it can be compared to product development in industrial engineering. In the following, a short summary of the results and key findings are given.

5.1 Design Development Process

Largely, the design development process was divided into three steps: I observation of existing solutions and user needs; II design conceptualization; and III product concept development. In the first step all similar existing facilities were mapped in and around Tallinn, Estonia, and ten existing facilities were selected by the project team for closer study. Then the team, including client representatives, the architect, the design project manager and the lead author of this article, paid a visit to these ten facilities during a period of two and a half days. The result of this was 20 page report, summarizing the problems, existing solutions, main users, use activities and user needs/requirements. In the second stage, the report developed in the first stage, became the basis for conceptualizing the product and articulating the design task. The team avoided compiling heavy documentation, instead through several iterations a two page design concept paper was compiled as a basis for schematic design. The third step, product concept development took place over many weeks in an iterative manner. The architect proposed concepts, which were discussed within the project team. The final outcome was the concept for modular and flexible combined warehouse, office and service spaces.

5.2 Observation of Existing Solutions and User Needs – Activity Domain

As a part of a activity domain, ten sites were visited and users were questioned regarding solutions and their satisfaction. The following are the main observations:

- **Complex nature of the client:** All observed companies were importing goods and depending on the type of a product, these companies were either doing wholesale, retail and/or provided product related services (e.g. a tire shop), determining which kind of functional spaces were needed. Overall the following target client categories were identified: wholesale, retail sales, product related services or combination of these.
- **Typical spatial layout:**
    - Average space area per company was 317 m^2, including either storage, office and show rooms or combination of these. However, the distribution of spatial area

varied remarkably, and excluding one very small company from the sample, the average area increased to 568 m^2.
  - There was no correlation between the number of people working in the company and storage and/or show room area.
  - The average office area per person was 14 m^2. However, most of the tenants indicated that it was too much and more storage space was required. It was concluded that around 10m^2 of space per person in the office would be around the optimal solution.
  - Show rooms must be flexible and situated on the first floor, meaning companies who want can use it as a show room and others as an office space or service space.
- **Limitations of building form, layout and solutions:**
  - Offices spaces were designed throughout the whole building depth on different floors. The problem was that companies who had storage spaces on both sides of office spaces had difficulty moving goods between these two, they had to either transport the goods through office space or from outside. The latter is a problem in winter.
  - Several solutions had storage space through three floors, resulting in heights around 9-10 m. For workers responsible for storing goods this was a bad solution as it complicated the process of stowing goods.
  - Poor layout of office spaces as people working in these indicated that they did not have space for resting, eating or meetings.
  - Thresholds between show rooms and storage spaces hindered transporting goods.
  - The shelves were too long hindering the entrance and exiting through the transportation doors.
  - Also, several companies indicated that the transportation doors for transporting goods in and out from storage space were disproportional, either too high or wide.
  - Lights and ventilation ducts were crisscrossed with roof trusses.
- **Technical solutions:**
  - Observed buildings were made of precast concrete or steel structures, including sandwich panels, steel or concrete structural frames.
  - For heating and cooling mainly electricity based systems were used, e.g. air to air heat pumps.
  - Five buildings out of ten had skylights either in office or storage sections as the storage buildings can be relatively deep.

5.3 Design Conceptualization – Organ Domain

The observations within activity domain became the basis for articulating the goal and requirements. The main goal was to develop: “Modular, flexible, spatially optimal, cost and energy efficient combined production, service, storage and office building for small and medium sized wholesale, retail or service companies.” Table 1 defines the value structure for the project, defining the category, expected performance and constraints.

Table 1. Summary of concept categories and expected performance.

Nr	Category	Expected Performance
	Suitability	
1	Modular spaces	Space range per module: 200-600 m^2
2	Flexible storage and show room spaces for expansion	Movable internal walls and flexible building services
3	Effective form, spatial layout and stowing of goods	• Office spaces shall be along the front exterior wall of building • Storage spaces shall have optimal paths for the movement of equipment and transportation of goods • Office spaces must have small kitchenette and toilet on first and second floors • The width of the corridor shall be designed based on maneuvering radius of forklifts with lifting capacity of ≤ 1.5 tons. Expected width between shelves ≥ 3.2 m • For the maximization of storage spaces the optimal spacing of shelves shall have two or three corridors • Office space ≅ 10 m^2 per person • Size of the transportation doors: ≥ 2.8m height and ≥3 m width • Clean height of storage space under trusses: 6m (clean height for stowing is 4.5 m)
	Aesthetics	
5	Comfortable working conditions	Well-lit working spaces and aesthetical materials
	Sustainability	
6	Energy efficient	Cost effective energy efficiency solutions: minimum requirement is B-class (consider renewable energy)
7	Indoor climate control	Users have possibility to control indoor climate, heating, cooling, ventilation and lighting
	Durability	
8	Optimized structures and details	Cost optimized solutions of structures and details
9	Optimal maintenance costs	Highly enduring materials and maximum lifespan (50 years for structures)
	Construction Cost	
10	Construction cost	≤ 400 €/m^2 (target cost)

The overall preferred layout for the business activities is that goods are transported from behind and clients enter from front. The functional decomposition depends on the business function or main activities, which here were divided into four categories: **wholesale**, **retail sales**, **product related services** or **combination of these.** These categories became the basis for spatial decomposition as follows:

- **Office spaces**: must be aesthetical, comfortable, functional and well lit. Companies want to provide good working conditions to workers. The office spaces must have good layout, providing enough workspaces, kitchenette and toilet. Typically, companies with total space around 400 – 600 m^2 also need small meeting room.
- **Show rooms**: Not all companies need this type of space, those who need have varying requirements in terms of size. Thus, first floor offices spaces must be flexible, either be used as a show room, reception space for clients or as an office space.
- **Service areas**: Companies, who need service spaces, must have rooms two floors high. Some companies who provide services also provide shower and dressing room for workers.
- **Storage spaces:** In general goods can be divided into two groups: small and large by size. Thus, larger goods are moved with forklifts and smaller ones by hand. Companies need enough space between shelves to manoeuver with forklifts. Regarding the indoor climate, few companies had products that required controlled indoor temperature and humidity levels.

5.4 Product Concept Development – Part Domain

In this stage, architect prepared the first draft based on the selected concept, linking functional requirements to physical characteristics. The overall concept was a modular warehouse for different user needs. Modules were defined as rectangles in varying sizes, which were combined in different ways to form a whole building. However, the whole size of the building will depend on a specific site, zoning requirements and design requirements by the local government. The driving concept for the architect was “organized chaos”. A model was prepared in Graphisoft ArchiCAD to facilitate the conversation between the architect and the client. The starting point for the architect was the storage space with two or three corridors between shelves and with the size of the columns, initially 300 x 350 mm.

The second aspect that the architect had in mind was modularity, the proposed main module being 6 m x 6 m. However, the first module, including office spaces and show rooms, was 7.5m deep. The architect also had to consider the other constraints, such as transportation door width and height. For example, based on the size of transportation doors, the first floor windows were chosen to be of the same size. During this iterative process several layouts were proposed and in each iteration, the architect focused on a specific aspect. After a few iterations, the structural, HVAC and electrical engineers were involved, performing the basic calculations to verify the architect’s assumptions and proposed conceptual solutions for different systems. For example, the columns were changed to 400 x 400 mm due to the fire safety considerations.

The biggest challenge was to find appropriate solutions for flexible spaces, which was considered as an important innovation and a primary goal of the project. As shown in Figure 1, the end walls of each section are movable. The same is with the office and show rooms, however, these can be expanded only to right and left in respect to the front and back of building. Flexibility was required considering how to build lighting systems and building services in the way that these would accommodate the changes in the layout of the building. Therefore, the meters for measuring the energy consumption were designed to be placed to the beginning of every rentable section of the facility. Lighting systems were connected through outlets, in case of moving walls the connections can be moved as well from one outlet to the other. For same reason of flexibility, the floors for second floor were planned to be built of standardized prefabricated wooden frame panels and the interior walls of sandwich panels that can be easily assembled or disassembled.

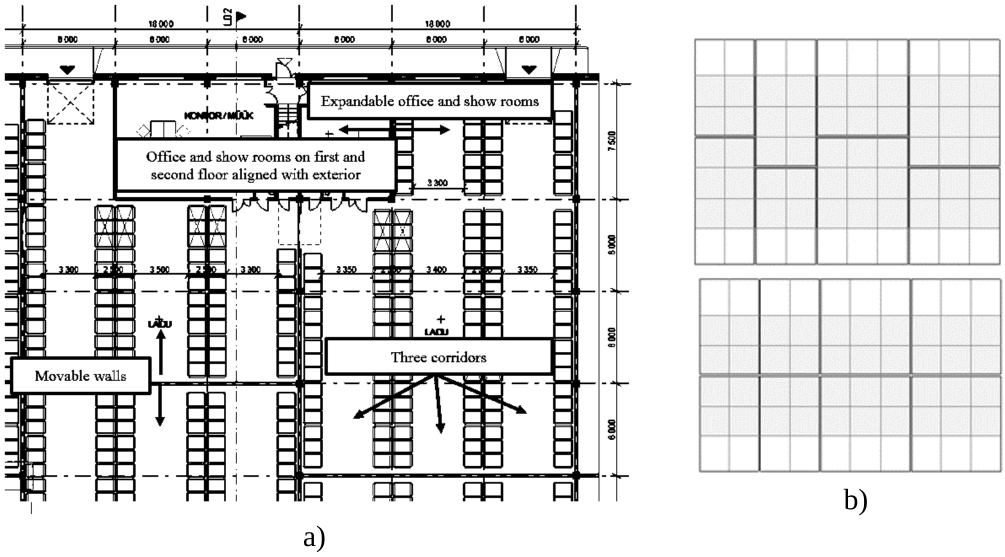

Figure 1. Combined storage, office, service and show rooms building: a) flexibility of spaces enabled by movable walls; and b) two examples of modules and composition.

At the end of the product development stage, one Estonian contractor was involved to validate the solutions from the perspective of buildability, and to make an early cost estimation. The model was used for quantity take-off and making buildability assessments. The target cost was set to 400 €/m^2, the contractor estimated 413 €/m^2. However, the team also figured that cost can be reduced by more detailed design and elaboration of technical solutions.

Furthermore, the client used the produced concept to validate the business model on the market. They used layouts and BIM based renderings to compile a fictive advertisement. Altogether, project got around 20 views on the website and three persons called and asked for more details. Although the interest could be considered low, it was also understood that organizations who are looking for new spaces are interested in facilities, which are already existing. The client confirmed the proposed product concept, and now the first project has been initiated.

6. Discussion

The case study, guided by the application of the DT, indicated the importance of a common design framework as a means for effective communication. Case study clearly indicates the content of the different stages: I stage as a part of activity domain was focused on observing existing solutions and user needs; II stage as a part of organ domain was for design conceptualization; and III stage as a part domain focused on the materialization of product concept. All involved parties agreed on the usefulness of common domains, entities and relationships. Furthermore, a clear articulation of project value structure, in terms of targets and constraints, facilitated the iterative design process. However, as the design team was busy with understanding the DT, the focus was not on design management, thus, causing the concept development to take three months more than was initially planned. Thus, this can also be considered as the main limitation of this research. In the future projects, design management aspects must be considered, including the implementation of Last Planner System and/or Scrum (from Agile Management) to plan, execute and control the design process by defining the information flows through pull mechanism. The other reason why this is particularly important is that currently the architect still tended to make many assumptions, instead of involving downstream engineers immediately to concept development. Thus, in the near future, the plan is to implement the cell layout for project design team, to facilitate real time communication and reduce the response time for request for information. The team also noticed that systematic approaches tend to be resource intensive, which currently is not a typical practice for the early stages of design. Thus, approaches such as Axiomatic Design theory, could be used to stage the design process by focusing on a key functional requirements and design parameters in each stage.

7. Conclusions

In this article, the DT and its implications for construction were studied through a case study. Answers for two questions were sought: How does the common design framework aid the conceptualization of a design solution from users' perspective? What implications does the framework have on design team and process? As for the first question, the DT provided the common language for the design team, a mental model for the design concept development. This means that the DT provided the common framework and reinforced focusing on key parameters, issues and design requirements. For the second question, the DT supported the design team in understanding the purpose of verification and validation. An example of verification was the involvement of structural and building services' engineers in the early stages of design, doing design review. However, the limitation of this case study was that the design focused solely on familiarizing with the DT, but not on the design management. The result was that the concept development took several months longer than was initially planned. Thus, in the future research, control methods must be implemented to maintain the schedule and avoid the architect's assumptions by using a pull mechanism.

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Multi-criteria Analysis of Service Life Prediction Methods Applied to Natural Stone Claddings

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Abstract

Depending on the user's perspective, a given reality can be represented in different ways and by different mathematical models. Service life prediction is a challenging task, due to the variability related with the degradation processes and the large number of variables that affect the buildings' life cycle. There are different possible approaches to the service life prediction of natural stone claddings. In this study, different models for service life prediction are proposed, grouped in four methodological families: i) deterministic models; ii) factorial models; iii) stochastic models; and iv) artificial intelligence-based models. These different approaches are established based on an expert survey of 203 stone claddings (directly adhered to the substrate), in-use conditions. This survey is performed by the authors on natural stone claddings in current buildings (housing and commerce) located in the Lisbon area, in Portugal. A comparative analysis is performed, through the comparison between the results obtained by each model and the data collected during field work, corresponding to the real degradation condition of the stone claddings analysed, in order to evaluate the sensitivity, specificity and accuracy of the models. Once the prediction capability of the proposed models is evaluated, a multi-criteria decision analysis is performed in order to compare the different models applied to service life prediction of stone claddings. This analysis intends to guide the choice of a particular model for a given application based on a set of decision criteria. Also, the main motivations and goals of the stakeholders are analysed, leading to different weights in the decision criteria. In real world, a rational process of decision-making incorporates subjective criteria and different "points of view". In this study, the multi-criteria decision analysis comprises two perspectives: the planner's point of view (who defines the model, e.g. the designer); and the user's perspective (who uses the model, e.g. a real estate manager). The essential parameters that may influence the selection of a given model are analysed. Based on the comparative analysis of different service life prediction models, some recommendations are made, concerning the advantages and limitations of the models proposed.

Keywords: Service life prediction; natural stone claddings; comparative analysis.

1. Introduction

Currently, there are different possible approaches to the service life prediction of natural stone claddings (directly adhered to the substrate). Naturally, different methods lead to different results, with (Lourenço et al., 2007): i) different levels of complexity; ii) different levels of availability; iii) different processing times, ranging from the instantaneous output of results to models that may require hours of computer processing; and iv) different costs. This study presents a review of different methodologies for service life prediction applied to natural stone claddings, grouping these approaches into four methodological families: i) deterministic models; ii) factorial models; iii) stochastic models; and iv) artificial intelligence-based models. All the proposed models lead to accurate results and are able to describe the degradation phenomena of stone claddings. Therefore, a comparative analysis is performed in order to evaluate the applicability of each model. The comparison between predictive models must take into account some basic principles: i) the model should be adjusted to the data, with a significant explanatory power, and must cover all the relevant aspects in the description of the phenomena under analysis; ii) it should respect the parsimony principle, i.e. in the presence of two models equally accurate, the model with lowest number of parameters should be chosen; iii) the model parameters should be easily interpretable; iv) the model should be able to describe the behaviour of the entire population, i.e. should not be over-adjusted to the sample, and must be able to predict the behaviour of new case studies, which have not been previous analysed by the model; v) it should be easy to apply, considering the ease with which the user understands how to use the model, the quantity and complexity of the data required for the model to work properly, and the software required and its processing time. Based on a set of different criteria, a multi-criteria decision analysis is performed, comprising two perspectives: the planner's point of view (who defines the model); and the user's perspective (who uses the model). Assuming that different stakeholders have different points of view, a sensitivity analysis is also performed in order to analyse the best model for different decision-making profiles. Based on the comparative and the multi-criteria analysis, some recommendations are provided, referring the advantages and limitations of the models analysed and thus allowing a more rational and informed selection of a service life prediction model concerning the purpose of the model and the planner's profile and the user's perspective.

2. Service life prediction models

In this study, 203 natural stone claddings (directly adhered to substrate) are analysed, in service conditions, surveyed through visual inspections. The overall degradation of stone claddings is evaluated through a numerical index, initially proposed by Gaspar and de Brito (2008), given by the ratio between the degraded area - weighted as a function of its state of repair - and a reference area, equivalent to the whole area of the façade with the maximum degree of degradation - expression (1).

$$S_w = \frac{\Sigma(A_n \times k_n \times k_{a,n})}{A \times k} \tag{1}$$

Where S_w represents the severity of degradation, expressed as a percentage, k_n the multiplying factor of defects n, as a function of their degradation level, within the range $K = \{0, 1, 2, 3, 4\}$, $k_{a,n}$ the weighting factor corresponding to the relative weight of the defect detected ($k_{a,n} \in R+$) according to the cost of repair (Silva et al., 2011), A_n the area of coating affected by a defect n, in m^2, A the façade area, in m^2 and k the multiplying factor corresponding to the highest degradation level of a cladding, as defined in *K* above, of area *A*.

To predict the service life of stone claddings it is necessary to define the instant in time in which they reach the end of its service life. However, this theoretical limit is not easy to define since it depends on a set of subjective criteria, varying according to time, place, user's needs and the building's context (economic, social, aesthetics, environmental or political). In this study, it is considered that a cladding with a severity of degradation higher than 20% has reached the end of its service life. This value was adopted based on the sample analysed and on a survey answered by the owner and users of the buildings analysed.

The different models described in the next sections include as explanatory variables the variables with higher statistical significance in the description of the degradation phenomena of stone claddings. The variables were selected using a sensitivity analysis and based on a stepwise technique described in Silva et al. (2012). All the proposed models include as explanatory variables age, distance from the sea and size of the stone plates, thus revealing a high relevance of these variables in the description of the degradation phenomena of stone claddings.

2.1 Deterministic models

Deterministic models use mathematical formulations and/or statistics, aiming to describe the relationship between the degradation mechanisms and the façades' degradation condition. These models, although being extremely effective in large and representative population samples, generally ignore the random nature of the phenomena under analysis. In this study, deterministic models comprise different types of regression analysis: i) simple regression analysis (degradation curves); ii) multiple linear regression; iii) multiple nonlinear regression. Simple regression expresses the loss of performance of façade claddings through a continuous function called "degradation curve". This curve can be graphically represented, where the *x*-axis represents the age of the stone claddings (assuming that age is the period of time between the date of the last intervention on the cladding and the inspection date) and the ordinate axis the index that expresses their global degradation (S_w). Equation (2) shows the result of the simple regression analysis performed.

$$S_w = 6\text{E}-05 \cdot A^3 - 0{,}0013 \cdot A^2 + 0.065 \cdot A + 1.538 \quad (2)$$

Where S_w represents the severity of degradation of the façade (%) and *A* the age of the façade.

The second model, multiple linear regression analysis, can be seen as an extension of the simple regression analysis that comprises more than one explanatory variable. Equation (3) presents the model applied to stone claddings with four explanatory variables. In the model's definition, a stepwise regression technique is applied, ensuring that all the assumptions concerning the statistical significance of the model are fulfilled.

$$S_w = 0.003 \cdot A - 0.429 \cdot S - 0.195 \cdot SS - 0.174 \cdot D + 0.772 \quad (3)$$

Where S_w represent the severity of degradation of the façade (%), *A* the age of stone claddings, *S* the distance from the sea, *SS* the size of stone plates and *D* the exposure to damp.

The third methodology is the multiple nonlinear regression analysis, which is similar to the multiple linear regression but uses a nonlinear function in the approximation between the model and the data. In this study, nine nonlinear models are applied: polynomial regression; Gompertz curve; Von Bertalanffy curve; Richards curve; Morgan-Mercer-Flodin curve; Weibull curve; Brody curve; exponential regression; potential regression - equations (4) to (12), respectively.

$$S_w = 4.033\mathrm{E}-05 \cdot A^2 - 0.080 \cdot S^2 - 0.083 \cdot SS^2 - 0.075 \cdot D^2 + 4.659 \cdot WR^2 - 0.069 \cdot O^2 - 4.213 \quad (4)$$

$$S_w = e^{-0.097 e^{-0.017 \cdot A + 1.440 S + 0.504 D + 1.058 SS + 0.553 O + 0.447 \cdot TS}} \quad (5)$$

$$S_w = \left(1 - e^{-0.05 \cdot e^{-0.011 A + 1.145 S + 0.0359 D + 0.74 SS + 0.299 TS + 0.366 O}}\right)^3 \quad (6)$$

$$S_w = \left(1 - e^{-1.896\mathrm{E}-04 \cdot e^{-0.018 A + 1.120 S + 0.938 D + 0.884 SS}}\right)^{1606351} \quad (7)$$

$$S_w = \frac{-76.557 + 1.756 \cdot \left(A^{1.249} + S^{-74.741} + D^{-32.849} + SS^{-49.303} + TS^{-53.132}\right)}{1594.935 + A^{1.249} + S^{-74.741} + D^{-32.849} + SS^{-49.303} + TS^{-53.132}} \quad (8)$$

$$S_w = 588.913 - 588.911 e^{-1.660\mathrm{E}-09\left(A^{2.863} + S^{-189.674} + D^{-107.606} + SS^{-164.604} + TS^{-216.957}\right)} \quad (9)$$

$$S_w = 1064.756\left(1 - 0.999 e^{-2.595\mathrm{E}-06 \cdot A + 4.148\mathrm{E}-04 \cdot S + 1.213\mathrm{E}-04 \cdot D + 2.060\mathrm{E}-04 \cdot SS + 3.013\mathrm{E}-05 \cdot TS}\right) \quad (10)$$

$$S_w = 7.478 e^{0.035 A - 1.501 \cdot S - 1.756 D - 1.777 \cdot SS - 1.062 \cdot TS} \quad (11)$$

$$S_w = 1.907\mathrm{E}-06\left(A^{2.718} + S^{-167.949} + D^{-102.858} + SS^{-152.310} + TS^{22.006}\right) \quad (12)$$

Where S_w represent the severity of degradation of the façade (%), *A* the age of the stone claddings, *S* the distance from the sea, *SS* the size of stone plates, *D* the exposure to damp, *WR* the exposure to wind-rain action, *O* the façades orientation and *TP* the type of stone. For the application of the deterministic models, the variables included in the models must be replaced by the numerical values presented in Table 1.

2.2 Factorial model

The factorial method is one of the main methodologies for service life prediction and is proposed in the international standard for durability (ISO 15686: 2000). In this method, the service life is obtained by multiplying a reference service life by the durability factors that influence the degradation process of the element under analysis. Equation (13) shows the application of this method to the service life prediction of stone claddings.

$$ESL = RSL \times A1 \times B1 \times B2 \times B3 \times B4 \times B5 \times E1 \times E2 \times E3 \times E4 \times F1 \times G1 \quad (13)$$

Where ESL represents the estimated service life, RSL the reference service life (68 years), *A* the type of stone, B1 the façade colour, B2 the type of finishing, B3 the size of stone plates, B4 the thickness of the stone plates, B5 the location of cladding, E1 the façades orientation, E2 the distance from the sea, E3 the exposure to wind-rain action, E4 the exposure to damp, F1 in-use conditions, and G1 ease of inspection of the façade. The quantification of the durability factors is presented in Table 1.

Table 1: Quantification of the variables included in the deterministic and factorial models

Durability factors			**Numeric value - deterministic models**	**Weighting value - factor method**
A1	Type of stone	Limestone Marble Granite	1.040 0.960 1.390	1.000 0.950 1.100
B1	Colour	Light colours Dark colours	1.010 0.880	1.025 1.000
B2	Type of finishing	Smooth Rough	0.993 0.991	1.100 1.000
B3	Size of the stone plates	Medium size Large size	1.040 0.940	1.000 0.900
B4	Thickness of the stone plates	Less than 2.5 cm More than 2.5 cm	0.970 1.000	1.000 1.100
B5	Location of the cladding	Integral or partial elevated cladding Bottom wall cladding	0.960 1.000	0.950 1.000
E1	Façade orientation	East/SE/NE North West/NW South/SW	1.010 0.960 0.930 1.040	0.950 0.900 0.900 1.000
E2	Distance from the sea	Less than 5 km More than 5 km	0.960 1.030	1.000 1.150
E3	Exposure to wind-rain action	Moderate Severe	0.986 0.984	1.000 1.000
E4	Exposure to damp	Low High	1.030 0.910	1.000 0.900
F1	Type of property	Private/Housing Commerce and services	1.000 0.990	1.000 1.000
G1	Ease of inspection	Normal Unfavourable	1.000 0.870	1.000 0.9000

2.3 Stochastic models

These methods allow analysing the probabilistic distribution of the degradation condition of stone claddings over time and according to their characteristics. With logistic regression it is possible to establish the probability that each case study has of reaching the end of its service life according to its age or characteristics - equation (14).

$$P(Y = "End\ \ of\ \ service\ life") = 1 - \frac{1}{1 + e^{-12,743 + 0,188 Age}} \quad (14)$$

2.4 Artificial intelligence based models

Artificial neural networks (ANNs) can be seen as emulations of biological neural systems, gathering information through a learning process. ANNs "learn" from a set of input and output patterns concerning the degradation of stone claddings, and are able to predict the behaviour of new case studies. Using this model, the severity of degradation of stone claddings is obtained depending on the values of the explanatory variables and a set of coefficients defined according to the proposed formulation - equations (16) and (17).

$$S_w = h_0 + \sum_{i=1}^{4} h_i \, H_i \qquad (16)$$

$$H_i = \tanh \left(c_{i0} + c_{i1} \, F + c_{i2} \, S + c_{i3} \, SS + c_{i4} \, A\right) \qquad (17)$$

Where variables *F*, *S*, *SS* and *A* are respectively the type of finishing, distance from the sea, size of the stone plates, and age of the stone cladding, and coefficients h_0 to h_4 and c_{i0} to c_{i4} are listed in Table 2.

Table 2: Coefficients of the proposed formula

i	h_i (-)	c_{i0} (-)	c_{i1} (-)	c_{i2} (-)	c_{i3} (m^{-2})	c_{i4} ($year^{-1}$)
0	1.368E-01					
1	-7.461E-02	1.040E+00	2.079E-01	-2.551E-01	-1.675E-01	-1.294E-02
2	-6.571E-02	5.543E-02	-1.161E-01	-1.838E-01	-3.709E-01	-6.621E-03
3	8.618E-02	7.720E-01	5.671E-02	-2.963E-01	-1.034E+00	4.278E-03
4	-1.190E-01	2.495E+00	1.620E-01	-2.387E-01	-1.596E+00	-2.333E-02

Fuzzy models are especially interesting when the problem modelled is subject to uncertainties, and are capable of describing systems and realities naturally vague. Fuzzy models combine numerical precision to transparency in the form of linguistic rules, dealing with complex phenomena with better performance than conventional linear models. In this study, a fuzzy model is used to estimate the severity of degradation of stone claddings - equation (18).

$$S_w(x) = \frac{\sum_{i=1}^{C} \beta_i f_i(x)}{\sum_{i=1}^{C} \beta_i} \qquad (18)$$

Where $f_i(x)$ denotes the function assigned to each of the rules and β_i the value of the membership function associated with the set of conditions that describe the case analysed (Vieira et al., 2015). The fuzzy rules describing the local input-output relation are presented in equations (19) and (20).

Rule 1: If u_1 is A_{11} and u_2 is A_{12} and u_3 is A_{13} and u_4 is A_{14} then:

$$y_1(k) = 4.25 \cdot 10^{-4} u_1 + 6.00 \cdot 10^{-4} u_2 - 2.78 \cdot 10^{-2} u_3 + 1.38 \cdot 10^{-3} u_4 + 1.56 \cdot 10^{-2} \qquad (19)$$

Rule 2: If u_1 is A_{21} and u_2 is A_{22} and u_3 is A_{23} and u_4 is A_{24} then:

$$y_2(k) = 1.04 \cdot 10^{-2} u_1 + 1.29 \cdot 10^{-2} u_2 + 1.09 \cdot 10^{-1} u_3 + 5.24 \cdot 10^{-3} u_4 - 1.96 \cdot 10^{-1} \qquad (20)$$

Where u_1 represent the type of finishing, u_2 the distance from the sea, u_3 the size of the stone plates and u_4 the age of the stone cladding. The membership functions for each of the four input variables are shown in Figure 1.

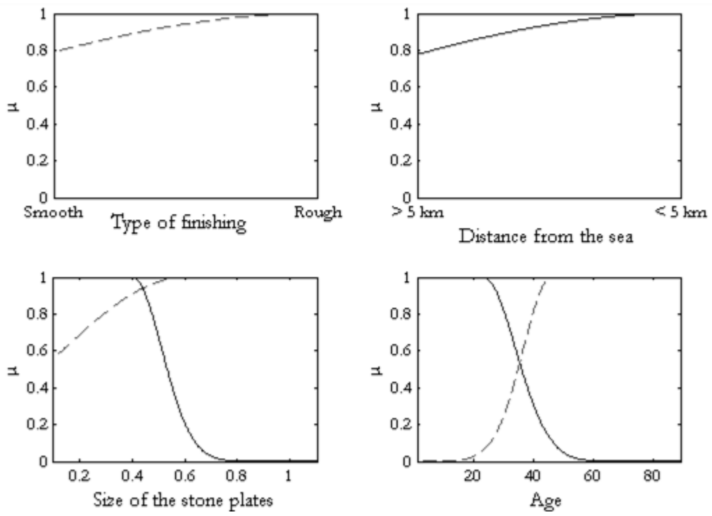

Figure 1: Membership functions for the first fuzzy model proposed

3. Comparative analysis of service life prediction models

All the proposed methods allow estimating the service life of stone claddings, leading to different results. The models present different characteristics; i) regression analysis and artificial intelligence based models are defined to obtain the estimated severity of degradation (S_w); in these models, to estimate the service life of stone claddings it is necessary to calculate the age of the façades corresponding to a S_w of 20%, corresponding to the end of service life of stone claddings; ii) stochastic and factorial methods are not intended to predict the severity of degradation of stone claddings - the first allows estimating the probability of each case study reaching the end of its service life and the second allows calculating directly the estimated service life of façade claddings. Table 3 shows the estimated service life obtained using each model, with the associated standard deviation. Furthermore, some statistical indicators are used to evaluate the performance of each model, namely: the Pearson correlation coefficient (r); the determination coefficient (R^2), the mean absolute percentage error (MAPE). Lewis (1997) refers that the MAPE can be used to measure the average relative size of the absolute prediction deviation as a percentage of the corresponding demand value; the author suggests that a value of MAPE less than 10% reveals a model with a potentially very good predictions. Besides these parameters, other indicators can be used to analyse the accuracy of the proposed models. In this study, ROC (Receiver Operating Characteristics) curves are used to evaluate the sensitivity, specificity and accuracy of the service life prediction methods. ROC curves are normally used to measure the performance of a diagnosis system; in this study, ROC curves are used to evaluate the accuracy of the models in classifying correctly the case studies that “reached the end of their service life” and the case studies that “not reached the end of their service life”. This test produces three relevant indicators: i) accuracy of the model - measure of the overall percentage of cases correctly classified by the model; ii) sensitivity - measures the ability of the model to correctly predict the cases that have reached the end of their service life; iii) specificity - measures the probability of the model assuming that a cladding has not reached the end of their service life, when it has really not reached that stage; iv) area under the ROC curve - varies between 0 and 1 and measures the classification capability of the model (models with an area under the ROC curve below 0.5 show no discriminating power). Concerning the fuzzy logic model, it is not possible to estimate the model’s sensitivity, since in the sample test (randomly selected) none of the case studies has reached the end of its service life.

Table 3: Estimated service life and the statistical indicators used in the analysis of the predictive ability of the proposed models

Model	Average ESL (years)	Standard deviation (years)	*r*	R^2	MAPE	Sensitivity	Specificity	Accuracy	Area under the ROC curve
Simple nonlinear regression	68.182	-	0.880	0.775	6.347	43.48%	95.00%	89.16%	0.692
Multiple linear regression	77.213	7.650	0.843	0.711	7.128	52.17%	98.89%	93.60%	0.755
Polynomial regression	69.110	2.873	0.886	0.785	6.388	56.52%	98.33%	93.60%	0.774
Gompertz curve	72.775	7.489	0.904	0.818	6.101	69.57%	98.33%	95.07%	0.839
Von Bertalanffy curve	73.585	8.114	0.895	0.801	6.502	73.91%	98.33%	95.57%	0.861
Richards curve	69.380	4.642	0.897	0.805	6.295	69.57%	98.33%	95.07%	0.839
Morgan-Mercer-Flodin curve	76.219	5.610	0.845	0.714	7.117	39.13%	100%	93.10%	0.696
Weibull curve	68.563	1.980	0.880	0.775	6.443	52.17%	95.00%	90.15%	0.736
Brody curve	79.370	8.358	0.799	0.639	8.198	21.74%	100%	91.13%	0.609
Exponential regression	73.193	7.422	0.879	0.772	6.353	43.48%	95.00%	89.16%	0.692
Potential regression	68.008	1.828	0.875	0.766	7.213	52.17%	95.00%	90.15%	0.736
ANNs	70.256	5.802	0.839	0.704	7.717	80.00%	93.48%	94.00%	0.867
Fuzzy systems model	90.275	31.230	0.882	0.778	7.635	-	78.43%	80.00%	-
Factor method	66.905	10.236	-	-	-	-	-	-	-
Graphical method	70.545	17.097	-	-	-	-	-	-	-

4. Multi-criteria analysis of service life prediction models

Table 4 shows the description of the criteria applied in the multi-criteria analysis performed.

Table 4: Description of the criteria adopted

Criterion	**Description**	**Analysis of the proposed models**
P1	The learning process includes: i) a comprehensive survey of the state of the art about the statistical tool underlying the prediction model; ii) an analysis of the potential and applicability of the model to service life prediction; iii) an evaluation of the results that may be obtained and the best way to achieve those results; iv) the model experimentation and statistical software necessary for its implementation; v) the ability to deduce the results.	The simpler method is simple nonlinear regression, which is based on fitting a mathematical equation to a data set. Fuzzy logic is the most complex method, with a time-consuming learning process and whose theoretical assumptions are more intricate.
P2	In this criterion the time necessary for the creation and processing of the model is considered. It is assumed that the researcher knows exactly what is to be achieved with and how to proceed to model each approach.	Simple and multiple linear regression are the models whose results are obtained immediately. Artificial intelligence based models are the most time-consuming approaches.
P3	In this criterion, two parameters are analysed: i) availability and prominence of the software; ii) cost of software's acquisition.	Models that use available online software (such as Excel) occupy the most favourable position. Models that require the application of expensive software adopted in this study appear in the bottom of the hierarchical scale adopted.
P4	Concerning the interpretability of results and usefulness of the information produced, two parameters are considered: i) readability of the output and ease of use provided by the mathematical equation models for a user unfamiliar with statistical models; ii) richness of the information obtained by the models and its usefulness for service life prediction.	Deterministic and artificial intelligence based methods lead to an average estimated value. On the other hand, stochastic models provide probabilistic information, with data concerning the risks associated to the degradation process (producing a richer information).
U1	The number and subjectivity of the variables included in the models are analysed in this criterion. Concerning the subjectivity associated with the variables, the following criteria are adopted: i) age is a parameter that is easily quantifiable; ii) variables such as distance from the sea are objective parameters (easy to quantify); iii) variables such as exposure to damp are more subjective and are more difficult to quantify.	The simple nonlinear regression and logistic regression are the most favourable models based on this criterion, since they use only one variable. The factor method is the model in the worst position, since it includes eleven variables in its definition.
U2	In this criterion, three factors are applied: i) the ratio between the average service life predicted by the model and the average service life obtained by the graphical method; ii) the deviation between the values of the estimated service life with a probability higher than 5% to be exceeded predicted by the model and observed; iii) the difference between the probability distribution that characterizes the observed values and the probability distribution associated with the observed values, assuming a normal distribution for all models.	Based on this criterion, logistic regression is the most accurate model, followed by the factorial method and nonlinear multiple regression using a Gompertz curve. The fuzzy logic model is the least accurate, resulting in an estimated average service life much higher than the values obtained through other methods, with the highest deviation between the predicted and the observed values.

The methodologies described in the previous sections are conceptually distinct and naturally lead to different results, but all of them are capable to accurately describe the degradation process of the stone claddings. The different actors in the construction sector need to decide which model to use. However, Basel and Brühl (2013) refer that a rational process of decision-making can be complex, vague and of a controversial nature, as it incorporates subjective criteria and different "points of view". In this study, a multi-criteria analysis is therefore performed taking into account the factors that should be considered by stakeholders, evaluating two points of view: the planner’s point of view (who defines the model); and the user’s perspective (who uses the model). From the planner’s point of view, four criteria are considered: P1) difficulty in learning the model; P2) time consumed in the model’s definition; P3) software used; P4) number and subjectivity of the variables included in the model. Regarding the user’s perspective, two criteria are adopted: U1) interpretability and utility of the information obtained using the models; U2) model’s accuracy.

Table 5 shows the impact profiles of the six criteria analysed for stone claddings. There are different approaches to multi-criteria models; in this study, an additive aggregation approach with compensatory rationality is adopted (Cochran and Chen, 2005). In an overall analysis, fuzzy systems are those with worst results, being the most complex model.

Table 5: Multi-criteria impact profiles evaluated for stone claddings

Model		P.1	P.2	P.3	P.4	U.1	U.2	Overall scale	Overall standardized scale
		Ease of learning	Time required to build the model	Necessary software	Variables included in the model	Utility of the results	Model’s accuracy		
Deterministic models	Simple nonlinear regression	1	1	1	1	1	0.343	5.343	0.969
	Multiple linear regression	0.75	0.998	1	0.857	1	0.878	5.483	**1.000**
	Polynomial model	0.625	0.877	0.108	0.143	1	0.576	3.329	0.520
	Gompertz curve	0.625	0.877	0.108	0.286	1	0.957	3.853	0.636
	Von Bertalanffy curve	0.625	0.877	0.108	0.286	1	0.983	3.879	0.642
	Richards curve	0.625	0.877	0.108	0.857	1	0.736	4.203	0.714
	Morgan-Mercer-Flodin curve	0.625	0.877	0.108	0.714	1	0.763	4.087	0.689
	Weibull curve	0.625	0.877	0.108	0.714	1	0.469	3.793	0.623
	Brody model	0.625	0.877	0.108	0.714	1	0.868	4.192	0.712
	Exponential model	0.625	0.877	0.108	0.714	1	0.945	4.269	0.729
	Potential model	0.625	0.877	0.108	0.714	1	0.429	3.753	0.614
Computational methods	Artificial neural networks	0.125	0	0.893	1	0.5	0.863	3.381	0.531
	Fuzzy logic model	0	0	0	1	0	0.000	1.000	**0.000**
Factorial methods	Factor method	0.875	0.752	1	0.857	1	0.991	5.475	0.998
Stochastic models	Logistic regression	0.375	0.939	0.108	1	1	1	4.422	0.763

The multiple linear regression is the model that globally presents the best results, combining an average degree of complexity with a high level of efficiency. Once the criteria to be used in a multi-criteria analysis are defined, it is possible to perform a new analysis considering the relative importance of each criterion for stakeholders. In fact, some criteria are more relevant than others, sometimes even decisive. For this, three hypothetical scenarios for the preferences of decision-makers are considered: i) scenario 1 - the decision-maker prefers the ease of the model's application, neglecting other criteria, i.e. a higher weight is assigned to the criteria related with the ease of learning, the time required to build the model and the number and subjectivity of the variables included in the model (Table 6); ii) scenario 2 - the decision-maker is essentially interested in the model's accuracy and the utility of the results (Table 7); iii) scenario 3 - the decision-maker needs to get most accurate model, in the shortest possible time (Table 8).

Table 6: Sensitivity analysis of weights assigned to scenario 1

Criteria's weight	Overall assessment of the models
λ P.1 = 2; λ P.2 = 2; λ P.3 = 1; λ P.4 = 2; λ U.1 = 1; λ U.2 = 1	1st Simple nonlinear regression; 2nd Multiple linear regression Worst performance - Fuzzy logic model
λ P.1 = 8*; λ P.2 = 2; λ P.3 = 1; λ P.4 = 2; λ U.1 = 1; λ U.2 = 1	1st Simple nonlinear regression; 2nd Factor method Worst performance - Fuzzy logic model
* Above this value, even increasing significantly the weight value λ P.1, maintaining the remaining weights unchanged, the hierarchical scale of models remains the same.	

Table 7: Sensitivity analysis of weights assigned to scenario 2

Criteria's weight	*Overall assessment of the models*
λ P.1 = 1; λ P.2 = 1; λ P.3 = 1; λ P.4 = 1; λ U.1 = 2; λ U.2 = 2	1st Factor method; 2nd Multiple linear regression Worst performance - Fuzzy logic model
λ P.1 = 1; λ P.2 = 1; λ P.3 = 1; λ P.4 = 1; λ U.1 = 5; λ U.2 = 20*	1st Factor method; 2nd Logistic regression Worst performance - Fuzzy logic model
λ P.1 = 1; λ P.2 = 1; λ P.3 = 1; λ P.4 = 1; λ U.1 = 20**; λ U.2 = 5	1st Factor method; 2nd Multiple linear regression Worst performance - Fuzzy logic model
* Above this value, even increasing significantly the weight value λU.1, maintaining the remaining weights unchanged, the hierarchical scale of models remains the same. ** Above this value, even increasing significantly the weight value λU.2, maintaining the remaining weights unchanged, the hierarchical scale of models remains the same.	

Table 8: Sensitivity analysis of weights assigned to scenario 3

Criteria's weight	Overall assessment of the models
λ P.1 = 2; λ P.2 = 2; λ P.3 = 1; λ P.4 = 1; λ U.1 = 1; λ U.2 = 2	1st Multiple linear regression; 2nd Factor method Worst performance - Fuzzy logic model
λ P.1 = 5*; λ P.2 = 5*; λ P.3 = 1; λ P.4 = 1; λ U.1 = 1; λ U.2 = 2	1st Simple nonlinear regression; 2nd Multiple linear regression Worst performance - Fuzzy logic model
λ P.1 = 2; λ P.2 = 2; λ P.3 = 1; λ P.4 = 1; λ U.1 = 1; λ U.2 = 3**	1st Factor method; 2nd Multiple linear regression Worst performance - Fuzzy logic model
* Above this value, even increasing significantly the weights values λP.1 and λP.2, maintaining the remaining weights unchanged, the hierarchical scale of models remains the same. ** Above this value, even increasing significantly the weight value λU.2, maintaining the remaining weights unchanged, the hierarchical scale of models remains the same.	

5. Discussion

The proposed service life prediction models analysed in this study present high levels of accuracy in the description of the degradation phenomena of stone claddings, according to the statistical parameters considered. In fact, all the proposed models show a MAPE lower than 10%, revealing a potentially very good predictive capacity. Additionally, the coefficients of determination (R^2) and correlation (*r*) are always greater than 0.6 and 0.8, respectively, indicating that there is a strong correlation between the observed data and the values predicted by the models. Regarding the capability of correctly classify the cases that have reached the end of its service life, it can be seen that all the models present accuracy higher than 80%, revealing a good discriminant power. The proposed models lead to an average estimated service life ranging from 66 to 90 years, for factor method and fuzzy systems, respectively. The results obtained seem realistic from a physical point of view, due to the high durability of stone claddings, and are coherent with the values present in the literature related to the service life of this type of cladding (Silva et al., 2011). When the service life of stone claddings is reached, they should be subjected to generalised rehabilitation actions in order to ensure that they are able to fulfil all the performance requirements. In fact, the knowledge of the ESL allows optimising the maintenance actions, in a rational and technically informed way, avoiding unnecessary costs (in an economic and environmental level).

For stakeholders to whom the simplicity of the model is the most relevant parameter (scenario 1), it is suggested to use an intermediate model, for example the multiple linear regression, whose modelling is extremely simple and allows encompassing the significant variables in the degradation process (unlike simple regression that only encompasses age) and factorial method (which includes more variables, although these may not be relevant to the phenomenon under analysis). In some situations, if the stakeholders want to define warranty periods and manage a large built park, it is important to obtain information regarding the degradation of the claddings in the form of a probability distribution, thereby evaluating the risk of a given decision regarding the rehabilitation of the façade; in this case, it is proposed to choose stochastic models. These methods are essential when the stakeholders intend to define with a known risk the instant after which they cannot ensure that the claddings will be able to conveniently comply with the function for which they were designed. Artificial intelligence-based models are definitely the most complex ones, whose definition is more intricate and whose results are more difficult to be interpreted. However, these models are obtained through a validation process that ensures the ability of generalization of the models. For an unfamiliar user, the accuracy of these models is not sufficiently compensatory, and it is advisable to opt for less complex models. However, in the case of a manager of a very large building stock, the high economic burden associated with the maintenance and rehabilitation of this heritage can justify the use of such tools.

6. Conclusions

Based on this study, it is not possible to unquestionably define the best model. In a global analysis, it can be concluded that simpler models consume less time and can be equally effective but analyse the problem only in one dimension, i.e. they only relate loss of performance of the stone cladding with its age. More complex models consume more time, are more complex and require software that may not be available to all and whose use may be more difficult; however, usually they are more robust and analyse various parameters that influence the degradation of stone claddings, allowing obtaining more interesting findings regarding the choice of a particular type of cladding over another depending on given environmental exposure conditions. Finally, stochastic models produce more relevant information, since they provide the probability of occurrence in order to evaluate the risk associated with the end of service life of stone claddings. Multi-criteria analysis allows a multidimensional analysis of the choice of a particular model for service life prediction. This analysis allows evaluating and comparing the different models, establishing hierarchical scales of preference. Regardless of the criteria adopted, there is always subjectivity associated with the decision-making process, since this process is conditioned by individual perceptions and actual preferences of the decision-makers. In fact, the decision-maker may not be able to define precisely the level of importance of each criterion (criteria weights), and even when he/she refers to the opinion of experts, they can assign different values to the weights of the criteria. Ultimately, it will be up to the decision-maker to choose the best model depending on the expected result, using the recommendations of this study. The selection of the best service life prediction model for a given application is extremely relevant for practical applications, such as the definition of maintenance policies for real estate managers, or the definition of warranty periods for insurance companies.

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Ageing and Living Environment: A Review of the Need for Smart Home Technologies (SHT) In Hong Kong

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Abstract

Smart home technology (SMT) has been identified as a promising means of meeting the desire of older people to remain independent, maintaining their quality of life (QoL) while containing spiralling elderly care costs. SHT development in Hong Kong, however, as well as in many other countries, lacks sufficient reliable information on such as the needs and requirements of older people concerning technical design needs and appropriate technological solutions to address these needs. Without a clear and accurate understanding of the needs of older adults, the value of the use and implementation of SHT in support of the living of old people in Hong Kong is questionable. The aim of this paper is to present the results of an investigation into the perceptions and expectations of home-based smart technology amongst the elderly in Hong Kong. Factors influencing the decisions of elderly people to use SHT have been identified. A focus group meeting (and snowball sampling) provided the data for this study. A total of 98 participants aged between 55 and 76 participated in the study. The participants were divided into fourteen interview groups. Twelve factors influencing the use of SHT were identified from focus group discussions, which were categorised into the four groups, *operational design of devices, functions provided by devices, personal considerations,* and *external influence*. By gaining an understanding of their needs and a QoL-oriented smart home devices design model, this study provides a preliminary insight into the way SHT should be designed, adopted and implemented so as to provide a better living environment for older people in Hong Kong living independently.

Keywords: Smart home technology, Ageing-in-place, Motivating factors, Hong Kong

1. Introduction

Hong Kong is facing a sharp increase in the proportion of older people in the overall population and an increasing number of independent-living older adults. This generates significant economic and social costs, and stress placed on family, carers and the community in general. With the age-associated decline in health and functional ability, supporting older adults in line with the 'ageing-in-place' concept may require modification of their existing home settings. Smart home technology (SHT) is regarded as a potential means of meeting the desire of the elderly to remain independent, maintaining their quality of life (QoL), while containing spiralling care costs. Despite the recent Government's pilot scheme (i.e. Hong Kong Housing Society) to promote SHT in housing for the elderly, there is limited understanding of the appropriate form such SHT interventions should take. In this regard, this study aims to fill this understanding gap by identifying the factors motivating the elderly to adopt SHT. The 'third age' is the targeted potential group of ageing people in this study, because they have an out-going attitude, a relatively open mind, and better financial status for the funding of SHT. The 'third age' is that group of post-retirement people who have fewer family responsibilities, adequate resources, and good health providing freedom to seek self-fulfilment and purposeful engagement (Rubinstein, 2002; Weiss & Bass, 2002). The perception of the 'third age' group, as prospective SHT users, provides preliminary and valuable insights into SHT development planning for aging people in Hong Kong.

2. Ageing-in-place: an opportunity of SHT development in Hong Kong

The Thematic Household Survey revealed that approximately 97% of elderly respondents in Hong Kong had no intention of moving to a residential care home, and 82% prefer to remain living in their own home when the choice is available to them and their physical health and financial situation allows (Census and Statistics Department, 2009). The growing desire of older adults for 'ageing-in-place', remaining in their familiar home environment or an environment of their choice for as long as possible, reflects an optimum strategy that can reduce stress, improve their QoL, allowing continuity and self-control over important aspects of daily life. 'Ageing-in-place as the core' has been recently launched as a strategic and holistic planning policy objective for the care of elderly in Hong Kong(Labour and Welfare Bureau, 2014).

A home living environment is considered to have a strong linkage with the physical and psychological well-being of older people (Oswald et al., 2007). Past research shows that older people are likely to spend 80% of their time at home, more than other age groups (Baltes et al., 1999; Iwarsson et al., 2007). The person-environment fit model (Lawton & Nahemow, 1973) posits that older adults become increasingly reliant on their surroundings, such as their physical living environment, to offset functional decline as they continue to age (Brawley, 2001). The home environment should function to accommodate losses of physical function, enhancing the independence of older adults in daily activities and autonomy (Lawton et al., 1973). The significant advances in microprocessor-based technologies over the last decade has led to the emergence of home automation and intelligent control technologies which provide convenience, comfort, energy efficiency, security, and a better quality of home living (van Hoof & Kort, 2009; Wong, Hang, & Wang, 2005). SHT have been proposed as a possible solution assisting older people to maintain independent and safe living at home in performing the activities of daily living, predicting normal and abnormal behaviour, and alerting carers of potentially dangerous behaviour (Blaschke, Freddolino, & Mullen, 2009; World Health Organization, 2012). SHT includes a range of emergency assistance systems, security and safety features, falls prevention, sensors, and timers that aim to reduce falls, disability, stress, fear, and social isolation, and monitor the daily functioning of the elderly at home (Barlow & Venables, 2004). For example, real-time monitoring and detection of accidental falls or slipping amongst elderly people from standing, chairs, or beds (Yu, 2008) would enable first-aid by carers, families, and paramedics as soon as possible (Abbate et al., 2012). Detection of unauthorised intrusion will maintain home security (Gaßner & Conrad, 2010; Lehmann, Giacini, & Davis, 2013). Arguably, a home setting equipped with SHT should reduce stress and optimise QoL: for example, by improving functional capacity; monitoring health status, enhancing psychological well-being, increasing social support, improving morale, enhancing independence, and allowing for coping and adjustment. SHT can also help relieve the burden on carers and social support services (Blaschke et al., 2009; Demiris & Hensel, 2008).

3. Research Method

A focus group was used to gather collective thoughts and insights into the use of SHT by the senior citizens in Hong Kong. Those collective views of the research participants emerged from evaluation of their informal conversations and debates (Kitzinger, 1994; Liamputtong, 2011). Those collective views of SHT consolidate the factors identified during the conservations of this study. This research study adopted snowball sampling to expand the recruitment of the participants. Subject recruitment information was sent in two ways. Firstly, the project information and subject recruitment details were sent to members of *The Institute of Active Ageing* (IAA) of the Hong Kong Polytechnic University with the institute’s support. *The Institute of Active Ageing* is a non-profit university-driven organisation that promotes active ageing to third age people by organising a wide range of programmes and activities. Secondly, subject recruitment posters were placed around a university campus, which is located at the city centre with high accessibility. The snowball effect started from these two spreads. Most of the participants were referred by the attending participants. A total of 98 participants aged between 55 and 76 recruits and took part in the group interviews. The participants expressed their interests in the SHT topic when they signed up for the group interviews. The participants were arranged into 14 groups of size between 6 to 9 participants. Ten SHT devices were presented to the participants by short video clips. These ten SHT devices and applications were classified into living environment control, safety, health monitoring, and social communication categories (Table 1). Semi-structured questions were asked to encourage discussions on their reasons, preference, acceptance, motivation, and suggestions for using SHT.

Table 1: Categories of Demonstrated SHT Devices and Applications

Categories	SHT Devices and (Source of Video Clips)
Living Environment Control	Environmental Control System (LSCM R&D Centre, 2015)
	Energy Management System – Smart Meters (Hkbnnewson, 2012)
Safety	Cooking Safety Control (Amano Connect, 2015)
	Infrared Environment Monitoring System (LSCM R&D Centre, 2015)
	Home-stay Wellness Sensing System (LSCM R&D Centre, 2015)
	Emergency Alarm (Senior Citizen Home Safety Association, 2000)
Health Monitoring	Cardiovascular Monitoring Device (LSCM R&D Centre, 2015)
	Non-Contract Electro-Cardiogram Monitoring Bedsheet (Centre for Innovation and Technology, 2010)
Social Communication	Smart Communication Board (LSCM R&D Centre, 2015)
	Video Conferencing (CFSC, 2014)

4. Findings: Factors influencing the adoption of SHT

System support and management of devices is considered an important factor underlying the successful adoption of SHT. SHT devices and applications are usually composed of electronic components, computer programmes, and communications networks. The elderly frequently express concern about the possibility of instability or malfunctioning of SHT devices and applications due to poor system performance and electricity supply. A number of participants asked '*What I can do if the device is out of order?*' after most of the video demonstrations and '*What will happen if the electricity supply is cut?*' after demonstration of a home environment control system. The respondents further explained that they did care about support for those SHT devices and the quality of support provided by the management when there are problems. The type of supports of concern included provision of instruction, on-site service, and the response rate and time to each inquiry. Apart from system support, management of the system connecting SHT devices to the off-site systems, such as the emergency alarm and the infrared environmental monitoring system, have been considered. For example, participants are worried about whether there is a response from the operator if they press the emergency button. Regarding some monitoring systems, the participants worry whether the staff in the off-site centres, actually notice the emergency condition even though the system has alerted them. A group of participators who care about personal privacy when their living environment is connected to an off-site system and personal data is stored. This implies there are issues of trust to consider and overcome.

The maintenance of devices is another concern raised frequently by elderly participants in group discussions. Corresponding to the last factor, this concern also emerges from their perceptions of using electronic devices. Most of the participants were concerned about the need to spend a lot on the maintenance, repair, and warranty of installed SHT devices. For example, two of the most raised questions after demonstrations, are '*Is it difficult to maintain the device in daily use?*' and

‘*Is it difficult to find someone to repair the device if it is damaged?*’. Those questions indicate that participants are concerned about the robustness and reliability of SHT systems. Therefore, an all-round warranty service is preferred by the respondents to maintain the devices.

In line with the concerns mentioned above, *operational design of devices* is another crucial factor if SHT is to be used by the third age participants. In term of design, the participants prefer SHT devices to be safe, effective for ageing people’s daily activities and safety, and suitable for the Hong Kong home environment. The participants also expressed their concern for contingency design. For example, a number of participants asked ‘*Can I operate the home appliances manually without electronic supply?*’ after a video demonstration of a home environmental control system. This implies that the basic operations and functions of home appliances should not be affected when SHT devices have problems. It was agreed that these requirements related to the design of devices were applicable for all SHT devices in general. For those SHT devices that interact with ageing people, such as the smart communication board, the participants are concerned that the devices must be user-friendly and easy to learn how to use.

The *increasing popularity and level of usage and penetration of smart devices* in society is another factor that influences the decision of whether to adopt individual SHT devices. Obviously, this factor is influenced by the reputation of particular devices. The participants expressed the view that if a SHT device has high usage and penetration rates into ageing people networks and society, they would be more willing to use it. They believe that high rates of usage and penetration of a particular device are correlated with a better support and reasonable device costs. Most participants have a good understanding of the emergency alarm services (EAS) provided in Hong Kong, which reflects its high penetration rate in society. Correspondingly, emergency alarms and associate services were found as the most well-known devices during group interviews. This indicates that higher usage and penetration rates of a particular SHT device influence the willingness of people to use them.

The participants were aware that their health and physical functions would get worse as they age. The participants expressed their willingness to use SHT devices if the devices would make housework easier. The third age people worried about heavy daily activities/tasks in the future, such as cleaning windows and hanging out clothes. As Hong Kong is a Chinese culture society, 63% of elderly citizens live with family members (Census and Statistics Department, 2009). Elderly people usually take over the family housework. Some participants stated that they would rather keep on helping their families with housework instead of receiving help.

Individual needs on SHT was another issue highlighted by the third age participants to show their willingness to use SHT. The participants argued that this important factor influence final decisions on the use of a particular SHT device. As the living space per person in Hong Kong is tight and the living cost is high (Economist Intelligence Unit, 2015; Ho, 2015), the third age people are likely to install handy SHT devices which suits their individual needs, such as health and physical conditions. Participants were concerned as to whether the particular device could reduce body disorders and help to perform some daily tasks due to body limitations. In the group discussions, the participants were frequently asked in what circumstances would they use a particular SHT device.

Enhancing home safety is considered a constituent of QoL for elderly people (Cardea & Tynan, 1987; Lin et al., 2007). The participants stated that home safety is a fundamental and essential purpose of a SHT installation. The participants stated that they would consider installing and using i) infrared environment monitoring systems, ii) home-stay wellness sensing systems, and iii) emergency alarms when health and physical condition were deteriorating. Despite the fact that many participants do not intent to install these SHT devices now, they are highly likely to install them when there is a need to enhance home safety. In terms of home safety, the significance of a cooking safety control system was highlighted in some group discussions. A number of participants had experienced the case of stove left on in their home. Avoiding fire incidents in the kitchen is one of their priorities in terms of home safety.

Health is a dimension of QoL for elderly people (Bowling et al., 2013; Farquhar, 1995; Gabriel & Bowling, 2004). The home safety function provided by SHT devices helps in emergency. SHT devices designed for health monitoring, aim at recording and analysing the health conditions of ageing people in order to reduce the number of emergency situations. The discussions of health monitoring devices is now seen as an issue of public health. A number of participants argued that a long-term health-monitoring programme assisted by SHT devices is a solution, also strengthening the awareness of health by the public. They stated that the installation of health monitoring devices at home should not only be beneficial to themselves, but also to their family. They agreed that health monitoring SHT devices were important, especially for long-term health issues of the society.

The cost of SHT devices is considered another factor of significance in determining the willingness to adopt SHT devices by third age participants. The participants expressed concern about spending due to a low or zero income after retirement. They tend to save money for medical expenses, manage their budget well during life after retirement. Their consideration includes the costs of devices, costs of maintenance, and costs of management, which aligns with their concerns about the maintenance of devices, (Point 4.2) above. In addition, *the level of support from Government* on SHT adoption was raised in group discussions. The participants agreed that SHT is a good idea to encourage ageing-in-place in Hong Kong. In this regard, the participants thought that initiatives by government would be an ideal way to promote the SHT concept. According to participants' comments, potential governmental efforts could be classified into three types. First, direct financial support from the government, such as subsidies, is suggested and highlighted by the participants as necessary for promoting the SHT concept among the elderly in Hong Kong. The participants would be happy to try SHT if there is a supporting government scheme. Second, support offered to groups and organisations concerned with SHT, including research and development, manufacturers, and contractors, is a way to strengthen the functions of SHT devices. Third, the participants suggested adoption of a wider pilot scheme for SHT devices in new senior housing, to help speed up promotion of SHT to the public.

In group discussions, the importance of *communication with different parties* and *maintaining social life* were discussed and highlighted after a video of a smart communication board and video conferencing devices had been demonstrated. Sustaining communication with different parties was raised by participants in connection with QoL in social relationships (Bowling et al., 2013; Farquhar, 1995; Gabriel et al., 2004). The participants commented that communication devices and applications, such as the smart phone and desktop computer equipped for instant chatting and video call applications, are commonly used by the third age elderly nowadays. They agreed that technology helps them to maintain social connections with family members, friends, and neighbours and is crucial to their lives. They also expect SHT devices to help maintain communication with the external environment using advanced and SHT high-tech devices, for example, video conferencing video functions integrated with other home appliances.

The factors identified in this study can be categorised into four types (Table 2). The findings indicate that ageing people take operational issues into account when thinking of using SHT devices. The identified factors relate to ***operational issues of SHT*** include system support and management of devices, maintenance of devices, and operational design of devices. The participants particularly raised some ***functional SHT considerations***. Those include support of housework, enhancing home safety, health monitoring, and maintaining communication with the external environment. Ageing people expect SHT to provide housework support, home safety, health monitoring, and communications. In addition, the individual needs and financial considerations indicate ***the individual concern*** when thinking of using and installing SHT. The identified factors indicate that ***external issues*** also affect the use of SHT by ageing people. These factors include levels of usage and penetration of devices, government support, and family support. These four types of factor encompass a wide range of considerations by ageing people when using SHT.

Table 2: Four categories of found factors

Categories	**Found Factors**
Operational Issues of SHT	System support and management of devices
	Maintenance of devices
	Operational design of devices
Functional Consideration on SHT	Support to housework
	Enhancing home safety
	Health monitoring
	Maintaining communication with external environment
Individual Concern	Individual’s needs
	Financial considerations
External Issues	Level of usage and penetration of devices
	Government support
	Family support

5. Conclusions and Further Study

This study has identified factors that motivate the adoption of SHT, which meets the ageing-in-place desires of the local older adults. This paper provides preliminary insights into the potential for SHT in Hong Kong, and makes four proposals for promoting aging-in-place through SHT, as follows: i) enhance the operational design of SHT devices; ii) match the needs of the elderly with the functionality of SHT, iii) improve support for SHT adoption, and iv) understand the needs of ageing people in relation to SHT. In the next phase, the data collected will be further analysed so as to understand the interrelationships between these factors using the interpretive structural modelling (ISM) approach. With the appropriate technological intervention, this generates a 'win-win' situation for the elderly, carers, the community and the government in the long run, by enhancing the independence of older people and reducing the burden and distress of the carers, releasing government institutional healthcare funds and older person's time for more productive activities in support of the national economy, leading to a more cost-effective and less-dependent need for public-sector service provision.

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Offsite Manufacturing in Nigeria: Feasibility Research and Future Directions

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Abstract

Nigeria is facing a deficit of 17 million houses due to a myriad of issues. This paper reports on the findings of a feasibility study which investigated Nigerian stakeholders' perceptions on the needs, promises and barriers of adopting Offsite Manufactured Construction (OSM) in Nigeria, in order to address this challenge. In-depth interviews were conducted with domain experts directly involved in housing delivery, the data of which was analysed using thematic analysis, powered by Nvivo software. Results showed that although OSM could improve housing delivery efforts in Nigeria, any such initiatives to support this were perceived to be considerably low. As such, this study concluded that there is a need for high-level awareness, greater collaboration, investment in training and education, and endorsement/encouragement from the Government. This study presents additional understanding of OSM in Nigeria based on expert opinion, the results of which were used in the development of a framework for the effective adoption of OSM in Nigeria. It is proffered that adopting OSM can help support housing delivery efforts in Nigeria, and may also leverage wider benefits to the construction industry and associated supply chain.

Keywords: Offsite Manufacturing, Housing Delivery, Stakeholders, Nigeria

1. Introduction

Nigeria is currently facing a significant and progressive housing deficit. Whilst it could be argued that this is similar to many other rapidly developing countries, there are some unique contextual facts that need to be noted. For example, it has a population of 177 million, with an annual growth rate of about 2.5% (PRB, 2014). It also needs about 17 million new houses in the short term (Okonjo-Iweala, 2014). Thus, in order to address these issues, several mitigation efforts have been deployed by the local industry, including: promoting locally manufactured building materials as a means of improving housing delivery (Olayiwola & Adedokun, 2014); directing the industry towards better implementation of the Nigeria National Housing Policy (Makinde, 2014); and seeking possibilities of introducing better mortgage systems in Nigeria

(Olayiwola & Adedokun, 2014). Despite the success of some of these innovative attempts to address the problems affecting housing delivery in Nigeria, a wide margin still exists between housing demand and supply (Ibimilua & Ibitoye, 2015). Acknowledging this, it has been argued in seminal literature that this is mainly due to the inherent problems of the exiting conventional housing delivery systems in Nigeria and concomitant challenges, such as time and cost overruns, skills shortage, inadequate quality, and labour intensive activities (Femi & Khan, 2014; Makinde, 2014). As such, Dada (2013) suggested that a paradigm shift from the conventional construction approach to a more innovative housing production processes was vital in the context of Nigeria.

This kind of radical change in housing delivery methods was also advocated in several other countries, e.g. in the UK, USA, Australia and South Africa. Several Government reports have also noted that collaborative working and integrated project delivery must be promoted in order to make a 'revolution' in construction projects. To leverage these, literature has proffered the adoption of Modern Methods of Construction (MMC) and Offsite Manufactured Construction (OSM) as viable delivery mechanisms for both developed and developing countries (Gibb & Pendlebury, 2006; Goulding et al., 2014; Mullens & Arif, 2006; Nadim & Goulding, 2010; Taylor, 2009). In this respect, the primary role of OSM here is to move some of the effort and risk prone construction site activities into a 'controlled environment' typically associated with a manufacturing or factory facility (Arif et al., 2012). This controlled environment and application of OSM offers several benefits, particularly: a higher speed of construction, improved quality of the finished product, lower costs, and lower labour requirements on-site (Mullens & Arif, 2006). These achievements are sustained and significant; and it is therefore proffered here, that such offerings may act as a platform for addressing the specific housing problems of Nigeria (discussed above).

Despite these potential benefits, OSM only has a negligible share of the housing market in Nigeria (Kolo *et al.*, 2014). Taylor (2009) asserted that this failure in many countries could be due to inaccurate public assumptions regarding offsite. This study therefore posits that, if offsite production and manufacturing are to make a positive contribution to the Nigerian construction industry, there is a need to identify the causal issues associated with its uptake and adoption. This undertaking would need to encompass several areas, not least, market drivers and dynamics, culture, societal issues, and existing economic business model

2. Background of the Study

Statistics are not promising at all about housing delivery in Nigeria, where only 10% of Nigerians can currently afford to either purchase or build their desired quality houses, compared to those for other countries 72% in USA, 78% in UK, 60% in China, 54% in Korea and 92% in Singapore (Ayedun & Oluwatobi, 2011). Olayiwola and Adedokun (2014) complained that the housing situation in Nigeria is far from being satisfactory, taking into account the high rates of urbanisation and population growth in this country. Makinde (2014) asserted that there was no perspective of improvement in near future; if the country decides to continue to rely on its conventional housing delivery systems, which are deficient in terms of quantity and quality of housing units delivered. These problems tend to have a cascading effect that results in the other housing problems, such as unstable businesses, shortage of skills and materials, inadequate infrastructure, lack of innovation and unfair distribution of resources.

3. Offsite Manufacturing and the Opportunity for Its Adoption in Nigeria

Offsite manufacturing falls under the broad umbrella of Modern Methods of Construction (MMC) (Nadim & Goulding, 2010) and, there are several acronyms associated with OSM. OSM can be defined as set of processes that incorporates prefabrication and pre-assembly to produce units and or modules that are then transported to site and positioned to form a permanent work (Gibb, 1999). From a system point of view, Gibb and Pendlebury (2006) defined OSM as a range of applications which involve moving operations that are traditionally completed onsite to a manufacturing environment. This transformation improves the quality, customer satisfaction, efficiency, predictability of delivery timescale and sustainability of a project (Nadim & Goulding, 2010). It has been widely advocated that several benefits are obtainable from the use/adoption of OSM. The following paragraphs provide a categorised summary of these benefits in accordance to main themes of housing challenges in Nigeria, which were discussed in the previous section.

Ajayi *et al.* (2008) presented shocking statistics about waste generation in Nigerian construction projects where more than one-ton per day waste is generated in more than 75 per cent of conventional building sites. They also argued that most wastes are generated from demolition works on site and material handling. According to a report by Waste and Resources Action Programme (WRAP, 2007) within the context of UK, 40 per cent of all council waste come from construction projects. OSM has been successful in reducing waste generation of typical construction projects by 70% to 90%. It has also been advocated that it is much easier to gather and recycle waste generated from OSM than those for conventional construction projects (WRAP, 2007).

Gibb and Pendlebury (2006) asserted that “time is a big-plus for offsite”. Similar to other countries, construction projects in Nigeria often delay due to some regular issues, such as material shortage, skills shortage and bad weather conditions (Mansfield *et al.*, 1994). With OSM, these issues are inherently addressed, since most of the building components are manufactured in factories and transported to site for speedy assembly at very predicted times with limited workforce (as per discussed with very much detail in: Arif *et al.*, 2012; Gibb & Isack, 2003; Taylor, 2009). (See Figure 1).

Despite the higher initial cost of OSM projects (NAO, 2005), savings from OSM can be achieved in the areas of cost certainty and reduced risk, reduced running and maintenance costs, reduced preliminaries and site overhead, and reduced construction time (Gibb & Pendlebury, 2006). WRAP (2007) also identified that, savings can be achieved by using OSM as a result of reduction in waste of building materials especially bricks. In Nigeria were sandcrete blocks are predominantly used, incorporating OSM will go a long way in reducing waste on site and this will in turn augment for the high cost of construction when using OSM.

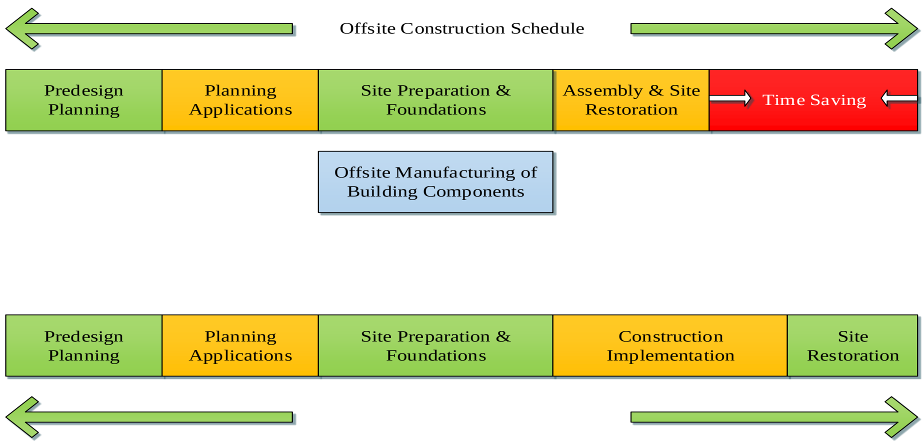

Figure 1: Comparison between OSM Schedule and Conventional Construction Schedule; Adapted from *MBI (2010)*

NAO (2005) advocated that OSM meets the three quality requirements of durability, whole life cost and performance. It was ascertained that achieving greater quality was a major benefit and a key driver to the adoption of OSM in various contexts of different countries such as India (Arif *et al.*, 2012) and UK (Gibb & Isack, 2003). Gibb and Isack (2003) linked this superiority in the production quality and output consistency to the controlled factory environment in OSM as opposed to the uncertain conditions of a conventional construction site.

Despite all benefits, seminal literature highlights myriad of barriers hindering the uptake of OSM (e.g., Arif *et al.*, 2012; Goulding *et al.*, 2014). It was crucial for this research to identify these barriers through reviewing literature and investigate their likelihood within the context of Nigeria based on evidence from primary data.

Initial cost of products has often been considered as the main barrier to the uptake of OSM in many countries including Nigeria. Scofield *et al.* (2009) also identified manufacturing capacity as another barrier to the uptake of OSM. Countries in which OSM usage has already been established, (e.g. UK, US, Japan and Nordic countries) have a robust supply chain including good number of factories to support OSM market. In a country like Nigeria, there are only few factories involved in the manufacturing of OSM components. This can certainly hinder update of this industry in the future. Another barrier hindering the uptake of OSM is the negative public and stakeholders' perceptions towards OSM. Arif *et al.* (2012) argued that one reason for this is that prefabricated housing was used during periods of high demand (e.g. post-world wars), resulting in mostly low quality shelters. Although this has changed in many countries, Opara (2011) confirmed that similar negative perception still is a real barrier in Nigeria.

Another major barrier for adopting OSM in many countries is lack of suitable building codes and standards (Goulding *et al.*, 2014). This is a problem in Nigeria also where there are no official codes and standards to guide the use of OSM. Shortage of skilled workers and labour specific for OSM has also been a regular issue for OSM adoption (Goulding *et al.*, 2014). This problem is even magnified in countries like Nigeria where the OSM industry is too small, so that there is too much reliance on expatriate skills (Opara, 2011).

4. Research Methodology

This study focuses explicitly on the barriers of adoption of OSM in Nigeria. As such, a narrow-bounded literature review lens was used to identify the main problems affecting housing delivery in Nigeria, cognisant of the globally recognised capabilities of OSM in addressing these issues, barriers and subsequent transformation from conventional construction to OSM. The results of the conducted literature developed the theoretical framework and identified main constructs, factors and variables of this study. It was also essential to get affirmation for the developed theories through checking them against tacit knowledge of stakeholders involved in the Nigerian housing industry. Since not much research have been conducted in the past to investigate issues related to OSM adoption in the context of Nigeria, a qualitative research approach was adopted, using in-depth interviews as the instrument for data collection, to engage profoundly with actual stakeholders, get their views and opinions, and capture deeper knowledge about the nature of these issues. Due to the nature of qualitative study, very high-level experts from various sectors of the Nigerian housing industry were selected and invited as the participants for the in-depth interviews.

The study followed Gu and London (2010) in shaping the main constructs of the study and interview questions around the three main dimensions of OSM, i.e. people, process and technology. Cost was also included as the fourth construct, since it has been identified as a major player in housing delivery by various studies. The interview questions were divided into three main categories in accordance with the main aim of this study, specifically: 1) The main problems of housing in Nigeria, 2) The potential capabilities of OSM, which can leverage housing delivery in Nigeria, and 3) The probable barriers to OSM adoption in Nigeria.

In order to engagement effectively with the respondents, face-to-face interview was selected as the method of conducting the interviews and about 30 minutes was allocated for each interview. Interview questions were also tailored to the expertise of each participant to assure maximum productivity of meetings. Reaching theoretical saturation (Kumar & Phrommathed, 2005) was the main strategy for determining sample size of each set of interviews; i.e., the study continued the interviews with new participants from each group, until the point whereby no new data was received from the new respondents. Data gathered for the interviews were audio recorded with the permission of the interviewees to ensure all necessary information were captured for proper analysis of the data.

Total of 26 experts were approached for interview based on the roles they play in the housing delivery value chain of Nigeria. All data gathered from 26 interviews was transcribed and analysed using the QSR - NVivo Data Analysis Software (V10.0.638). In order to systematically investigate the core issues of housing delivery in Nigeria and the potentials of OSM to address these issues, this study adopted thematic content analysis.

5. Results and Discussions

5.1. The Problems of Housing Delivery in Nigeria

From an exploratory analysis of the interview results, it was obvious that despite the various mitigation attempts, the problem of housing deficit in Nigeria continues to remain. It was reaffirmed by results of this study that a large housing deficit still exists in Nigeria and currently, there is no promising prospect for improvement. It was strongly pointed by many interviewees that this problem is likely to be even more serious than what has been officially reported, and nothing significant is being done to tackle this issue. The following paragraphs present the details of the problems of effective housing delivery in Nigeria.

Respondents of this study identified *financial issues* as a major hindrance to effective housing delivery in Nigeria. High cost of construction in Nigeria was brought into conversation by many of interviewees and this concurs with results of a previous research conducted by Odunjo (2013) highlighting this issue. The results of the interviews point out several factors which account for the high cost of housing in Nigeria. One of the most crucial issues highlighted here was overheads imposed due to lack of proper infrastructure. Another subset of cost is the cost of getting title documents in Nigeria which is usually very high and this also impacts on the overall building cost. Other sub categories indicted as major factors contributing to high cost of construction in Nigeria included importation of building materials and poor earning power.

In terms of *construction sector related issues*, this study identified various factors which have negative impact on housing delivery in Nigeria. Lack of construction standards and poor professional ethics were identified as two main codes under construction sector related issues. One of the interviewees argued that *"so many people tend to cut corners with regards to building materials…"*. This concurs with the findings of an earlier study by Solaja (2015) which complained about poor ethics within the Nigerian construction industry at every level. Similarly, it also reaffirms the findings of Oseghale *et al.* (2015) who argued that use of unqualified professionals, lack of maintenance culture, poor quality materials and inadequate fund are some of the major causes of building failure in Nigeria. Similar to every other context (Kamara *et al.*, 2004), the issue of the fragmented nature of the construction industry was also identified as a major contributor to hindrance of housing delivery in Nigeria. Other sub categories identified under this theme by the interviewees were reluctance to innovate and lack of investment and research.

The last theme identified in this section was *Government related issues*. This theme referred to issues concerning the Government role in supporting or hindering housing delivery at all levels. Importance of the Government to assure that everyone has access to at least a quality shelter as basic need of mankind (Olayiwola *et al.*, 2005) was highlighted by many of respondents. The respondents complained that the Government has not been successful in providing this in Nigeria. Other codes highlighted under this theme were inflation of contract prices, poor Government policies and lack of control on corrupt practices. The results of the interviews conducted revealed that these three areas tend to significantly affect housing delivery in Nigeria.

It was also argued by the interviewees that Nigeria needs a robust mortgage system to assure continuity of supply and demand within the construction industry. It was also brought to attention through the interviews that the issue of poverty affects the acquisition of housing in Nigeria and this is further compounded by the poor Government policies concerning housing and mortgage.

5.2. Barriers to the Use of Offsite Manufacturing in Nigeria

With regards to contribution of OSM to the Nigerian construction industry, many interviewees that participated in this study argued that OSM is almost of non-existence in the context of Nigeria. Similarly, they also asserted that OSM has not been accepted formally or even informally in this country. However, some interviewees mentioned that OSM had an acceptable share of the construction market of Nigeria during the 1970s and 1980s, and then it gradually disappeared due to the minor demand for housing at that time, and the fact that it was only the Government demanding for prefabricated houses during that period. Nevertheless, the stakeholders interviewed in this study admitted that prefabrication is vastly used in some civil engineering projects carried out by large construction firms in Nigeria, but this has nothing to do with the housing sector, which heavily relies on the conventional bricks and blocks construction methods. Despite its missing role, this study argues that due to the typical challenges that the Nigerian housing industry currently faces, it would be paramount for this industry to adopt OSM, which is already capable of addressing many of these issues (Arif, 2012; PrefabNZ Incorporated, 2013). In the meantime, for OSM to be adopted in Nigeria there was a need to identify the barriers that can hinder its adoption. This study identified three core themes (Pan *et al.*, 2004) with respect to barriers to OSM adoption, namely "human barriers", "technical barriers" and "industrial barriers".

Human barriers covers barriers that are concerned with the stakeholders involved in the delivery of housing in Nigeria as well as the end-users. Several studies identified negative perception about OSM as a major barrier for its adoption (e.g. Arif *et al.*, 2012; Pan *et al.*, 2004; PrefabNZ Incorporated, 2013). This was also echoed by the respondents of this study who argued that people in Nigeria have a negative perception about OSM components and think they are not so strong. Based on the results of this study, other major codes identified under the category of human barriers to OSM adoption in Nigeria include: maintenance difficulties, client's resistance, cultural issues and design flexibility.

Technical barriers refer to the barriers that hinder the construction process and the procedure that end up with the final product, i.e. a house. The main categories identified under this theme were lack of necessary infrastructure, lack of machinery, logistics and technical expertise. In terms of Infrastructure development, it was discussed by many respondents that Nigeria needs much better roads, transportation system, and power grid in order to be able to adopt OSM. These results resonate with the results of a similar study by Arif *et al.* (2012), which identified infrastructure as a major challenge to OSM adoption in a similar context such as India.

This study identified the *industrial barriers* as high cost of establishing factories, importation of materials, need for expatriate workers and limitation of existing OSM factories as major barriers to OSM adoption in Nigeria. Although cost has been identified as a major barrier, many of the interviewees argued that some of the initial costs could be offset through the areas such as cost certainty and reduced risk, less overall life cycle costs due to better quality of products, reduced preliminaries and site overhead, reduced construction time. This is very aligned with the findings of Gibb and Pendlebury (2006). Some interviewees also advocated that despite being capital intensive, investment in OSM could be very beneficial for Nigeria anyway, since the country would reap the benefits of OSM in the long-term.

6 Conclusion

Research findings indicate that whilst there is still a very large housing deficit in Nigeria, there are currently no significant measures implemented to address this challenge. However, OSM has been proffered as a potential solution, particularly though its ability to meet volumetric delivery patterns with reduced costs and improved quality thresholds. That being said, contextual conditions need to be assessed before this can be considered a viable solution. In doing so, several barriers to OSM adoption were presented and discussed. Based on this, low-impact construction methods (such as OSM) were considered viable methods for improving sustainability and particularly, feasible solutions for improving the housing deficit. This study presented a series of underpinning steps based on the view of various stakeholders on the issues regarding these housing challenges, and the possibility of OSM adoption. Whilst these context-specific OSM barriers highlighted the barriers, this is just a start. There is an exigent need to investigate these issues further, as it is important to proffer bespoke solutions to this environment e.g. infrastructure and local suitable materials for OSM. For this to be achieved, the experience garnered in other contexts need to evaluated regarding their suitability.

In pursuance of this, the ultimate goal of this research will be to develop a roadmap that will facilitate the effective adoption of OSM in Nigeria. This paper presented a series of underpinning steps based on the views of various stakeholders on the barriers to OSM adoption in Nigeria. Whilst OSM barriers have been highlighted within the Nigerian context, there is an exigent need to investigate these issues further, as it is important to proffer solutions to this environment e.g. infrastructure and local suitable materials for OSM. For this to be achieved, it is imperative that these issues are studied further, cognisant of experience garnered in other contexts and this will be useful in developing a suitable roadmap for the successful adoption of OSM in Nigeria.

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Plot Ratio/Building Height Restrictions for High-Density City Using 3D Modelling and Spatial Analysis Technology

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Abstract

Hong Kong is an international metropolis, which is suffering from a chronic lack of land resources, housing supply, and the effects of high density urban development. Although a number of studies have been conducted to explore the feasibility of increasing development intensity by assessing environmental impacts, infrastructure capacity and public consultation, these reviews and assessments were implemented using 2D Geographical Information System. However, most people cannot visualize the impact of relaxed plot ratio/building height (PR/BH) restrictions from a 2D drawing, as the spatial distribution of land unit in the real world is 3D. This study aimed to measure the effects of minor relaxation of maximum PR/BH restrictions of 21 sites in Kai Tak Development Area from a sustainability perspective using 3D modelling and spatial analyses, including urban skyline, visual effect of mountain ridgeline, shadow and solar exposure, wind ventilation, and air temperature. Different scenarios with various PR/BH restrictions for the 21 target sites were generated and compared. With Hong Kong as the case study area, results indicated that people could obtain a more holistic view and be able to make more effective and informed decisions based on 3D modelling and spatial analysis. Considering the minor effects or slight changes during the various analyses, Scenario 4 is the recommended reasonable scale to relax the maximum PR/BH restriction for the 21 target sites. The proposed method can also be applied in urban renewal for other densely populated cities.

Keywords: 3D modelling, 3D spatial analysis, Micro-climate simulation, Planning decision, High-density city

1 Introduction

Similar to many global cities, Hong Kong (HK) is suffering from a chronic lack of land resources, housing supply, and the effects of high-density urban development. Over 7,000,000 people live in this tiny place with an area of only 1104 km^2. Even worse, almost 75% of this land is covered with mountains and country parks, which are unsuitable for urban development/redevelopment. Shen et al. (2009) explained that land use is crucial for both current and future sustainable urban development. To achieve sustainable development in HK, the Government has made every effort to increase land supply by adopting a multi-pronged approach in the short, medium, and long term. To increase land supply within a short time frame, increasing development intensity of built-up area by minor relaxation of the PR/BH height restrictions is commonly employed.

In HK, development intensity is mainly controlled based on lease conditions, statutory outline zoning plan (OZP), and the Building Planning Regulations, which aim to impose restrictions on site coverage and PR/BH of individual land lots. As a statutory organization, the Town Planning Board (TPB) is responsible for the approval of OZP and any subsequent amendments. There have been rising concerns in recent years that possible undesirable effects of high-density development may be caused by further relaxation of density control in urban areas. Therefore, TPB needs to consider these applications while ensuring that the proposed changes not only have the satisfactory and acceptable environmental impacts on surrounding areas but also will be in line with the HK Planning Standards Guidelines. The employment of 3D modelling and Geographical Information System (GIS) analysis technology meets this demand, which can facilitate a more interactive debate on urban density and informed planning decisions toward better provision of urban space.

As part of the Government's effort to increase housing and office supply, the Civil Engineering and Development Department (CEDD) proposed a minor relaxation of the maximum PR/BH restrictions for three study areas marked in Fig. 3, including 21 sites zoned as Residential, Commercial, Mixed Use, as well as Government, Institution, or Community, on the approved Kai Tak OZP (CEDD, 2015). Although previous research findings can provide fundamental and valued resources for this study, they were conducted using 2D GIS. Given that the spatial distribution of the land unit in the real world is three-dimensional, 3D GIS can help us examine the world in true perspective and make effective decisions. Therefore, this study aimed to measure the effects of minor relaxation of the maximum PR/BH restrictions of 21 sites in the Kai Tak Development Area (KTDA) from a sustainability perspective through 3D modelling and spatial analysis technology, including urban skyline, visual impact of mountain ridgeline, shadow and solar exposure, wind ventilation, and air temperature. The results of this study can be used to develop informed strategies for other global cities facing similar issues on urban development/redevelopment.

2 Literature Review

With the rapid development of 3D GIS technology, an increasing number of researchers are using 3D GIS to assist in various decision-making processes for urban development.

Zhang et al. (2004) conducted 3D spatial analyses for urban development using 3D models, including visibility, solar panel, flood, and air pollution. Similarly, to obtain more vivid effects, Mak et al. (2005) conducted an urban skyline analysis covering HK using 3D GIS technology. Their findings indicated that 3D GIS plays an important role in implementing the urban design guidelines (UDGs) of HK, including the quantitative measurement of mountain ridgeline, the height of buildings, and urban skylines. Stevens et al. (2007) employed a novel tool named iCity, which runs in a 3D environment to assist in spatial decision making during urban planning. Alternatively, Li et al. (2004) used ArcGIS spatial analysis functions to analyse the sky view factor, which is one of the important factors affecting climate during the urban design process. Wong et al. (2011) described an original methodology applied 3D GIS to investigate the "wall effect" caused by proliferation of high-rise buildings along the coast in Kowloon, HK.

Although the abovementioned studies focused on using 3D spatial analysis technology to address certain issues encountered during urban development, few researchers have emphasized development control, such as the effect of minor relaxation of the maximum PR/BH restrictions on surrounding environments. Therefore, the present study, investigated the viability of minor relaxation of the maximum PR/BH restrictions using 3D modelling and simulation technology to provide sufficient evidence to the decision maker.

3 Research methodology

3.1 Overview of the Research

Fig. 1 presents the overall framework of this study. First, based on the available 3D spatial data and approved Kai Tak OZP, a model of the whole KTDA was generated. A number of spatial analyses from various scenarios on urban skyline, visual effect of mountain ridgeline, shadow and solar exposure, wind ventilation, and air temperature were then conducted. Besides, Digital Elevation Model (DEM) was integrated with the 3D models to conduct the spatial analysis of mountain ridgeline. The findings of the above spatial analyses were compared under four different PR/BH scenarios. Furthermore, a previous study on the Environmental Impact Assessment and carrying capacity of infrastructure was used as a reference before a conclusion was drawn.

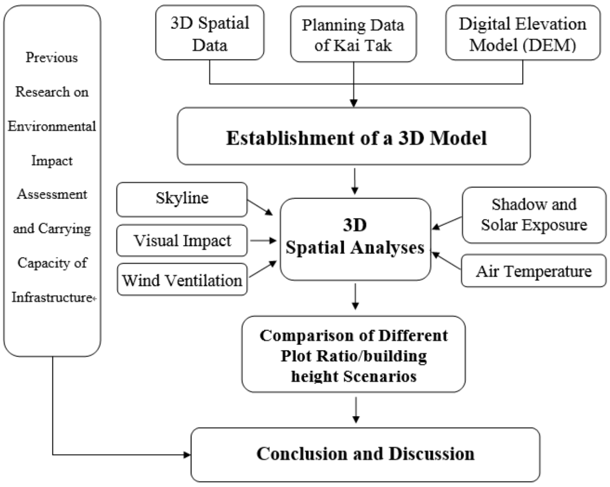
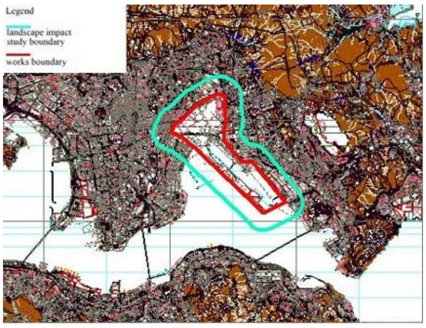


Figure 1: Framework of the study

3.2 Data Collection and 3D Modelling

A case study was chosen in HK, which is an international metropolis with a high population density. The study areas were finally defined with assistance from DEM, the ridgeline of mountain, visual environment, and other related factors. Fig. 2 shows that the inner area boundary in red is the Kai Tak rebuilt planning area, whereas the outer area boundary in green represents the potential boundary of the affected adjacent region.



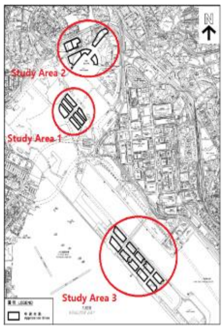


Figure 2: Selected study area *Figure 3: Target sites distributed in three study areas*

To date, only part of the 3D data for the KTDA is available from Lands Department of Hong Kong. However, for areas without existing 3D data, the 3D models were generated by commercial software CityEngine according to the planning scheme. Fig. 4 shows the 3D spatial data covering the highlighted area (in pink). The creation of new buildings should refer to a number of planning regulations, including TPB (2012 & 2015) and Building Department (2012).

Four various scenarios with different PR/BH restrictions were established for our study. Scenario 1 (S1) represents the original plan, which follows the maximum PR/BH defined by KTOZP or BPRs. Scenario 2 (S2) is the approved plan proposed by CEDD. Scenarios 3 (S3) and 4 (S4) are the further increased PR/BH based on S2, which was assumed intensively in this study. In the site of 1k1 in Area 1, the plot ratio was increased by 22% (from 4.5 to 5.5) between S1 (the original plan) and S2 (already approved plan) after comparison. Similarly, the plot ratio of S3 increased by half of this growth rate (11%) to 6.1, whereas the plot ratio of S4 increased by the same growth rate of 22% to 6.7. A similar formula was applied to the calculation of building height for each scenario. Simultaneously, the same area was assumed with the height of 2.9 m for each floor. Finally, the Gross Floor Area per floor and site coverage in each scenario could be achieved. In the same way, rules for establishing scenarios of other sites were acquired.

ArcGIS and CityEngine were employed to model 3D buildings for the three study areas. ArcGIS was applied to model the footprints of buildings. Footprints were modelled in/around the three study areas according to the layout map. CityEngine helped transform 2D footprints to 3D models. Finally, all the generated 3D building models, surrounding building models, and terrain data were integrated (Fig. 5) for further 3D spatial analyses.

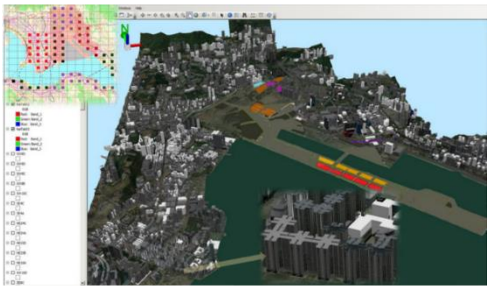


Figure 4: Example of the visualization of 3D spatial data

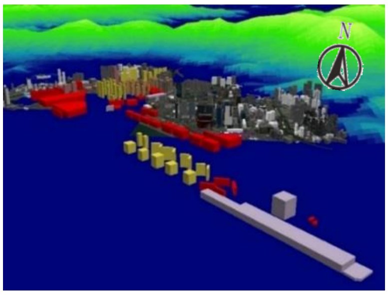


Figure 5: 3D models of the KTDA

3.3 Three-dimentional Spatial Analyses

1) Urban Skyline

Urban skyline serves as a kind of fingerprint as no two skylines are alike. For this reason, skylines are always presented to establish a city location, as well as used for city renewal (Skyline, 2015). As Fig. 8 shows, two skylines were drawn to show the profile of this study area. In particular, Skyline 1 crosses Study Areas 1 and 2, whereas Skyline 2 passes through Study Area 3. A comparison of the four different scenarios will reveal the extent in which the increased building height affects the profiles.

Figure 8: Two skylines

Figure 9: Ridgelines on Kowloon and HK Island

2) Visual Effect of Mountain Ridgeline

Ridgelines and peaks are valuable assets for HK according to UDGs, especially those located close to the city center in Kowloon and HK Island, shown in red in Fig. 9 (Planning Department and RMUM Hong Kong Limited, 2002). Therefore, protection of ridgelines is an important step and worth special attention during urban development. The long-term objective is to promote HK's image as a world-class city by enhancing the quality of our built environment from both functional and aesthetic perspectives.

There are seven vantage points around Victoria Harbour (VH) as start reference points for consideration of views to ridgelines/peaks (Fig. 10). Considering the study area location and visual factors, only three vantage points along VH in HK Island were chosen, namely, Quarry Bay Park, HK Convention and Exhibition Center, and Sun Yat Sen Memorial Park.

Figure 10: Popular vantage points

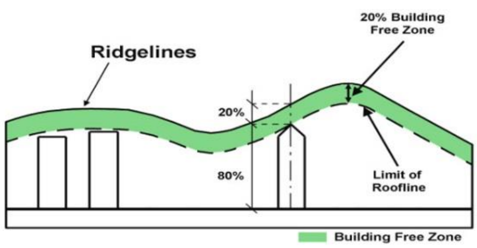


Figure 11: Building free zone

To conserve the precious ridgelines and peaks, a 20% building free zone (Fig. 11) is recommended to be maintained according to Metroplan (Hong Kong Planning Department, 1991) guidelines. Following this suggestion, a number of sampling points with 1° interval were identified along the limit of roofline for the mountain in Kowloon Island. View corridors from the three abovementioned vantage points to the limit of roofline were established to determine the effects of visibility.

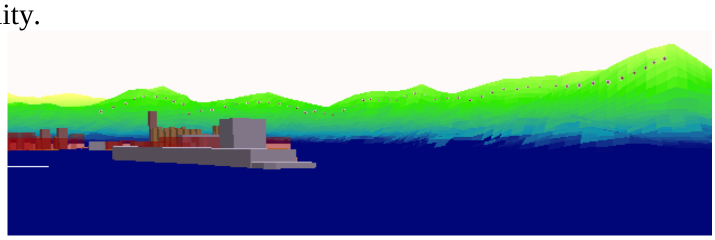


Figure 12: Sample points on the limit of roofline

3) Shadow and Solar Exposure

Sunlight is visible during the day when the sun is above the horizon of the Earth, which is a part of electromagnetic radiation emitted by the sun (Sunlight, 2015). A shadow is a region where sunlight is obstructed by an opaque object (Shadow, 2015). Generally, sun exposure hours are normally used to measure solar exposure.

In this analysis, the effects of sunlight hours and the distribution of solar exposure with the minor relaxation of PR/BH through comparison of S2 versus S3 and S2 versus S4 were investigated. With careful consideration, three analysis areas shown in Fig. 13 were determined based on solar altitude (20°) and sunlight shadow. Considering sunlight intensity and illumination time, summer was the most suitable season out of the four seasons. Finally, the average sunlight hours per day and related locations were calculated.

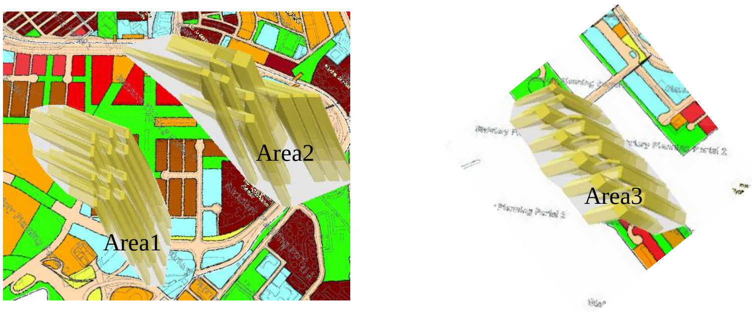


Figure 13: Three analysis areas chosen in summer

4) Wind Ventilation and Air Temperature

(i) Introduction of ENVI-met

ENVI-met is a 3D model that can simulate the microclimate of an appointed area. The simulation is based on fluid dynamics and thermodynamics, and the results consider the interaction among soil, vegetation, and the atmosphere. To simulate the microclimate using ENVI-met, a few assumptions should be considered, such as a steady temperature inside buildings and no heat storage in buildings. Therefore, the simulated result only relies on physical influence instead of anthropogenic effect. Moreover, the soil temperature and humidity in the modelling areas follow the default setting during the simulation.

(ii) 3D Modelling Regulations in ENVI-met

The model size in ENVI-met in the early stage should be determined using building footprints. To avoid the jet effect of the wind above the top of the models during the simulation, some regulations must be followed. The building height (Z) of the models in the three study areas should be twice the height of the highest building for each study area. The resolutions of all the models were the same to prevent the simulation results from being affected by different modelling settings.

(iii) Modelling of the Study Areas and Surroundings

After determining the model size, the study areas and surroundings were modelled in ENVI-met. With the aid of ArcGIS and CityEngine, the same building location, shape, and building height used in the former analyses were extracted. The building model was developed in ENVI-met by allocating height values to the grids forming the shape of the buildings. In the modelling process, only buildings were considered, and the wall properties and the roof materials of the buildings were assumed to be hollow block and concrete slab. The equidistance method was chosen for the generation of vertical grid; thus the vertical grids were of the same size apart from the bottom one. Similarly, the same four scenarios were developed for future simulation and comparison of wind ventilation and air temperature.

(iv) Configuration Setting and Simulation

To implement a simulation, configuration settings should be provided beforehand. This software requires initial weather information, including wind speed, wind direction, air temperature, relative humidity, and special humidity in 2500 m, for a particular date and time (Table 1). All the past raw weather data records were kept by the Hong Kong Observatory. Considering that significant changes in wind ventilation and air temperature appear in winter, 4 February 2014 was chosen as the testing date. The air temperature on this selected date was close to the average temperature that February.

After completing the configuration setting, the models were run for different scenario simulations. During the simulation, the calculated meteorological data, including wind speed, air temperature, humidity, and some other data such as surface temperature and soil humidity, were allocated to each grid in the ENVI-met model. The data formed an output file in the designed time interval for further analysis.

Table 1: Configuration setting in ENVI-met

Figures \ *Values*	*4 Feb 2014 (Winter)*
Start time of simulation	*7:00am*
Total simulation time (hour)	*24*
Model state saving interval (min)	*180*
Receptors state saving interval (min)	*60*
Wind speed in 10 m above ground (m/s)	*5*
Wind direction	*Southeast*
Roughness length at reference point	*0.1*
Initial atmosphere temperature (K)	*291*
Specific humidity in 2500 m (g Water/kg air)	*7*
Relative Humidity in 2m (%)	*88*

4 Experimental Results and Comparison

1) Urban Skyline

Fig. 14 shows Skyline 1 of the three study areas in different scenarios. The building heights in Areas 1 and 2 gradually increased from Scenario 1 to Scenario 4. However, the effect of increasing PR/BH on the scene of Skyline 1 was not significant. Compared with the traditional baseline photographs for landscape assessment, 3D GIS provides a more vivid and convenient way to show the city profile using skyline.

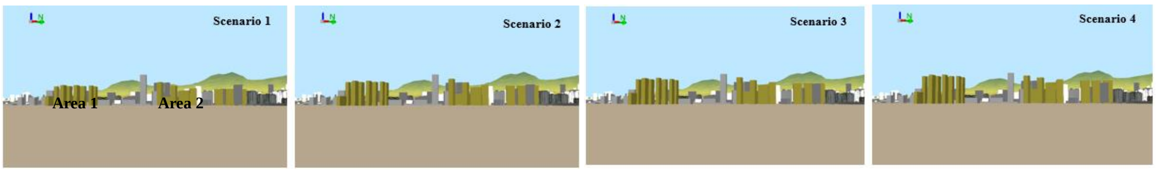


Figure 14: Scenes of Skyline 1

2) Visual Effect of Mountain Ridgeline

With continuous increases in heights for four different scenarios, three blocked sightlines only existed in S4 at the vantage point of Quarry Bay Park (Fig. 15). Besides, a further step was conducted based on the three blocked sightlines. A maximum area was designed to calculate the blocked sightline in red from the leftmost to the rightmost side with a much smaller interval of 0.01°, which means that the sightlines within this angle area should always be blocked. Following a number of new blocked sightlines, the summation block angle of all angles between adjacent sightlines within this block area was calculated. Finally, a block percentage was calculated for each sightline bundle (left is 1.36%, middle is 1.4%, and right is 1.58%). This result indicated that the visual effect on conservation of ridgelines was relatively small after the increasing PR/BH.

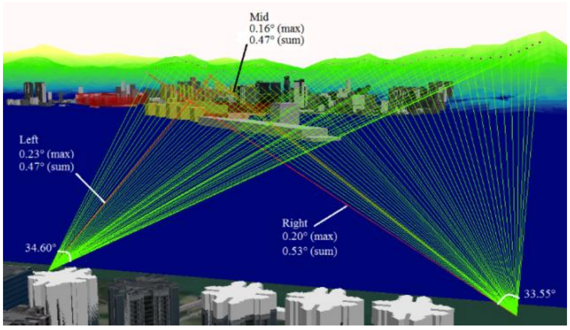


Figure 15: The situation of the Quarry Bay Park vantage point

3) Shadow and Solar Exposure

The average sunlight hours per day were calculated for the three study areas. The findings are presented in 3D environment within the chosen analysis regions in summer (Fig. 16). Specifically, ten classes of sunlight hours ranging from (0, 1] to (9, 10] are shown in different hues. These findings revealed that the differences between S2 versus S3, S2 versus S4 were not evident.

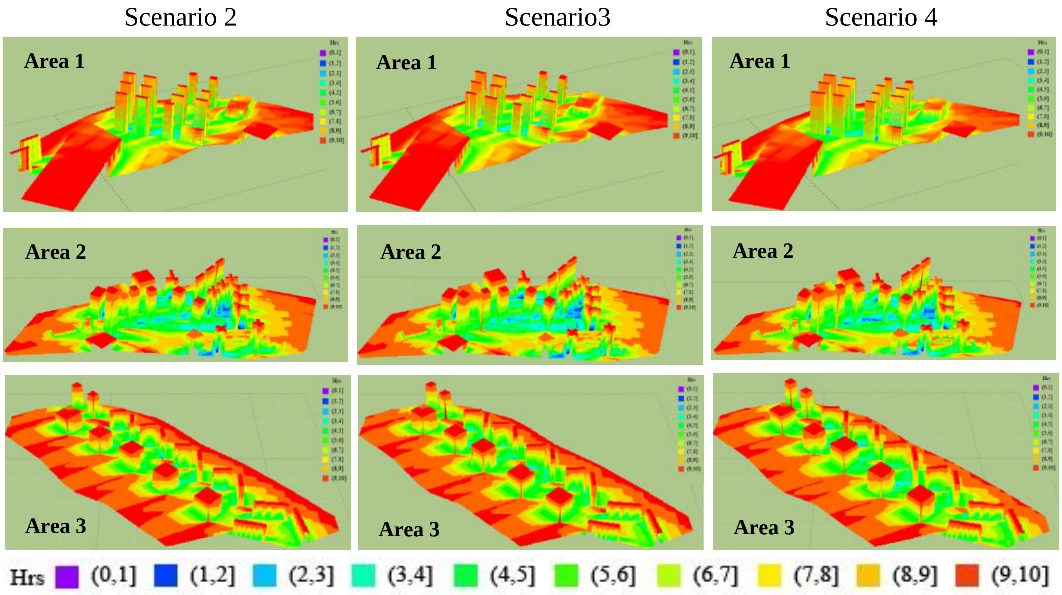


Figure 16: Results of average sunlight hour per day in summer

To further analyse the variation trend of sunlight hours for different scenarios, the differences in area range and related percentage between S2 versus S3 and S2 versus S4 were calculated and described in blue and red curves in Fig. 17, respectively. However, a consistent trend was observed. The two curves illustrate the difference in long sunlight categories; for example, (9, 10], (8, 9], and (7, 8] decreased because of the increased PR/BH. For short sunlight categories, such as (3, 4] and (2, 3], the difference increased accordingly. The fluctuations in the vibration rate were almost 0% for the shortest sunlight category. Moreover, the vibration rate of hours in middle categories such as (6, 7], (5, 6], and (4, 5] may not be fixed for different study areas because of the various distributions and directions of buildings. During this middle category, Sunlight hours increased in Areas 1 and 3, but decreased in Area 2, possibly because the spacing between the buildings in Area 2 was relatively larger than that in Areas 1 and 3. In general, all changes were insignificant, which demonstrated that the effect of increased PR/BH on shadow and solar exposure in summer was relatively small.

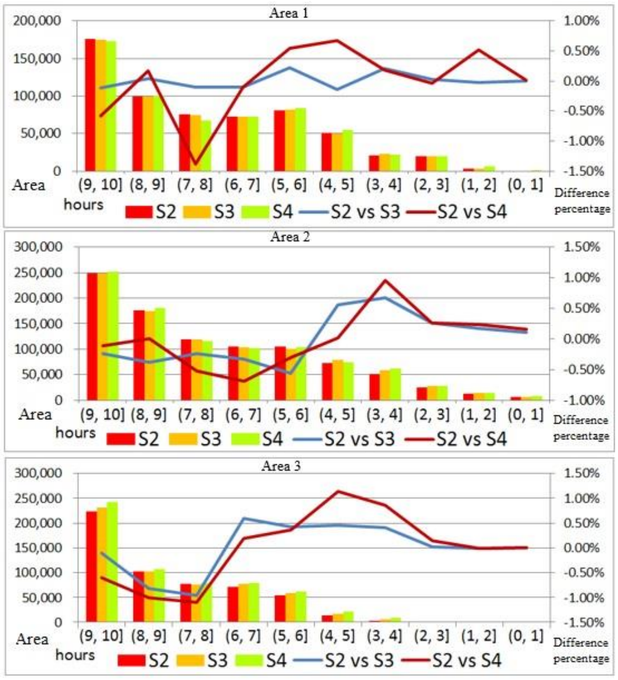


Figure 17: Sunlight hours and areas comparison in summer

4) Wind Ventilation and Air Temperature

To understand the extent of changes in different scenarios, various simulations were carried out in winter night as an example. The temperature range (−0.20 °C to 0.020 °C) presented in the legend in white is defined as an insignificant change. Air temperatures outside that range (below −0.20 °C in green or above 0.20 °C in red) were deemed significant changes. Fig. 18 shows an insignificant change in air temperature for most areas between S3 versus S2 and S4 versus S2. A small part of the red area is presented only for the upper left corner of Area 2, which indicated a slight change in air temperature between 0.2 °C and 0.3 °C in this area after increasing building height.

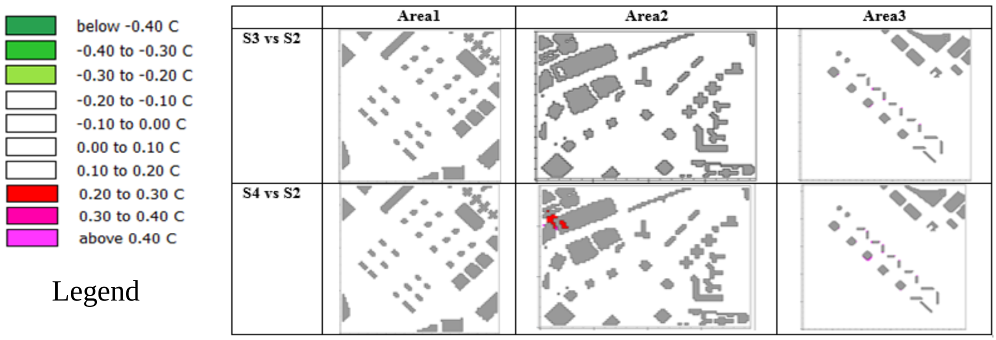


Figure 18: Air temperature comparison in different scenarios in winter night

Similar to air temperature, the difference in wind speed was also classified into different intervals. According to the subjective response to air motion (Bradshaw, 2006), the minimum wind speed that can be detected by human beings is 0.25 m/s, and the speed between 0.25 and 0.51 m/s that can be sensed by people is considered comfortable. Except for wind speed, wind direction in the study areas was also simulated and symbolized by the arrows, where a long arrow represents a fast wind speed.

As shown in Fig. 19, Areas 2 and 3 both showed some changes in wind speed. The extent of increase/decrease became more obvious in S4 versus S2 in the winter night. The decreased wind speed was due to the increase in building height, which blocked the wind. Meanwhile, increased wind speed was possibly due to the enlarged height difference between tall buildings and adjacent low buildings after the increase in PR/BH. According to wind direction, a southeast wind was defined for initialization during this simulation. The changes in wind direction depend on the site conditions, including position and layout of the buildings. As shown in Fig. 19, wind direction slightly shifted to allow wind to pass through the buildings. Finally, the findings indicated only small changes both in wind speed and wind direction for the three study areas, but more obvious changes were observed in Areas 2 and 3.

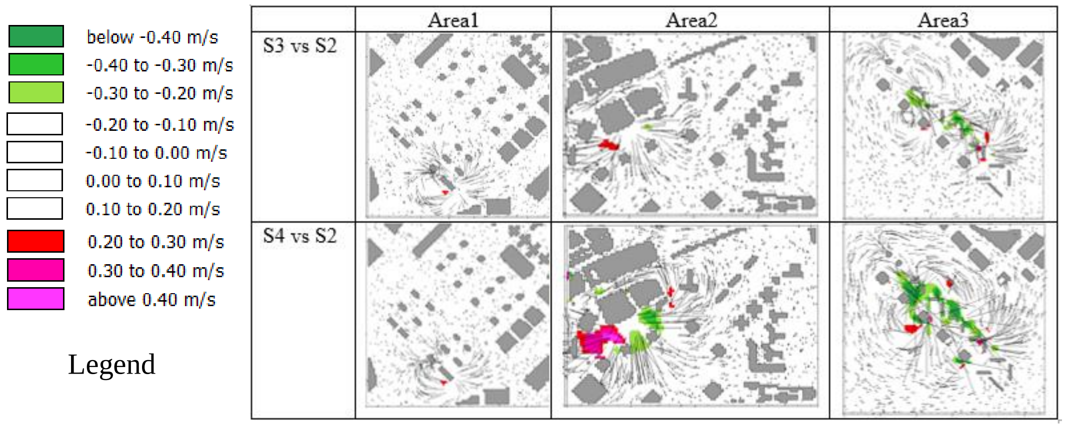


Figure 19: Wind speed comparison in different scenarios in winter night

5 Discussion

For wind speed analysis, more obvious changes were presented in our findings. Both increased and decreased wind speed appeared in Areas 2 and 3. The difference in wind speed was around 0.4 m/s, which was within the comfortable range sensed by humans (0.25–0.51 m/s), so the results were still identified as slight changes.

To prove the effects of minor relaxation of the maximum PR/BH restrictions of 21 target sites, 3D modelling and simulation technology were employed. However, only primary and simple 3D models were generated in this study. Therefore, more complicated and realistic 3D models should be produced and designed in terms of different building structures, materials, suitable layout and directions, and podium and car park employment for further studies. Besides, the simulation of thermal properties of buildings, types of gas sources, and energy source in water bodies was limited, which resulted in a less accurate simulation compared with the real case. Furthermore, more ideas about the formation of numerical model and microclimate can also be investigated in the future.

6 Conclusions

3D modelling and spatial analysis technology were introduced in this study to conduct simulations based on 3D models, which could aid in people's understanding and provide more vivid visualizations than 2D GIS. The effects of increasing PR/BH toward urban skyline, visual effect of mountain ridgeline, shadow and solar exposure, air temperature, and wind ventilation for the three target study areas in four scenarios were successfully observed. Based on the findings of various spatial analyses, minor relaxation of the maximum PR/BH led to the following conclusions.

(1) Urban skylines were drawn to check the city profiles of the three study areas in four scenarios. The effect of increasing PR/BH on urban skylines was not significant, which was reasonable and acceptable.
(2) Sightlines were generated by connecting the selected vantage points and sampling points on the mountain to check the visual effect of mountain ridgeline. With continuous increasing height for the four scenarios, the blocked sightlines only existed in S4 at the Quarry Bay Park. Three bundles of sightlines were blocked. Based on the figures, a very slight visual effect was noted on the conservation of ridgelines.
(3) During shadow and solar exposure analysis, the conditions in summer were considered for the whole study areas. The average sunlight hours per day, sunlight area size, and corresponding percentages for different categories of sunlight hours were calculated and presented by figures. The findings showed that the changes were insignificant, which indicated that the effect of shadow and solar exposure to the surrounding environment in summer was relatively small when we increased PR/BH.
(4) For air temperature, only a slight change appeared in Area 2 in summer night. The changes were between 0.2 °C and 0.3 °C.
(5) For wind ventilation, more obvious changes were shown in wind speed and direction for Areas 2 and 3. However, the magnitude of change in wind speed was only that sensed by humans and deemed as a comfortable change. Therefore, only slight changes were observed when increasing PR/BH for the study areas.
(6) The findings of 3D spatial analyses revealed that S4 was the recommended reasonable scale for relaxation of the maximum PR/BH restriction for the 21target sites in the KTDA.

The use of 3D modelling and spatial analysis technology provides people with a more holistic view and allows them to make more effective and informed decisions. The method proposed in this paper can also be applied in urban renewal studies or new development areas in other densely populated cities similar to HK.

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Introduction of sustainable low-cost housing. Experiences from a demonstration project viewed from an innovation diffusion perspective

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Abstract

The purpose of the study is to describe and analyse, from an innovation diffusion perspective, factors important when using demonstration projects as a tool for introduction of sustainable low cost housing. The study is focused on Ethiopia, a country with big challenges as regards population increase, lack of resources, deforestation, land erosion and a general need for better and sustainable housing, especially in rural areas. The study is furthermore focused on the adobe technology as a more sustainable alternative to the traditional building technology which is very timber consuming. Many attempts have been made to introduce this technology with the use of demonstration buildings. A great part of these attempts have failed, some have been successful. In order to study and discuss important factors in connection with the use of demonstration buildings, a project executed some years ago in southern Ethiopia has been analysed. The study is based on findings collected during and after the erection of these buildings mainly through practical tests, interviews and observations. From a technical point of view this demonstration project was successful. It was possible to develop an appropriate production technology and the result was buildings with a good standard and good function. Experiences up to now indicate a good durability. From an innovation diffusion perspective however the demonstration buildings have not fulfilled their purpose. The impact in the region seems to be very small. The conclusion in the paper is that the reasons behind this failure mainly are: (1) Lack of clear and visible relative advantage in comparison to the traditional building technology. The supply of construction timber in the area in question is still good. (2) Lack of a champion advocating the technology by using the demonstration buildings and thereby giving the message to the society that the technology is valuable and trustworthy. (3) Lack of continuity in the demonstration efforts, as a result of the lack of a champion.

Keywords: innovation diffusion, adobe, demonstration project, sustainability, low-cost

1. Introduction

Ethiopia is currently ranked as number 174 of 187 countries in the world by the Human Development Report (2015). The ranking is based on a Human Development Index which is a composite index measuring among other things the standard of living. The low ranking indicates difficult living conditions for the vast majority of the inhabitants of Ethiopia. This is caused by current serious problems such as a very large population with a high population growth rate putting a high pressure on already inadequate resources causing e.g. high rate of deforestation, (Barton and Dlouhá, 2014).The deforestation in its turn causes other problems and difficulties, e.g. land erosion and lack of suitable timber for construction, (Barton and Dlouhá, 2014).

In 2011 the Ethiopian Government issued the document "*Ethiopia's Climate-Resilient - Green Economy. Green economy strategy*" (2011). In this publication it is stated that Ethiopia aims to achieve middle-income status by 2025. The aim is to develop a climate-resilient green economy by avoiding sharp increases in greenhouse gases (GHG emissions) and unsustainable use of natural resources.

A vast majority of the Ethiopians, about 80%, are living in rural areas. This means that a majority of the Ethiopians have rather bad housing conditions. A study by Kumie and Berhane (2002) indicated poor living conditions for many persons living in rural areas, with overcrowded houses with poor sanitation conditions. The authors stress that this fact predisposes to adverse health conditions and that appropriate interventions are needed.

As regards the Ethiopians living in urban areas the average situation seems to be better with a much bigger variation in living standard from case to case; (Abelti et al, 2001) and (Bihon, 2007). Anyhow, the need of improvement is great also for urban areas.

From what is written above it is obvious that there is a great need to improve the housing conditions for many Ethiopians. New methods for erecting dwelling houses must be introduced. These methods must be sustainable and take into account the present situation in the country and the Ethiopian Governments aims regarding GHG emissions and the sustainable use of natural resources. In addition to this, the methods must result in durable and safe dwelling houses that have a healthy indoor climate. A technology that is interesting in this context for erection of walls is the adobe-technology.

During the years several attempts have been made to introduce this technology in Ethiopia. Many times demonstration buildings have been erected in connection with the introduction. Some of the attempts have been and are successful, many have been failures.

The aim of this paper is to present and discuss from the innovation diffusion perspective factors of importance for the introduction of adobe-technology technology in Ethiopia. The discussion is based on findings and experiences from a demonstration project executed during the years 2009 – 2012. The aim of the demonstration project was to introduce this technology in a region in southern Ethiopia. The data from this demonstration project presented in this paper was collected mainly thorough practical tests, interviews and observations.

2. Innovation diffusion

Innovation has been defined in many ways, in different contexts, but all are more or less pointing in the same direction, with slight differences. One definition that has gained a wide acceptance is “the implementation/adoption of new or significantly improved production or delivery methods” (OECD, 1997). It is useful as it links innovation to value creation and recognize this in a broader sense than short-term economic perspectives, as well as move away from the linear process best measured by R&D spending (Loosemore, 2014). That makes it also useful in this context. Innovations evolve in an economic, social, cultural and political context and are highly influenced by this (Weisenfeld, 2003). This explains why innovation vary between different contexts such as industry, political, national etc. This suggests that different national contexts when transferring an approach or technology between contexts, for example when transferring between countries, need to be addressed (Abdul-Azis, 2002). Developed and developing countries have to address different problems in relation to innovation (Bröchner, 2011). Differences in education, communication, business maturity etc all affect innovation. As learning is a central to innovation, and it is a social activity, which involves interaction between people (Lundvall, 1992) it is important to have a supporting framework around the innovation project or innovation diffusion project suited to the context enabling people to learn about the innovation.

Undertaking construction innovation outside of projects appears to be a very unusual process (Tatum, 1987). This result in that innovation in construction, from a process perspective, is complex and involves different stakeholders and components (Manseau, 2005). From a technical perspective the innovation in the current context is not as complex as in most western countries, but the process may be as complex, but in other ways. The development of a collective understanding of the innovation and building trust at the operational level where individuals are more likely to encounter it is important. A critical success factor is involvement, from the early stages of development, of those who will be responsible for implementation, possibly requiring mediation between new development and existing routines and duties within the organizations affected (Barlow et al., 2006).

In an earlier study where common areas of importance for the diffusion process, compare with Stoneman (2001), have been applied on non-commercial innovation diffusion in developing countries, it was found that the factors, apart for commercial factors, are applicable (Hjort and Widén, 2015). Those cases where there was a champion, where there was a “market”, a need, where the cultural context allowed for the innovation, the diffusion succeeded. In the cases where a majority of the factors were missing the diffusion failed. Other factors that may be of importance for diffusion, not specifically studied in the earlier work, are relative advantage, compatibility, complexity, trialability and observability (Rogers, 2003). Relative advantage is how much better the innovation is perceived to be than the technology it is supposed to replace. Compatibility is the extent an innovation fit within the existing values, past experience and needs of the adopters. Complexity addresses how difficult the adopter finds the technology to use. Trialability deals with the adopters’ potential to experiment with the technology. Observability is about how the results are visible to others. Some of these factors are to some extent overlapping the factors tried earlier, for example relative advantage share much with if there is a market. The market will be there if there is a relative advantage of the innovation. Compatibility has some parts in common with the cultural dimension. Does the innovation fit into the contextual setting where it is to be diffused? Whereas complexity, trialability and observability are not dealt with to the same extent explicitly in the earlier study, compare with Hjort and Widén (2015).

3. Alternative building technologies

The traditional way of erecting a dwelling-house in Ethiopia is to use a framework of timber in the walls. Timber-poles with an appropriate length are put into the soil. The timber-specie mainly used varies from region to region according to availability. In the highlands the timber-specie mainly used, has been and still is fast growing Eucalyptus. However, in order to enhance the durability of the walls, some poles of more durable timber species, have been used in the walls with a spacing of approximately 1000 mm. The framework is provided with a roof structure which is covered with grass or corrugated iron sheets. This framework is later on covered with mud mixed with straw. Sometimes one of the last steps in the process is to provide the walls with a "foundation". This is done by arranging a stone masonry around the outer walls. It is clear that this masonry actually is not a real foundation but protection of the lowest part of the walls. The timber core of the walls are in contact with the soil and can thereby be exposed to termite attack and decay caused by high moisture content. With regard to this the use of more durable timber in the walls is crucial.

Dwelling houses that give a good indoor climate and that are reasonably durable can be erected if these houses are provided with a proper foundation and sufficiently long roof overhangs. Despite this it is very doubtful if this technology can be used on a broader scale in the future. There are important reasons for this standpoint. Firstly, the traditional technology is very "timber-consuming". With regard to the current de-forestation in Ethiopia and resulting timber-shortage, it seems clear that an alternative technology must be used. Secondly, the possibility to obtain durable timber species, traditionally used in connection with construction of walls, e.g. Thid (*Juniperus Procera Hochst*) and Kosso (*Hagenia Abyssinica*), will be very limited in the future, (Bekele et al, 1997). Because of the ongoing deforestation such species are very difficult to obtain, at least to a reasonable price. This has had, and will have, a serious impact on the possibility for ordinary people to erect dwelling houses with framework that could resist termite-attack and decay.

The termite problem, which is underlined in Berhane (1984), seems to have be a growing problem in Ethiopia a rather long time. A rather recent study on termite damage on rural housing in the Central Rift Valley in Ethiopia, (Debelo and Degaga, 2014), confirms this. According to this source the wood/straw thatch buildings characteristics of farming communities in Ethiopia, are susceptible to termite damage, particularly in the tropical savanna areas. They forward a source, (Abduraman ,1990) which reports that in western Ethiopia, where the termite problem is accentuated, thatched roof huts are destroyed in less than five years and corrugated iron roof houses in less than eight years.

A realistic alternative to this traditional building technology is to use adobe blocks for the walls, i.e. to build walls in dwelling houses with sun-dried blocks made of mud; with or without straw included.

The technology is not a traditional technology in Ethiopia as a whole, although there are some areas where the technology has been in use for a rather long time, e.g. in the eastern Ethiopia.

In a recent study, (Petersson and Ström, 2015) the spread and diffusion of this technology in some locations in the eastern, the central, south-central and western parts of Ethiopia has been analyzed. As regards the diffusion, adoption and spread of the adobe technology the main of the study result can be presented as follows:

- In some parts of the country, mainly rural, there is a development which can be described as a spontaneous spread of the technology. The technology is commonly adopted and the driving force behind this development is clearly the present effect of deforestation – lack of construction timber at reasonable prices. This is the case in some parts in Eastern Ethiopia and in the Central Rift Valley.

- During the years a number of initiatives have been taken in order to introduce the adobe technology in Ethiopia, both in rural areas and in urban centers. The erection of demonstration buildings has been an important part of these initiatives. Most of these initiatives seem however to have failed, as they have not resulted in a sustainable diffusion of the technology. The reasons behind this are many and interdependent. Petersson and Ström (2015) mention, among other things the following: lack of continuous efforts, neglecting of training and education, market forces, negative attitudes from authorities and absence of advantages that are easily and clearly identified.

- In some cases the adobe technology has been used in a way that is not recommendable from a technical point of view. The reason behind this seems to be a lack of understanding of the limitations of adobe and a lack of experience. It can be anticipated that cases like these creates negative demonstration that limits further diffusion of the technology instead of promoting it. These observations underline the importance of proper demonstration and education.

Several cases in Ethiopia, see e.g. Hjort and Sendabo (2007), show that durable houses with a good indoor climate can be built by a proper use of adobe technology. The technology has many advantages: it is real low-cost, local material can be used to a very great extent and the “timber content“ is very low. In addition to this it is rather simple with no need of special equipment with the exception of some simple forms for block-making. The technology has really the potential to become “the property of everybody”.

As regards durability however a special concern must be given in some regions to termite-attack also for adobe-houses. This is clearly demonstrated by Debelo and Degaga (2014). In connection with site-visits in Central Rift Valley in Ethiopia they have noted that more than 85 % of 35 houses built by mud blocks where prone to termite infestation. The corresponding figures for 23 houses built according to the traditional technology was 100%. It can be noted that the great majority of the houses, both adobe and traditional, were rather young, i.e. less than six years old.

Debelo and Degaga (2014) argue that it is more likely that infested wooden wall houses have a shorter life then adobe houses as they attack the load bearing structure, the wooden wall. However, also in adobe houses, the termite can cause serious problems. In adobe walls they can simply move through the walls without affecting these and the roof structure and cause heavy damages.

4. The demonstration project

At Halmstad University studies concerning low-cost housing with a special focus on the Kambaata Region in South Central Ethiopia have been conducted for several years; (Hjort and Sendabo, 2004). The overall aim has been to introduce low cost housing technologies and at the same time study and analyse the attitudes of ordinary people towards these technologies. From the beginning the importance and necessity of erecting demonstration buildings have been underlined.

In accordance with this a project aiming at erection of four demonstration buildings in the town of Durame in the Kambata Region was initiated. The aim was to study and demonstrate two low-cost housing technologies; adobe technology and a technology based on cement stabilised soil blocks. The purpose was to get a basis for technical studies as well as studies concerning attitudes. The technology based on cement stabilised soil blocks will not be commented further in this paper.

When the project started the adobe technology was by and large unknown in the Kambaata Region. Although this region was and still is densely populated, the access to timber for construction purpose was and still is rather good, at least as concerns eucalyptus. This means that an important driving force for a spontaneous development of the adobe technology was and still is lacking.

The project was planned and conducted in cooperation with a local development organisation. The plan was that this organisation should own and use the erected demonstration buildings in the future. The work at the site started in the beginning of 2009. Due to different difficulties the project was delayed and the demonstration buildings were not finalized until the beginning of 2012.

The studies related to these demonstration buildings can be divided into two groups: studies which focuses on technical issues and studies related to attitudes towards the new technologies. They have been executed before, during and after the erection of the demonstration buildings, see Table 1.

Table 1. Studies within the project – overview.

Type of study	*Before erection*	*During erection*	*After completion*
Technical studies	*Trial tests of soil reported in Andersson and Berglund (2002)* *Laboratory and field tests regarding adobe blocks; reported in Hjort (2009).*	*General observations with focus on methods for weather protection during manufacturing of blocks and masonry work of walls.*	*Follow-up studies that will focus on durability and function.*
Studies regarding attitudes		*Observations* *Inquiry form*	*Observations* *Interviews.*

The detailed design of the demonstration buildings was executed by two BS.C students. It is described in Johansson and Wartainen (2008). These two students based their design from findings obtained during a field study in Ethiopia. An essential part of their field study was a visit to Challia in Western Ethiopia, where they studied a successful low cost housing project. Interviews with people living in houses erected by adobe technology were an essential part of their study.

Three buildings were designed according to the following:

- Buildings: Dwelling House, Kitchen and Toilet:
- Sizes: Dwelling House : 5,5 x 5,8 m^2, Kitchen: 3,4 x 3,4 m^2, Toilet: 2,5 x 2,5 m^2
- Foundation: Stone masonry for all buildings
- Walls: Adobe;
- Roofing: Trusses of eucalyptus. Corrugated iron sheets for all buildings
- Flooring: Concrete slab on natural stone for all buildings
- Ceiling: Dwelling House Of cloth
- Doors and Windows: Wooden. Locally fabricated for all buildings

This is a description of the main features of the design. However, many important details are discussed and appropriate solutions are proposed by Johansson and Wartainen (2008). The following can be mentioned: foundation details, roof overhang, securing of roofing against wind-forces, fastening of door and windows.

The soil available at the spot was used for the production at the site of adobe blocks with the size 150 mm x 200 mm x 400 mm. The soil, taken at a depth of about 500 mm after the topsoil had been removed was mixed with water and straw. The straw, consisting of" teff-straw" was purchased locally. Simple forms made of ply-wood were used. These forms were open in the bottom and in the top. The manufactured blocks were stored and cured, at a first stage inside a store and at a second stage under a weather protection roof, see below. The expected and intended curing time was 28 days. However, for some of the manufactured blocks this time was prolonged considerably due to rainy and thereby humid air conditions. As mortar in the adobe walls soil mixed with water and straw was used.

The weather in Durame and its surroundings seems to have become unpredictable. Because of this the erection of a temporary roof structure was necessary as adobe blocks are very sensitive against water and wetting up. Because of this, and because of difficulties in planning the project work in relation to rainy periods, a temporary roof structure acting as weather protection was erected for the Dwelling House. This temporary roof structure consisted of the final roof structure (eucalyptus trusses, eucalyptus purlins and corrugated iron-sheets) for the building in question resting on temporary eucalyptus poles. The manufactured blocks were in a first stage stored below this temporary structure. In a second stage the walls were erected below it. At a final stage the roof structure was made to rest upon the walls and the eucalyptus poles were removed.

The general impression and experience from the use of this technology in Durame is that it is very suitable for the region and that it is easily understood and easily adopted by workers involved. The manufacture of adobe blocks and the erection of the buildings arouse a great interest among the inhabitants of Durame and most people expressed a positive attitude towards the technology.

In Table 2 the result from a questionnaire regarding the attitude towards the adobe technology is presented. The questionnaire was written in the official national language amharinja and in the local language kambatinja. It was made with the erection of the demonstration buildings as a reference. The questionnaire was distributed to 40 persons whose answers were analysed.

Table 2. Studies of attitudes towards adobe technology

Part	***Statement***	***(%) responding positively***
Regarding the acceptance of adobe technology	*I don´t support the idea*	*5*
	I support the idea	*93*
	I support the idea but I don´t think it will be accepted	*2*
Regarding training in adobe technology	*I am willing to participate*	*90*
	I am not willing to participate	*5*
	Before I answer – let me see the training	*2*
	No answer	*2*

5. Follow-up studies

During a visit in the beginning of 2015 to Durame observations and semi-structured interviews in the region were made. The observations showed that from a technical point of view the demonstration buildings were in good condition. Some defects were however noted, e.g. has the cement-lime plaster on the walls, which is intended to protect the walls from rain, come loose. It was also noted that the demonstration buildings were not used; neither by the local development organisation in its daily business, nor as demonstration objects related to ongoing education regarding adobe technology.

At an interview with a person representing the local development organisation it was mentioned that this organisation, due to lack of resources, had not been able to utilise the demonstration buildings as intended from the beginning. One of the intentions had been to continue with educational activities within adobe technology with the use of the demonstration buildings as reference objects.

The observations indicated further that the impact of the project and the demonstration buildings with regard to introducing the adobe technology in Durame and its surroundings was very small, if any. This impression was confirmed by interviews. At the interview with the person representing the local development organisation it was stressed that the adobe technology would have big advantages as a building material in the Durame region but that it has not been adopted by the local population mainly due to lack of knowledge.

6. Concluding discussion

The project showed that it is possible to erect durable and functional adobe buildings in the Durame area. Appropriate material is available and the technology can easily be understood and adopted by local workers. Furthermore, it showed that it is possible to handle the somewhat unpredictable weather conditions in the area by erection of a temporary roof structure that later on can be transferred into the permanent one.

The outcome of the project with regard to introducing a new technology can be discussed and analysed from an innovation diffusion perspective based on the attributes defined by (Rogers, 2003):

"***Relative advantage".*** The relative advantage of the adobe technology, in relation to the traditional technology, might be underestimated or even denied by ordinary people in Durame. In this region there is no shortage of timber for construction; one of the main driving forces behind the spontaneous spread of the technology in other regions in Ethiopia. Other advantages, such as a better indoor climate and a better resistance against termite attack can only be perceived by the use of the building and after a longer period respectively.

*"**Compatibility" .***The adobe technology can be regarded as a compatible technology as mud mixed with straw is a very important part of the traditional building technology. In accordance with this working with mud has a long tradition in Ethiopia. However, working with clay has low status in Ethiopia; (Hjort and Sendabo, 2005). This might deter potential users from building their dwelling house almost entirely of mud.

*"**Complexity".*** Adobe is a simple technology; it is easy to understand and it is easy to adopt as clearly demonstrated during the erection of the buildings. However, the use of a temporary roof structure as a shelter and as a storage area and later on using this as permanent roof structure might have been regarded as complicated and difficult. It is possible that this part of the process has deterred potential users from adopting the technology.

"***Trialability".*** The adobe technology offers a good trialability as such. It is thus possible for a potential adopter to try the technology in small scale, for instance by using it for a minor building, e.g. for a store or similar. In this case this has only been done when executing the demonstration project. The reason for that is that the organisation championing the diffusion had to withdraw earlier than planned.

*"**Observability"*** The adobe technology offers a good observability of its buildability which was used in connection with the demonstration buildings erected in Durame. But, the observability of the finished product, its durability, indoor climate etc has to be observed for some time, years. As the building has not been used and the organisation championing the diffusion withdrew this has not been done in this case.

From a comparison between this study and the study presented in Hjort and Widén (2015) it is clear that the role of a champion is very important as is the perceived relative advantage and the cultural context. In this case several of the factors pointed out by Rogers (2003) was not fulfilled, but could, or would, have been if a champion had been present over time, also after the demonstration project finished.

This study, together with the earlier study, forms an interesting base for future studies of non-commercial innovation diffusion in developing countries. In future studies the focus will be on the role of the champion of the innovation over time, the role of relative advantage and the cultural context and how these influence the success of diffusion, as well as how these influence the other factors said to be important for innovation diffusion.

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Advanced Intelligent Agents for Optimised Dynamic Process Monitoring and Defect Inspection in Construction Projects

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Abstract

Defects and errors in new or recently completed work continually pervade the Architecture, Engineering and Construction (AEC) sector. Whilst inspection and monitoring processes are established vehicles for 'control', the procedures involved are often process-driven, time consuming, and resource intensive. Paradoxically therefore, they can negatively impinge upon the broader aspects of project time, cost, and quality outcomes (the three central tenets). Acknowledging this means appreciating concatenation effects such as the potential for litigation, impact on other processes and influence on stakeholders' perceptions – which in turn, can impede progress and stifle opportunities for process optimisation and innovation. This also deleteriously affects opportunities for improving: logistics, carbon reduction, health and safety, asset underutilisation, and labour distribution. This study evaluates these challenges from a time, cost, and quality perspective, focusing on identifying opportunities for process innovation and optimisation. It reviews the state of the art technologies that support optimal use of artificial intelligence, cybernetics, and complex adaptive systems within the AEC sector. From this, a conceptual framework for the development of a real-time intelligent observational platform supported by advanced intelligent agents (RtIOP), is presented as a solution to these challenges. RtIOP actively, autonomously, and seamlessly manages intelligent agents (e.g. cameras, RFID scanners, remote sensors, etc.) in order to identify, report, and document 'high risk' defects. Findings underpin a new ontological model that supports ongoing development of a dynamic, self-organised sensor (agent) network, for capturing and reporting real-time construction site data. The RtIOP model is a 'stepping stone' towards the advancement of independent intelligent agents, embracing sensory and computational support, which are able to perform complicated (previously manual) tasks to optimise dynamic processes seamlessly and autonomously.

Keywords: Intelligent agent, process, innovation, ICT, sensors, optimisation

1. Introduction

Defects and errors within the AEC sector still continually pervade the industry. Whilst detailed inspection and monitoring processes are established vehicles for their 'control', the procedures involved are often process-driven, time consuming, and resource intensive. These checking and monitoring processes can negatively impinge upon the broader ambitions of project time, cost, and quality outcomes as they are very resource-intensive. In recent years, the trade-off between an increasing need for non-stop inspections during construction work and their negative ramifications have focussed on the ‘value’ of systematic, innovative monitoring of construction operations (vis-à-vis conventional ‘inspector-based’ methods). Research in this area has attempted to address this through various proffered systems, typically embracing the ability to automate, capture, process and share project data among relevant stakeholders.

These systems have provided additional project benefits, for example improved: logistics, carbon reduction, health and safety performance, project efficiency savings, increased asset utilisation, and smoother labour distribution. However, unlike other industries, the AEC sector has not been quite as successful in adopting such automated monitoring systems; especially, for small and medium scale projects (Navon and Sacks, 2007). This is mainly due to the: nature of construction products (Howell, 1999); unsuitable nature of construction sites for high-tech monitoring solutions (Cheng and Chen, 2002); disaggregated nature of construction project teams (Davidson and Skibniewski, 1995); and slow, error prone existing project data collection systems (Saidi *et al.*, 2003).

Given these challenges and associated conditions, the majority of construction projects retain their protracted and inaccurate traditional (inspector reliant) control mechanisms. Among other things, this leads to a lack of ‘as-built’ construction project information (Saidi *et al.*, 2003) – which results in a general disorganisation of projects in relation to schedule, cost, and workforce control (Howell and Koskela, 2000). Acknowledging these issues, this study evaluates these challenges associated with current technologies from a time, cost, and quality perspective. The overall focus is to identify opportunities for the introduction of hybrid low cost systems which are specifically able to optimise the monitoring and control process; thereby allowing significant innovation opportunities to occur.

2. Related Works

This section overviews the state of the art technologies for facilitating systematic onsite monitoring of construction projects. In pursuance of this, it should be noted that regardless of the core functions and associated technologies, the majority of thinking on monitoring and control systems can be categorised into two groups: 1) Tracking or Scanning Equipment based technologies; and 2) Still Image based technologies. The challenges and opportunities of these two categories are presented as a prelude to making recommendations for the development of a hybrid, intelligent monitoring system (RtIOP).

2.1 Tracking or Scanning Equipment Based Technologies

There are a myriad tracking or scanning technologies available to facilitate systematic and automated construction project monitoring. One popular example is the Global Positioning System (GPS) which can be widely used to determine the geometric properties of a constructional element e.g. equipment within a construction site. Others include for instance, augmented reality (AR) (Chi *et al.*, 2013). These systems are now being used for tracking and managing the workforce (Hammad *et al.*, 2009), as well as monitoring and helping control the implementation of constructional elements (Behzadan *et al.*, 2008). Additional similar functions are supported by technologies such as Radio Frequency Identification (RFID) (Kelm *et al.*, 2013), Ultra-Wide Band (Zhang and Hammad, 2012), and Barcoding (Chen *et al.*, 2002). Hybrid systems use a combination of these options; such as when GPS is merged to work alongside RFIDs (Kelm *et al.*, 2013). Despite their merits, the reliability of such systems has always been something of a challenge, since they can be affected by unexpected interfering fields (Chi *et al.*, 2013). Another downside is the comparatively high capital investment needed for such equipment, which in many cases ultimately becomes 'buried' in the completed construction facility – which can add significantly to the overall project cost.

An alternative system relies on laser-scanned point clouds. Laser scanning is not a new technology, but due to the increasing take up of Building Information Modelling (BIM), as-built BIMs scanned by these tools are gaining popularity, with increased use being acknowledged within the AEC sector. This is mainly because they are capable of measuring geometric characteristics of environments, with high accuracy and within short timescales (Tang *et al.*, 2010). The as-built BIM generation – which is also known as 'scan to BIM' – is described by Tang *et al.* (2010) as a process comprising the following: 1) data collection through dense measurement of points about the building using laser scanners; 2) data pre-processing, which includes filtration of point clouds and the integration of coordination systems; and 3) modelling the BIM, which is a process of transforming the point clouds to semantically rich BIM objects. The downside of as-built BIM technology is that whilst data pre-processing is a fairly straightforward process, the data collection and modelling tasks are often very costly, time consuming and error prone (Bosché *et al.*, 2015; Brilakis *et al.*, 2010). These challenges have made many scholars to suggest Still Image based technologies as a viable alternative.

2.2 Still Image Based Technologies

Advancements in technology and the declining prices of mobile and fixed cameras have encouraged the increased use and uptake of photography to record daily activities and progress of construction projects. This also includes monitoring, logistics, documentation, and control purposes (e.g. resource management, Health and Safety etc.). This has also underpinned the emergence of new photographic documentation and distribution services, to provide 'visual' progress records for efficient distribution among stakeholders (Han and Golparvar-Fard, 2014). With the aid of multi-view geometry methods, image processing, and computer graphics, these 'as-is' images can either be compared with one another throughout the construction process or against an ideal 'to be' 4D BIM, which represents the assumed flow of processes. These options help flag up possible deviations (e.g. errors) in construction works (Yang *et al.*, 2015).

Due to their distinctive benefits, for example cost efficiency, accuracy, and reliability – such systems are increasingly popular. This popularity includes: detection and recognition of building elements (Chi and Caldas, 2011; Gong and Caldas, 2011); tracking 2D and 3D positions of objects (Hu *et al.*, 2004); controlling and monitoring site activities (Rezazadeh Azar *et al.*, 2012); and managing productivity (Gong and Caldas, 2009). Their downside is however, that they are fully dependant on the quality and supply of the images – which can yield challenges due to volume regarding the need to continuously capture photographs with site data. These solutions can also be highly labour-dependent for systematic image capture when 'high-tech' equipment is not available. Another challenge can be access, especially to all parts of construction site; as in some cases this is not practically feasible.

3. Research Methodology

The research methodological approach adopted in the research includes a reflection on extant literature within the field of reference to evaluate the state of the art technologies employed within the AEC sector in order to capture the salient challenges facing researchers examining automated project appraisal. This process involved the selection of cognate discipline fields (see keywords) and text from seminal journals and core reports to not only identifying the challenges associated with each technology, but also the current thinking and future trajectories proffered. From these results, a theoretical propositions is presented for discussion. This was based on the scientific foundations required to support such systems, including the optimal use of artificial intelligence, cybernetics, and complex adaptive systems. The resulting conceptual framework (RtIOP) presents a typology, which includes software agents to access and address multiple data analysis tasks, including vision-based object recognition and tracking for construction monitoring.

4. Future Perspectives

Extant literature confirms significant achievements and emerging advancements, especially in computer graphics, 4D modelling, BIM, AR, big data processing, aerial robotics, cybernetics, and smart agents. These are now starting to pervade the market, and are starting to revolutionise construction project monitoring. However, whilst it could be argued that collaborative multi-agent systems for real-time monitoring and planning on construction sites is not particularly new (Zhang et al, 2009); there are still many challenges associated with seamless integration. In terms of computer graphics, Karsch *et al.* (2014) developed an interface based on the Structure-from-Motion (SfM) technique to automatically compute alignment of photos taken from a selected model. This engages automatic reasoning on both real-world construction data and established multi-view datasets.

Modern photogrammetry and remote sensing have a strong heritage (Thompson, 1977; Richards, 2013). However, new technological advancements and the declining costs of equipment - especially computer processing and visualisation, robotics and geomatics engineering has resulted in a an increase in the use of low cost accurate aerial systems for collecting and analysing geometric and geographic data (Colomina and Molina, 2014). Similarly, Siebert and Teizer (2014) developed an innovative programme for photogrammetric flight planning and control to generate 3D point clouds from digital mobile images. They evaluated the performance of a purposively developed Unmanned Aerial Vehicle (UAV) system, which was able to rapidly and autonomously collect 3D data.

With the aim of capturing large amounts of data with minimum manual input Zollmann *et al.* (2014) used a UAV system controlled by an automatic flight path planning programme. Larger UAVs were able to capture the whole geometry quickly; while smaller, less expensive vehicles were employed to capture more detailed, localised data from parts of the target boundary. Due to limitations in battery life for such vehicles, an optimisation algorithm for programming flight paths and task objectives was also designed (*ibid*.). Despite these kinds of valuable advancements for systematic use of UAVs on projects, issues of capital cost and the requirement for in-house expertise, puts their use beyond the capabilities of many construction projects.

Given these issues, it is postulated that these kinds of challenges can be overcome by employing a mix of artificial intelligence, cybernetics, and complex adaptive systems. Intelligently combined, these could support novel arrangements of independent equipment solutions (as smart agents), with sensory and computational resources to perform complicated tasks of dynamic data collection and analysis of construction projects. Within such a network, agents could take the form of any device capable of collating and communicating site data, such as still time-lapse or video cameras, RFID tags, GPS receivers, range sensors, and other type of sensors capable of localised sensing.

A set of optimisation agents for managing project resources would need to complement project targets, including delivery of just-in-time logistics; distribution and management of materials; and labour optimisation, across the entire works. The system would actively embrace the model of the ‘invisible hand theory’ (Minowitz, 2004), whilst also taking account of concomitant human factors typically engaged in site-related activities. A conceptual model of this RtIOP architecture is shown in Figure 1.

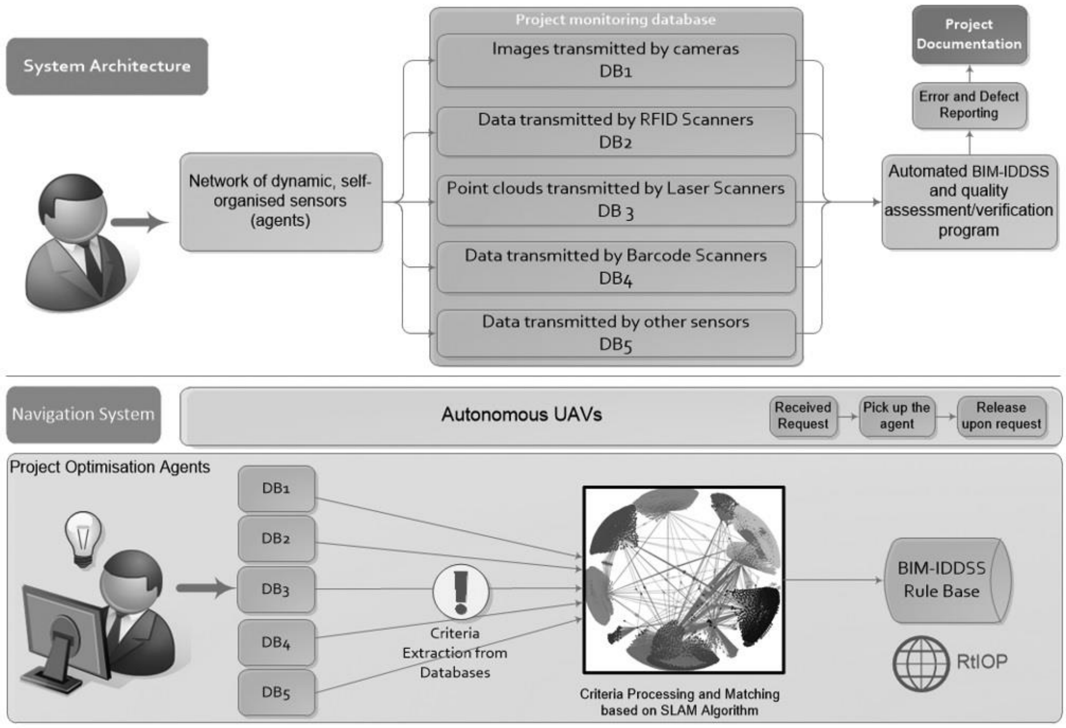

Figure 1. Conceptual model: architecture of the proposed intelligent project monitoring system

5. Discussion

In developing the conceptual model, specific consideration should be given to the optimisation of inter-agent communication and collaboration schemas, possibly in the form of a dynamic autonomous management tool. The system could have wide scope of application including identification, reporting, and documentation of defects and errors within a construction environment; monitoring of the construction progress; creation, maintenance and updating of the construction site materials repository; and optimisation and monitoring of workforce deployment.

The architecture of this system is envisaged to rely on a network of dynamic, self-organised sensors (agents) for capturing and reporting construction site data in semi or real-time. The network could consist of a set of multiple, autonomous ‘clip on’ sensing agents (including intelligent cameras) that are easily attached to different structures – typically engaging a ‘pick and reposition’ sensor concept. A particular feature of the proposed system would be the availability of relatively low cost of individual sensing devices; to a level at which they can, if desired, be treated as disposable units. One of the most expensive and least reliable subsystems of the robotic agent is its propulsion mechanism. The mobility of the RtIOP device would depend on its acceptance by and cooperation with, the construction workforce. This is important, as pick and reposition requests will need to 'be moved' in relation to data capture mechanisms, which would be signalled audio-visually (e.g. by flashing LED). A key requirement here would therefore be for a worker to physically reposition the (signalling) unit. For instance, by clipping it to an appropriate safe structural component. Worker input would also extend to include simple repositioning tasks as required. The RtIOP system would therefore require operatives to be trained accordingly in order facilitate this interchange.

From a sensor perspective, each sensor unit is able to estimate its own position with respect to the construction site topology and the target work activity; thereby being able to plan the optimal trajectories needed reach its final destination in a finite number of 'pick and reposition' steps. Given this, the key enabler here is the low cost technology needed to making this a possibility, using for example a combination of existing proprietary ('off the shelf') GPS systems and SfM [Tao and Matuszewski, 2013; Tao *et al.*, 2013]; combined with Simultaneous Localisation and Mapping (SLAM) (Davidson *et al.*, 2007) computer vision algorithms.

Another but more expensive option would be to manage sensors' positional arrangements with the help of autonomous UAVs. This will engage pick and repositioning agents – to send out signals, indicating when a change of position is required. UAVs could then reposition sensors as and when prompted by the system. A set of software agents would address multiple data analysis tasks, including: vision based object recognition for non-obtrusive inventory; tracking and action recognition for onsite personnel management; and site map building (using an intelligent SLAM algorithm) for construction progress monitoring.

6. Conclusion

This study was motivated by the need for automated project monitoring and control systems for optimisation of day-to-day activities within AEC projects. This paper presented a review of the state of the art technologies that typically facilitate systematic project monitoring within the AEC domains. In order to address the issues (challenges) identified with existing systems, a proposed conceptual model was presented for discussion. This relies on the optimal use of artificial intelligence, cybernetics, and complex adaptive systems. The RtIOP model is supported by advanced intelligent agents; where the proposed platform can actively, autonomously and seamlessly manage intelligent agents (cameras, RFID scanners, remote sensors, etc.) in order to identify, report and document 'high risk' defect areas or activities.

The findings underpin a new ontological model that complements ongoing development of a dynamic, self-organised sensor (agent) network, for capturing and reporting real-time site data. As such, RtIOP is a 'stepping stone' for the advancement of automated project monitoring and control systems – using independent intelligent agents and sensory and computational support to perform complicated (previously manual) tasks. It is proffered that this solution can help deliver the three central tenets of project time, cost and quality.

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Investigation of Relined Rehabilitated Piping in Residential Buildings

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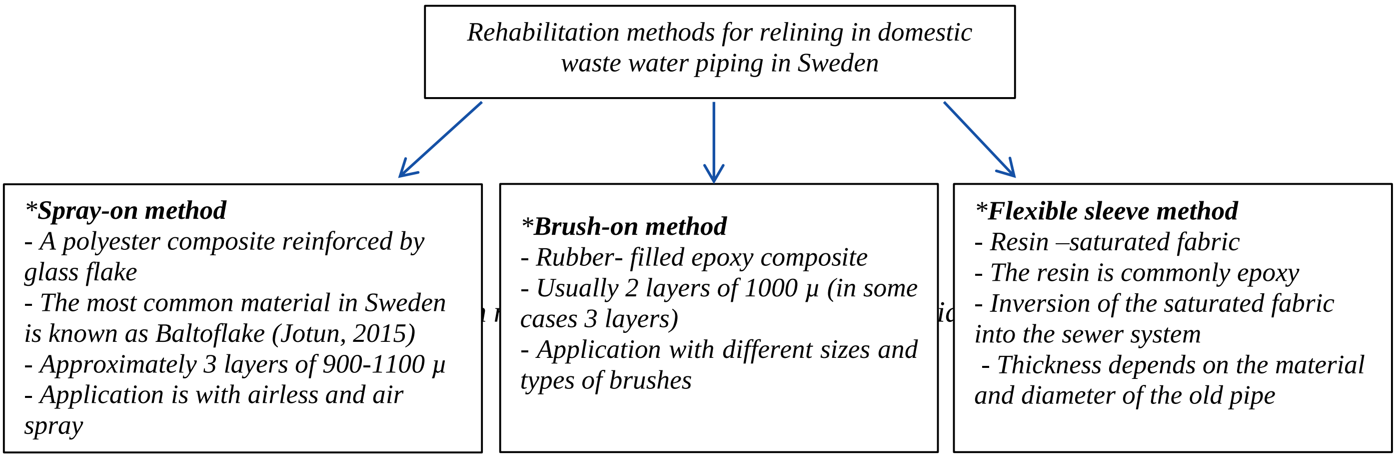
Abstract

In this paper rehabilitation methods for piping systems by relining in Sweden are reviewed. The paper also includes analyzing relined pipes which have been in the field between one to ten years to evaluate the quality and performance of the relining as well as typical problems which can occur. The investigated samples were sent to the laboratory for investigation and since they were not randomly taken out, the notations in this study should not be an indication of relining performance in general. However it can be said with certainty that improvement in technology is needed which is the reason of our study.

Keywords- Building, Pipe, Rehabilitation, Relining, Sewer

1. Introduction

Aging of water and waste water pipelines is a growing problem. Replacing of pipes in the traditional way is costly, disturbs local environment and is time consuming. These challenges have led to finding other types of renovation solutions such as rehabilitation with relining. In the relining technique, a new polymer pipe forms inside the old pipe without the need for taking the old pipe out. The use of relining methods and materials is increasing in Nordic countries, also in Sweden, due to the fact that water piping systems are getting old. Renovation by relining is faster and considerably cheaper compared to replacement of the old pipes. Flow chart 1 describes the three most common relining methods in Sweden.



One relining company, has introduced another technique with is called hybrid where both flexible sleeve and brush-on method are used to reline the host pipe. Different types of relining which are used in Sweden can be also classified and known as non-structural, semi-structural or fully-structural (AWWA, 2014), (Kharazmi, Björk, 2016).

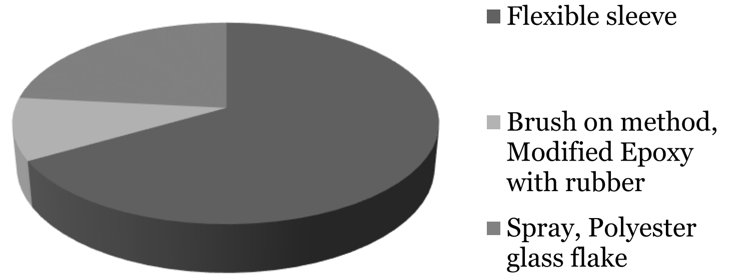


Figure 1 – Distribution of the three main relining application methods between relining companies in Sweden (2013)

Table 1- Pictures of pipe inspection by closed-circuit television

		
Figure 2-Closed-circuit television (CCTV) for inspection of the interior side of the water pipe and to evaluate condition of the host pipe (Proline, 2013)	*Figure 3- Application of the epoxy relining by brush-on method and controlling the procedure by camera(known as Dakki method in Sweden)*	*Figure 4-Closed-circuit television (CCTV) inspecting the interior of the pipe after application of the relining to evaluate condition of applied relining (Proline, 2013)*

Closed-circuit television (CCTV) is usually the method to inspect the interior of the water pipe and to evaluate quality of the installed pipe. The main reasons of inspecting the pipe are first, to evaluate the degree of cleaning and the required preparation for the existing pipe before starting the lining application, to detect any structural problems such as cracks, holes, leakage and also to check the pipe bends that can affect cleaning. The basic principle of CCTV inspection is that a television camera, together with a light source, is mounted on a tractor or skid which is pulled or propelled through the sewer from one manhole to the next. The camera transmits pictures by cable to a monitor (Ian G, 1997). To remove corrosion and standing water before application or installation of the relining, cleaning is required. The cleaning method is usually mechanical using a steel rod, which is called Drag Scrapers (Najafi, 2010). Based on recommendation by a manufacturer for the polyester composite (Jotun, 2016) all surfaces should be clean, dry and free from contamination. The surface should be assessed and treated in accordance with ISO 8504. Adequate drying time is related to the substrate temperature and the air circulation. For example based on the manufacturer's (Jotun) specification data, for the polyester Baltoflake, the temperature of the substrate should be at least 3°C above the dew point of the air to reach a good curing degree.

Although relining has been used in Sweden around 30 years, studying of the old relined pipes which have been taken out from the field, show improvement is needed, particularly regarding monitoring the quality of final products. Critical investigation of the quality level and studying the performance of different relining materials will create a basis for well-founded advices and recommendations. Moreover more investigation such as this ongoing study will provide better understanding regarding advantages and limitations of relining in comparison to a traditional replacement of the piping in residential buildings.

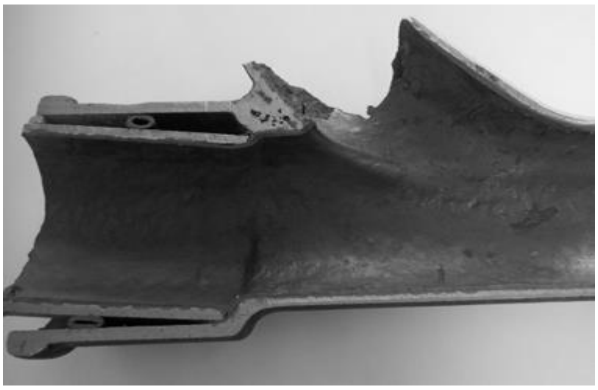
2. Performance of relined pipe with polyester and epoxy composites

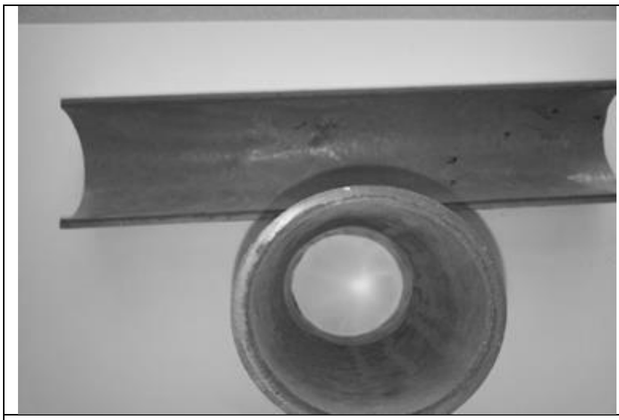
Relining as a renovation technique is expected to perform well during a longer time. Therefore, it is promising to investigate the quality of common materials and techniques over time. To study the performance of relining, a study has been carried out on 11 relined pipes (as listed in Table 2) which have been in the field in different parts of Sweden. Different analyses were used to evaluate the quality of the installation and materials performance and in this paper the visual inspection, thickness measurement and materil comparison with FTIR spectroscopy will be discussed. Samples numbered from 1 to 6 were relined with rubber modified epoxy material applied by brushing method and samples 7 to 11 had relining material based on reinforced polyester with glass flake and applied with spray-on technique. Table 3 shows a cutted piece of each sample and provides a short summary of notification from visual inspection. The names of the relining companies for each sample will not be mentioned but the related information about each sample such as the applied material and technique, the time that they have been installed in practice and defects seen in visual inspection will be discussed.

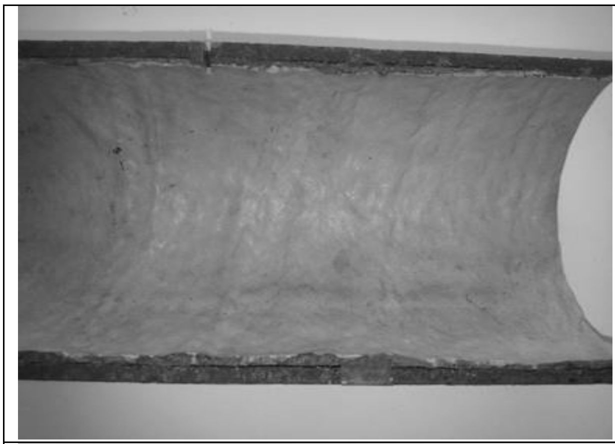
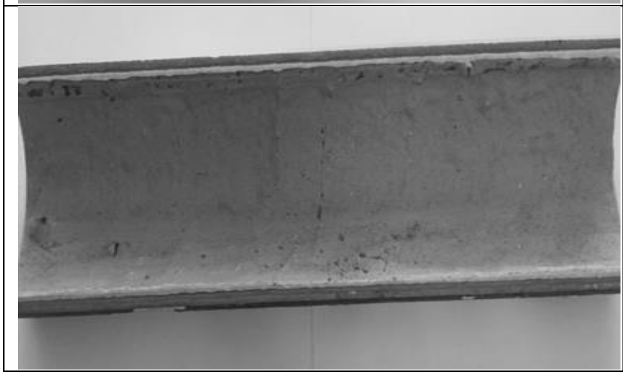
Table 2- Samples description

Sample	*Type of relining material*	*Application method*	*Approximate time in service after relining*
1	*Epoxy based composite (Rubber filled)*	*Brush-on*	*6 years (2005-2011)*
2	*Epoxy based composite(Rubber filled)*	*Brush-on*	*6 years (2005-2011)*
3	*Epoxy based composite(Rubber filled)*	*Brush-on*	*10 years (2001-2011)*
4	*Epoxy based composite (Rubber filled)*	*Brush-on*	*14 days (2009)*
5	*Epoxy based composite(Rubber filled)*	*Brush-on*	*3 years (2008-2011)*
6	*Epoxy based composite(Rubber filled)*	*Brush-on*	*4 years (2007-2011)*
7	*Polyester based composite (reinforced with glass flake, known as baltoflake)*	*Spray-on*	*3 years (2008-2011)*
8	*Polyester glass flake(reinforced with glass flake ,known as baltoflake)*	*Spray-on*	*7 days (2010)*
9	*Polyester glass flake(reinforced with glass flake, known as baltoflake)*	*Spray-on*	*3 years (2008-2011)*
10	*Polyester glass flake(reinforced with glass flake, known as baltoflake)*	*Spray-on*	*2 years (2009-2011)*
11	*Polyester glass flake (reinforced with glass flake, known as baltoflake)*	*Spray-on*	*3 years (2008-2011)*

Table 3- Relined pipe which have been installed in the field

	*Sample 1- A relined pipe with rubber modified epoxy composite applied with brush-on method. The approximate time in service after relining has been 6 years.* *As can be seen, relining has been unevenly applied. Cracks could be seen and corrosion between lining and the host pipe can easily be detected.*
	*Sample 2- A relined pipe with rubber modified epoxy composite applied with brush-on method. The approximate time in service after relining has been 6 years.* *Corrosion and naked spots without any coverage with epoxy layer can be seen.*
	*Sample 3- A relined pipe with rubber modified epoxy and applied with brush-on method. The approximate time in service after relining has been 10 years.* *Uneven application of relining can easily be seen. Lining film was loose which could easily be separated in the edge of cutted pipe and heavy corrosion was spread through the relined pipe*
	*Sample 4- A relined pipe with rubber modified epoxy and applied with brush-on method. Approximate time in service after relining has been 14 days.* *The relined pipe was taken out only after 2 weeks because of the fail in application.*

	*Sample 5- A relined pipe with rubber modified epoxy and applied with brush-on method. Approximate time in service after relining has been 3 years.* *Besides air bubble which could be seen randomly on the outside of the film, no major defect can be detected.*
	*Sample 6- A relined pipe with rubber modified epoxy applied with brush-on method. Approximate time in service after relining has been 4 years.* *Sample had uniform film application without any major defect.*
	*Sample 7- A relined pipe with polyester baltoflake applied with spray method. Approximate time in service after relining has been 3 years.* *The lining was not applied in totally uniform layer. After cutting the piece of the relined pipe, the lining layer came off totally showing heavily corroded substrate surface of the original pipe.*
	*Sample 8- A relined pipe with polyester baltoflake applied with spray method. Approximate time in service after relining has been 7 days.* *Pipeline was taken out shortly after relining due to fail in rehabilitation. Uneven film and thickness variation can easily be seen.*

	*Sample 9- A relined pipe with polyester baltoflake applied with spray method. Approximate time in service after relining has been 3 years.* *Relining has formed a uniform film without major defect while a thin layer of corrosion between relining and host pipe can be seen.*
	*Sample 10- A relined pipe with Polyester baltoflake applied with spray method. Approximate time in service after relining has been 2 years.* *Relining has formed a uniform film without major defect but small cracks can be seen in a close inspection.*
	*Sample 11- A relined pipe with Polyester baltoflake applied with spray method. Approximate time in service after relining has been 3 years.* *Relining has formed a uniform film without major defect but small cracks can be seen in a close inspection.*

2.1. Thickness evaluation

According to the manufacturer of the relining materials (Jotun, 2015), also information provided by relining companies (e.g. proline, Dakki), lining with rubber modified epoxy (brushing method) and polyester based material (spray-on technique) shall be produced to have nominal thickness of 2 and 3mm respectively. Circumferential thickness measurements were carried out using a digital caliper with 10 measurements with 5 measurements from each edge of relined sample pipes. The results are shown in Figure 5 for the pipes relined with epoxy based relining applied with brushing and in Figure 6 for the pipes relined with polyester based relining material and spray technique.

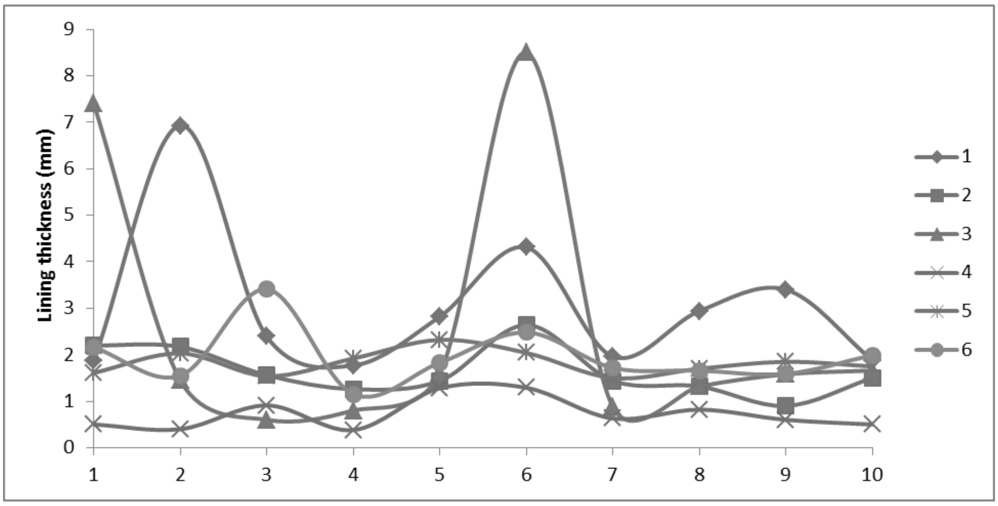


Figure 5: Circumferential thickness measurements for sample 1 to 6

In relining application, a uniform thickness application of the lining material should be applied all around the pipe for the material to be able to perform as expected; too much or too little material, causing very thin or very thick layers, remaining uncoated spots or forming sag, all are defects leading to poor performance of the relining. As it can be seen in Figure 5, sample 3 (which is the oldest sample) showed the highest variation in thickness. This is also possible to see in visual inspection and in the picture in table 2.

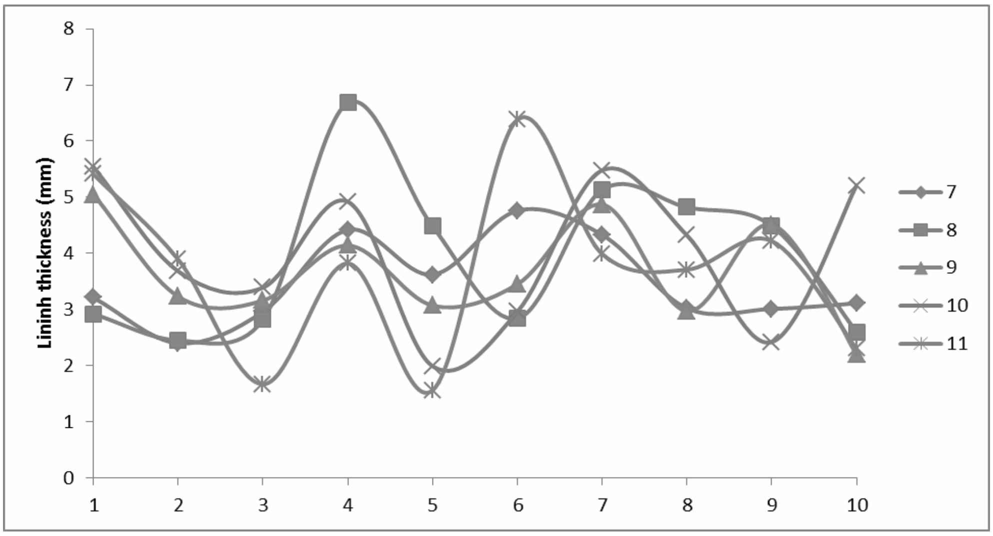


Figure 6- Circumferential thickness measurements for sample 7-11

Figure 5 shows that sample number 4 has the lowest thickness average and it can be seen from figure 6 that sample number 8 has a very uneven film thickness. These two samples have been taken out due to failure of the system and poor relining application.

2.2. Fourier transform infrared spectroscopy (FTIR)

FTIR spectroscopy was used to see if there is significant difference between the materials that have been used by different relining companies in each technique. The spectra were recorded from 400 to 6000 cm^{-1} using a Perkin Elmer FTIR instrument with scan number and resolution of 4 and 4 cm^{-1} in order. Figure 7 shows the FTIR spectra for the samples relined with epoxy based relining materials and Figure 8 shows FTIR spectra of relined samples with polyester based relining material.

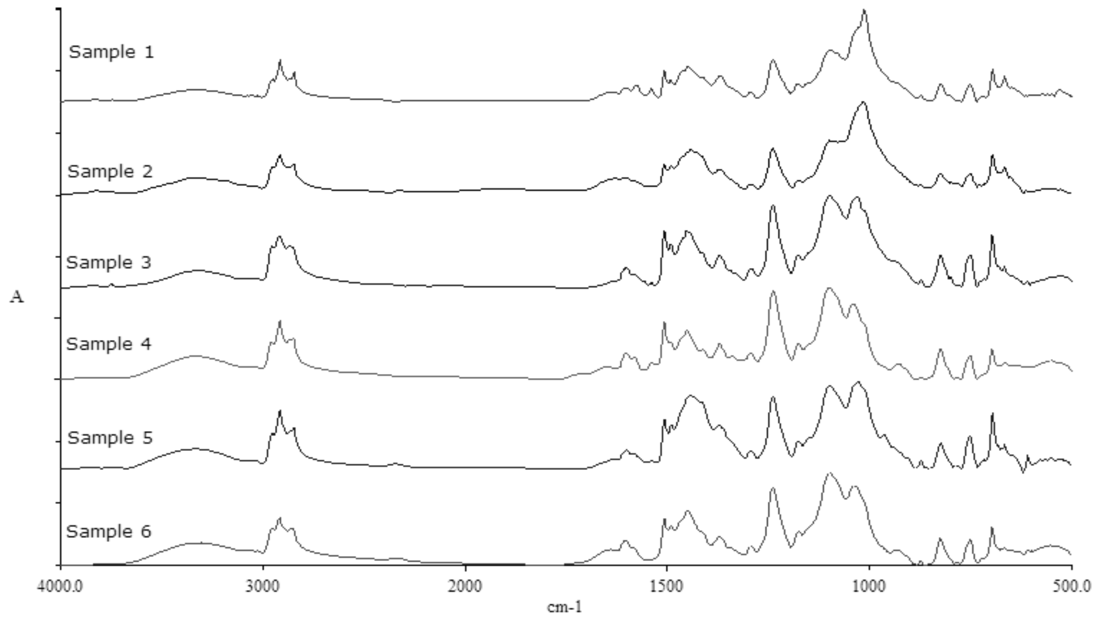


Figure 7- Normalized FTIR spectra for samples 1, 2, 3, 4, 5, and 6 (Epoxy based relining material)

Comparison of FTIR spectra shows that molecular structures of the materials which have been used in different projects are not the same. As it can be seen in the changes in spectra at 1100 cm–1, sample 1 and 2 are not similar to 3, 4, 5 and 6. This indicates that installation companies do not use the exact same material in brush-on method.

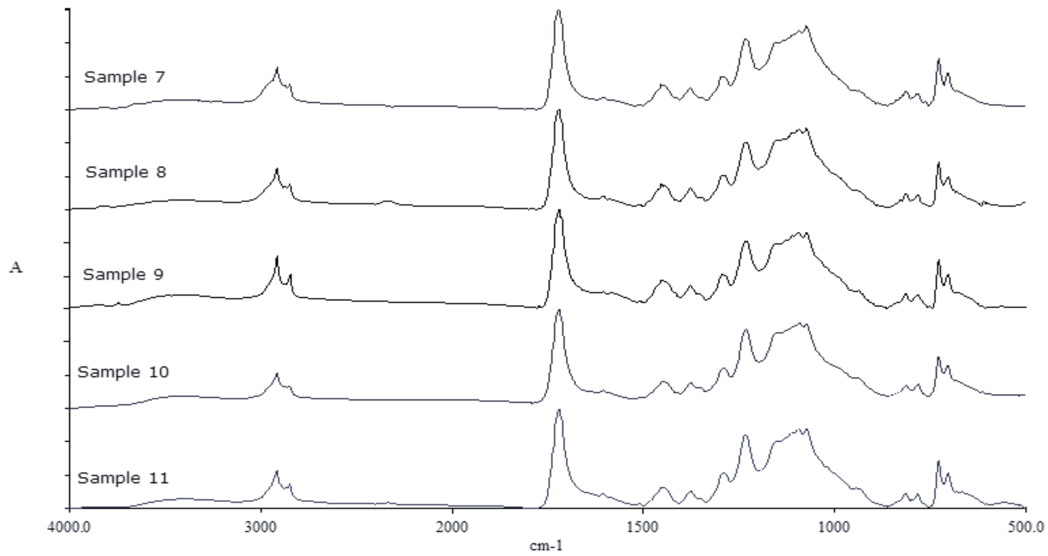


Figure 8- Normalized FTIR spectra for samples 7, 8, 9, 10 and 11 (Polyester based relining material)

FTIR spectra showed that molecular structures of the materials which have been used for sample 7 to 11 are similar indicating the same formulation/material that have been used in the different projects (more likely all have provided material so called Baltoflake).

3. Discussion

The uneven relining layer in Sample 1 can be due to a wrong viscosity of the composite in liquid state and before application. This can cause sagging, as can be seen in picture of sample 1, especially in gravity sewers which are majority of sewers in residential buildings. The existence of corrosion between liner and host pipe can be because of improper cleaning. In sample 2, relining was applied in a thinner layer than normal and this was the reason for inadequate coverage of the film, leaving some spots uncoated and consequently causing corrosion. Sample 3 shows uneven film formation of relining which was a cause of fail after application.

The reason for getting a loose lining layer can be mainly due to insufficient cleaning before application of relining. Sample 4 was taken out only two weeks after application due to poor application of relining. The layer of the applied film was very thin and the other problem was the material of the host pipe. A PVC pipe, as the original pipe, needs more consideration regarding preparation of the host pipe and before application of relining to secure adequate adhesion between lining layer and the host pipe. The air bubbles which can be seen in sample 5 can be due to inadequate mixture of the resin and hardener. Loose lining and corroded surface of the pipe in sample 7 can be again because of insufficient cleaning and poor preparation of the host pipe before relining application. The uneven film application in sample 8 can be due to the fail in proper preparation of the coating composite in liquid phase and before application. Uniform film application and good adhesion in sample 10 and 11 is mainly due to proper cleaning of the host pipe.

The investigation is highlighting the importance of proper cleaning and preparation before relining application. The other repeated result was a fail in applying a uniform and adequate film using lining material. Both of these defects are possible to prevent with enough attention to the quality of application.

Thickness measurements indicated that circumferential lining thickness for spray-on technique was more consistent compared to the brushing method in those samples which were studied here.

The FTIR analysis showed that materials used in Swedish market differ from some companies compare to others. This difference more likely will not cause any problem as long as the quality of the provided material is high enough. However it must be checked, for example with comparison of the purchased new batch of material with an accepted high quality sample as the reference.

It is worth mentioning that theses samples were not randomly taken out from different relining projects, therefore cannot be an indication of the quality performance of the relining techniques in general.

4. Conclusion

The investigation on the old relining samples taken from the field showed that developing a detailed quality control plan for each relining technique would provide more consistent quality between installation companies and manufacturers which are active in the field. The provision of the quality control requirements should be higher in different steps, such as inspection of the host pipe, cleaning, application and curing. Moreover choosing and applying the right material and giving adequate curing time and conditions can lead to a higher quality of the final result. Thickness measurements in this study indicated that circumferential lining thickness for both spray-on technique and brushing technique can be improved. It should be noted that samples discussed in this paper were not randomly taken out from different relining projects, therefore cannot be an indication of the quality performance of the relining techniques in general.
Studying the old relined pipes which have been in the field and in real conditions contributes greatly to a better understanding of the materials and techniques, limitations and advantages of this type of rehabilitation compare to the replacement of the pipelines and will help towards providing practical recommendation in close future.

Acknowledgement

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Research on the Air Quality in the Classroom with Fresh Air Systems

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Abstract

Natural ventilation is generally used in classrooms in China, though such ventilation strategy could not ensure good indoor air quality all the time. In order to establish healthy and comfortable air environment in the classroom, this study installed fresh air system (FAS) and analyzed the relationships between the fresh air rate and $PM_{2.5}$ and CO_2 distributions. On-site measurement shows that after turning on the FAS, the fresh air rate raised from 2.4 m^3/h per person to 6.1 m^3/h per person, and the indoor $PM_{2.5}$ concentration decreased from 40 μg/m^3 to 18 μg/m^3. However, the CO_2 concentration still exceeded 2000 ppm, as the actual airflow rate of the FAS was 43.6% of its' rated airflow rate. Through calculation, this study recommended the minimum fresh air rate in the classroom should be 24.0 m^3/h per person to ensure the CO_2 concentration less the 1000 ppm. Furthermore, the economic analysis indicated that the FAS we chosen had both low initial invest and operating cost.

Keywords: Fresh air rate, Carbon-dioxide, $PM_{2.5}$

1. INTRODUCTION

Indoor air quality (IAQ) is highly related to student's health, comfort and study efficiency in the classroom. With the increase of the ventilation rate from 2.5 m^3/h per person to 19 m^3/h per person, the study performance would increase 10% (Kaneko, et al., 2007). A 1000 ppm increase in ΔCO_2(indoor minus outdoor CO_2 concentration) was associated with 10~20% increase in student absence (Shendell et al., 2004).

However, the IAQ is not so satisfy in Chinese classrooms nowadays. The CO_2 concentration was over 1000 ppm in 89.7% of the measured classrooms (Liu et al., 2005), In Deng's (2007) study, the CO_2 concentration in the classroom was 3800 ppm, with the fresh air rate of 0.29 ACH. Zhu et al. (2012) monitored $PM_{2.5}$ concentration of 114 classrooms in Shenzhen, China, and found the average $PM_{2.5}$ concentration was 71 μg/m^3, which was much higher than the limited level in *Ambient Air Quality Standards* (*GB3095-2012, Chinese standard,* 35 μg/m^3).

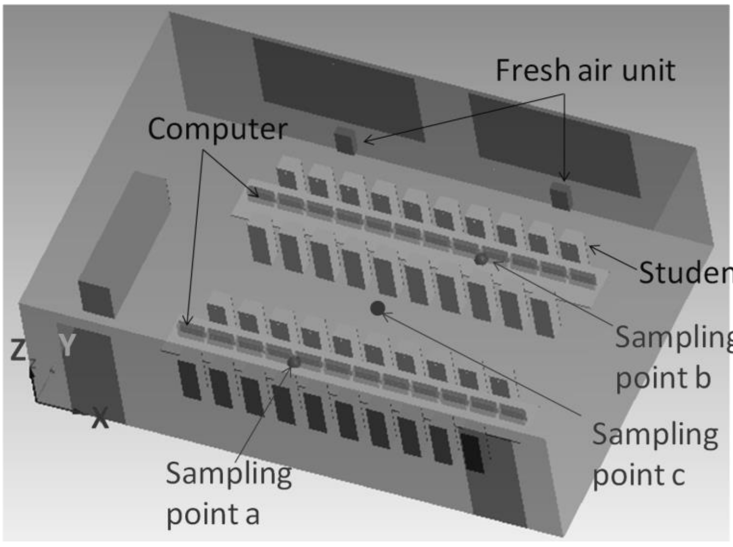
Natural ventilation is generally adopted in the classroom in China. Such method highly depends on the outdoor air quality. Due to the heavy haze resent years in China, it is recommended to close the window to prevent the outdoor contaminant spreading to indoor space. On the other hand, closed window leads insufficient fresh air, causing high CO_2 concentration and odors. In order to establish healthy and comfortable indoor air environment in the classroom, this study installed fresh air system and analyzed the relationship between the fresh air rate and $PM_{2.5}$ and CO_2 distributions.

2. METHODOLOGIES

2.1 Experimental method

This study installed the fresh air system (FAS) in a computer classroom of a middle school located in Shanghai, China. The classroom was 11.74 m in length, 7.97 m in width and 3.24 m in height (Figure 1). Ventilation rate, $PM_{2.5}$ and CO_2 concentration were measured in both cases of FAS on and off. There were 40 students in the classroom during the measurement.

(a)



(b)

Figure 1: The classroom configuration (a) used in the measurement (b) used in the model

Tracer gas decay method (Zhu, 2005) was adopted to measure the air change rate, and the tracer gas was Sulfur hexafluoride (SF_6). INNOVA 1303 and 1312 were used to test the SF_6 concentration. Dusttrak8530 aerosol monitor was used for $PM_{2.5}$ concentration measurement, with the sampling frequency of 1 min. AZ7798 CO_2 datalogger was used for CO_2 concentration measurement, with the sampling frequency of 2 min. As shown in Figure 1 (b), The sampling points for CO_2 concentration were placed on the desk, which were close to the breathing zone of students. The sampling point for $PM_{2.5}$ concentration was in the middle of the classroom.

2.2 Calculational method

The indoor $PM_{2.5}$ concentration was calculated via the following mass conservation equation:

$$V\frac{\mathrm{d}C}{d\tau} = G + C_{out}Q_l\sigma + C_{out}(1-\eta)Q_i - CQ_o - C\times CADR \quad (1)$$

where C is the indoor $PM_{2.5}$ concentration at τ time (μg/m^3), C_{out} the outdoor concentration (μg/m^3), G the indoor $PM_{2.5}$ emission rate (μg/h), σ the penetration coefficient, η the primary filtration efficiency of the fresh air system, Q_l the air leakage rate (m^3/h), Q_i the supply air rate (m^3/h), Q_o the exhaust air rate (m^3/h), $CADR$ the clean air delivery rate (m^3/h), V the room volume (m^3), τ the time (h).

Considering steady condition, this study set $\frac{\mathrm{d}C}{dt} = 0$. Via measurement, the $PM_{2.5}$ concentration at inlet was zero and there was no air cleaner in the room. Then Equation (1) was simplified as:

$$G + C_{out}Q_l\sigma_i - CQ_o = 0 \quad (2)$$

Moreover, this study also simulated the indoor CO_2 concentration distribution by Computational Fluid Dynamics (CFD). We discretized the classroom space into 1.08 million cells via Ansys Workbench 2014. Hexahedral mesh was used, with the skewness less than 0.97. All the boundary conditions were measured and input into Ansys Fluent 14.0. Re-Normalization Group k-ε (RNG k-ε) model was selected to approximate the Navier-Stokes equations. As for numerical schemes, this study used the SIMPLE algorithm to couple the pressure and velocity. The PRESTO! scheme was used for pressure discretization and the second-order upwind scheme for all the other variables. The solutions were considered to be converged when the sum of the normalized residuals for all the cells became less than 10^{-6} for energy and 10^{-3} for all other variables (Fluent, 2011)

3. Results

3.1 Ventilation rate

Figure 2 depicts the designed and measured fresh air rate with the fresh air system (FAS). When the windows and FAS were both closed, the fresh air rate in the classroom was 96.4 m^3/h, namely 2.4 m^3/h per person. After using the FAS, the fresh air rate increased to 244.0 m^3/h, namely 6.1 m^3/h per person. According to *Code for Design of School* (*GB50099 -2011,Chinese standard*), the minimum fresh air rate in the middle school should be 14 m^3/h per person, so that the designed ventilation rate should be 560 m^3/h (as for 40 person). However, the actual airflow rate of the FAS was 43.6% of its' rated value. The reason for such deviation between the rated and actual airflow rate was that the FAS was rated at laboratory condition, which was quite different with the actual operating condition. Under the operating condition, the fresh air unit external static pressure was not the same as the value when it was tested in laboratory, so the actual supply air rate was not its' rated airflow rate. Therefore, this study suggested the FAS rating test condition should be more close to its' actual operating condition.

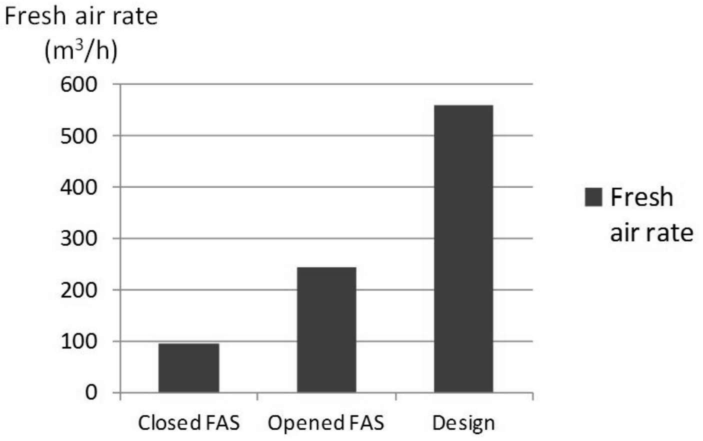


Figure 2: The designed and measured fresh air rate with the fresh air system(FAS)

3.2 CO_2 concentration

Figure 3 compares the CO_2 concentration in the classroom during the school day and weekend with natural ventilation. When the windows and FAS were both closed, the CO_2 concentration was approximately 3200 ppm during the class, while it was around 400 ppm at weekend. According to *Indoor Air Quality Standard* (*GB/T 18883, Chinese standard*), the indoor CO_2 concentration should be less than 1000 ppm. However, the CO_2 concentration in the classroom was much higher than the standard limit with natural ventilation.

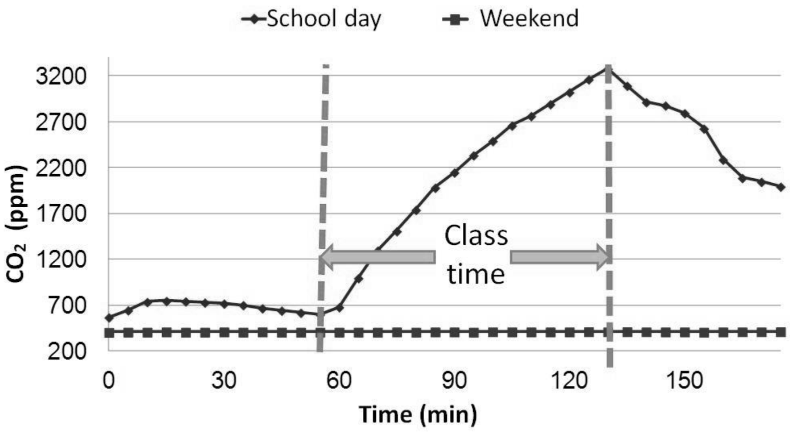


Figure 3: Indoor CO_2 concentration with natural ventilation

Figure 4 shows the CO_2 concentration from 9:45 to 14:00 at sampling point a. The CO_2 concentration at sampling point b was also monitored and similar results could be found. At stage 1, the FAS was off, so the CO_2 concentration rose from 848 ppm to 1927 ppm at sampling point a, and from 802 ppm to 2063 ppm at sample b. During the break (stage 2), the CO_2 concentration reached the peak at first, and then it started to decrease as the doors were opened and some students went out of the classroom, which lead more fresh air rate and fewer CO_2 sources. At stage 3, the FAS was turned on at the beginning of the second class. Comparing with stage 1, the CO_2 concentration growth rate declined. However, the CO_2 concentration still exceeded 2000 ppm at the end of stage 3. As mentioned in section 3.1, the actual supply air rate was much less than the designed value, causing the indoor CO_2 concentration exceeded the required value in the standard.

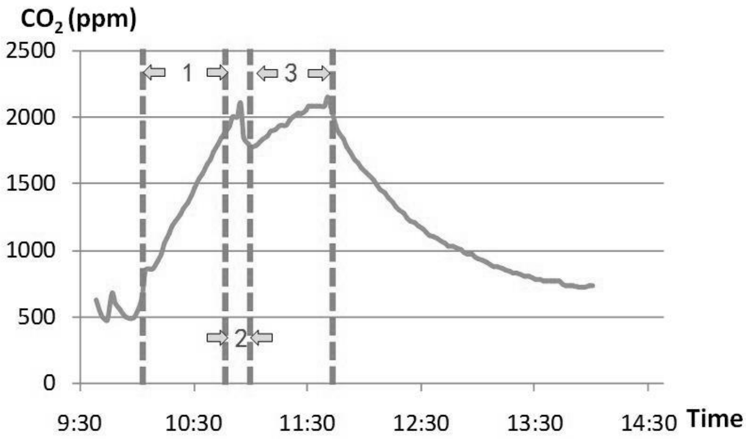


Figure 4: CO_2 concentration at sampling point a (stage 1: the class time with closed FAS; stage 2: the break; stage 3: the class time with opened FAS)

In addition, CFD was employed to simulate the indoor air and CO_2 distributions. As seen in Figure 5, when the fresh air rate increased from 244.0 m^3/h (6.1 m^3/h per person) to 960.0 m^3/h (24 m^3/h per person), the CO_2 concentration decreased from 2024 ppm and 2191 ppm to 908 ppm and 762 ppm at sampling point a and b respectively.

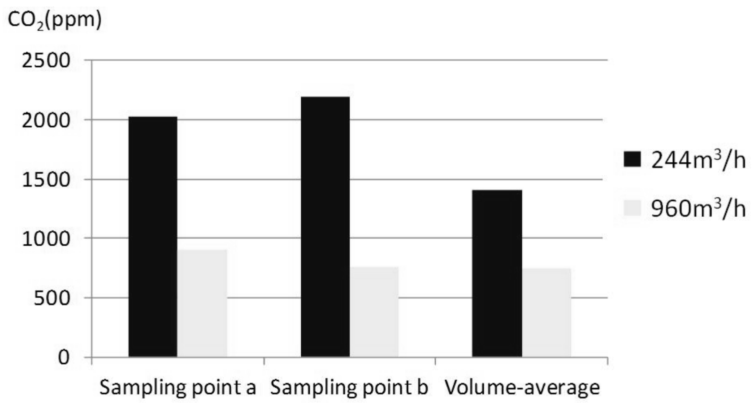
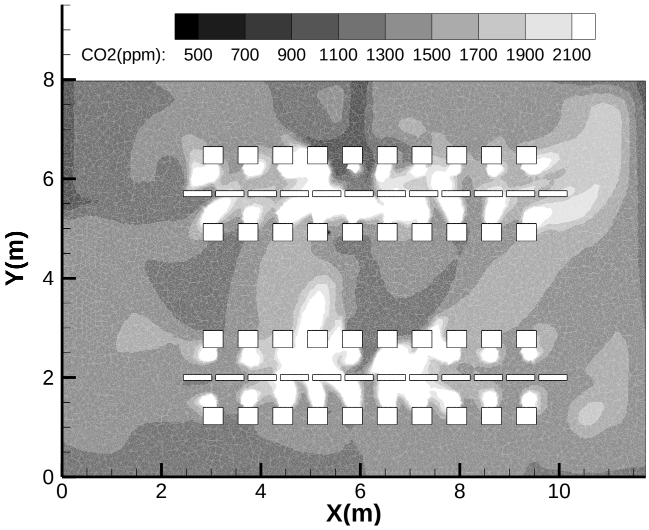
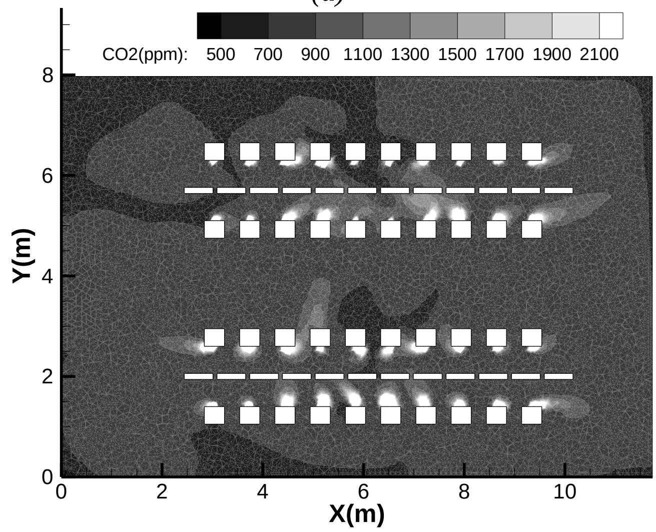


Figure 5: The CFD simulated CO_2 concentration at sampling point a, b and the volume-averaged concentration with different fresh air rate

Figure 6 displays the CO_2 distribution at Z=1.1 m in the classroom. When the fresh air rate was 244 m^3/h, the CO_2 concentration around students was higher than 1300 ppm. When the fresh air rate was 960 m^3/h, the CO_2 concentration in most space was lower than 900 ppm. With the increase of fresh air rate, the volume-average CO_2 concentration decreased from 1409 ppm to 750 ppm， which could meet the requirement of the *Indoor Air Quality Standard* (*GB/T 18883*, *Chinese standard*).



(a)



(b)

Figure 6: The CFD simulated CO_2 distribution at Z=1.1 m in the classroom (a) with fresh air rate of 244 m^3/h (b) with fresh air rate of 960 m^3/h

3.3 $PM_{2.5}$ concentration

This study also analyzed the $PM_{2.5}$ concentration in the classroom. We monitored the indoor and outdoor $PM_{2.5}$ concentration simultaneously. As shown in Figure 7, when using natural ventilation, the $PM_{2.5}$ indoor/outdoor (I/O) ratio was 0.50~0.70 with the closed windows, while it rose to 0.89 in 30 min after opening the windows. Thus, natural ventilation could not prevent outdoor $PM_{2.5}$ spreading to indoor spaces.

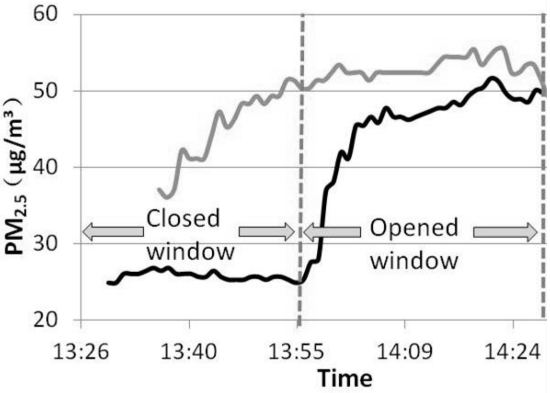


Figure 7: Indoor and outdoor $PM_{2.5}$ concentration with natural ventilation

When using the FAS, the indoor $PM_{2.5}$ concentration decreased from 40 μg/m^3 to 18 μg/m^3 and the I/O ratio decreased from 0.75 to 0.32, as shown in Figure 8.

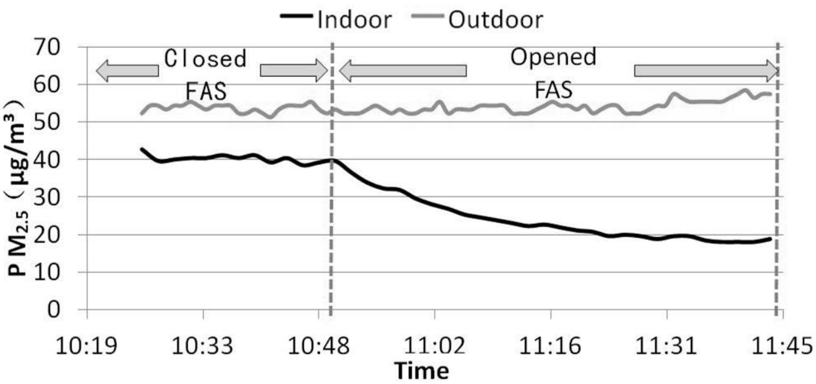


Figure 8: Indoor and outdoor $PM_{2.5}$ concentration with the FAS

Moreover, this study calculated the indoor $PM_{2.5}$ concentration via mass conservation equation. The main indoor $PM_{2.5}$ source was occupants. As Xu (1998) studied, the particles emission rate from occupants ranged from 2.2μg/m^3 (sit) to 3.0 μg/m^3 (wrist movement) for 40 persons. The outdoor $PM_{2.5}$ concentration was set as 54.1 μg/m^3 and the air leakage rate was 96.4 m^3/h based on measurement data. The calculated indoor $PM_{2.5}$ concentration was 19.4 μg/m^3～20.2 μg/m^3 via Equation (2) and the deviation between the calculated and measured results was -7.8%～-12.1%.

3.4 Economic analysis

The initial invest on the FAS was 8000 RMB. The operating cost depended on the operating time. This study set the operating time as 128 days (school days) per year and 8 h per day, whose daily-average outdoor $PM_{2.5}$ concentration exceeded 35 μg/m^3 (the requirement of *Ambient Air Quality Standard GB/T 3095)*. The outdoor $PM_{2.5}$ concentration data was acquired from Shanghai Environmental Monitoring Station. The rated power of the fresh air unit was 92 W and the electricity price was 1 RMB/kWh. Through calculation, the energy charge of the FAS was 94 RMB per year. Thus, the FAS had both acceptable initial invest and operating cost.

4. Conclusion

This study installed fresh air system (FAS) in the classroom to ensure healthy and comfortable indoor air environement. Both measurement and calcultion were used to analyze the relationship between the fresh air rate and $PM_{2.5}$ and CO_2 distributions. The following conclusions can be drawn:

1) The fresh air rate was 2.4 m^3/h per person in the classroom with closed windows. After using the FAS, it rose to 6.1 m^3/h per person. However, the actual airflow rate of the FAS was 43.6% of its' rated value, due to the deviation between the FAS rating test condition and the operating condition.

2) The indoor CO_2 concentration was approximately 3200 ppm during the class with closed windows. After using the FAS, the growth rate of the CO_2 concentration declined. However, the indoor CO_2 concentration still exceeded 2000 ppm, due to the insuffient supply air rate of the FAS. Through calculation, this study recommended the minimum fresh air rate in the classroom should be 24.0 m^3/h per person to ensure the CO_2 concentration less than 1000 ppm.

3) Natural ventilation could not prevent the outdoor contaminant spreading to indoor spaces. When using the FAS, the indoor $PM_{2.5}$ concentration decreased from 40 $\mu g/m^3$ to 18 $\mu g/m^3$ and the I/O ratio decreased from 0.75 to 0.32

4) The initial invest on the FAS was 8000 RMB and the energy charge was 94 RMB per year, which was economical acceptable.

5. Acknowledgement

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SECTION

4

Risk mitigation, resilience and health and safety

An Investigation on Fire Hazard and Smoke Toxicity of Epoxy FRP Composites

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Abstract

The fire performance of two types of fibre reinforced epoxy composites (GFRP and CFRP) was studied in bench-scale using cone calorimeter test method in two incident heat fluxes of 35kW/m^2 and 50kW/m^2. Ignitability, time to ignition, heat release rate, total heat release, smoke release parameters and Carbon monoxide production were measured and discussed. Both thermal and smoke toxicity hazard of the material was studied. The time to flashover in an assumed room lined with the tested FRP was predicted with using Conetools software. The obtained results showed that the tested FRP products had a dangerous behaviour in case of fire, so it could show a high contribution to fire growth due to the combustible nature of epoxy resin. The tests also showed that these kinds of resins have a low glass transition temperature, around (50-60) °C. Therefore, the mechanical strength (and strengthening potential) of the product might be critically reduced at first stages of a fire incident. This shows that a regular thermal barrier, which is typically used for protection of plastic foams against fire, may be not sufficient for this purpose for FRP composites and a higher level of fire protection may be needed for prevention of failure of the strengthened system. The performance of protected FRP composites with a type of mineral spray applied coatings is discussed in another article.

Keywords: FRP, fire hazard, reaction to fire, ignitability, smoke.

1. Introduction

One of the main concerns with using polymer composites is their performance in the case of fire. The reason is that the FRP materials are inherently flammable due to nature of its polymeric resin. Furthermore, typical polymer resins for FRPs for civil engineering applications typically have glass transition temperatures between 60°C to 80°C [1, 2]. Hence, it is necessary to assess their fire behaviour due to widespread structural applications including strengthening and retrofitting. For assessment of fire hazard of a material, measurement of its reaction to fire properties are needed, including ignitability, peak and average values of heat release rate (PHRR and Av.HRR), total heat release (THR), etc. Other important properties include smoke and yield of toxic gases especially carbon monoxide, which in turn affect on visibility and ability of people to escape from the building engaged in fire, i.e. on life safety aspects [3]. In this paper fire performance of the two types epoxy CFRP and GFRP composites is discussed. Reaction-to-fire properties of specimens including thermal, smoke and toxic gases were measured with ignitability and cone calorimeter tests. Then the fire hazard of the specimens were assessed, based on Petrella method, in which the flashover propensity (x parameter) is defined and used for this purpose, as is outlined in continue. Time to flashover (t_{fo}) was predicted based on cone calorimeter results by Conetools software.

2. Experimental

2.1 Materials

The samples were two kinds of epoxy/glass (GFRP) and epoxy/carbon composites (CFRP). The specimens were provided by the commercial sources. The reason for choosing these two FRP composites is that they are common for external reinforcement of concrete structures in Iran. The matrices of both FRP composites were epoxy resin and only their reinforcing fibres were different (glass and carbon fibres). The thicknesses of all samples were approximately 3 mm.

2.2 Test procedure

Ignitability fire test

The ignitability test was carried out according to ISO 11925-2, which specifies a method of test for determining the ignitability of vertically oriented test specimens when exposed to a small flame, either at the edge or the surface of the specimens. Flame spread and occurrence of burning particles and droplets are observed during the specified flame exposure. The six flat specimens shall be used with dimensions: 250mm × 90mm and maximum thickness 60mm. The flame is applied for 15s (test duration 20s) and 30s (test duration 60s). The test results can be used for assessing a classification according to EN 13501-1.

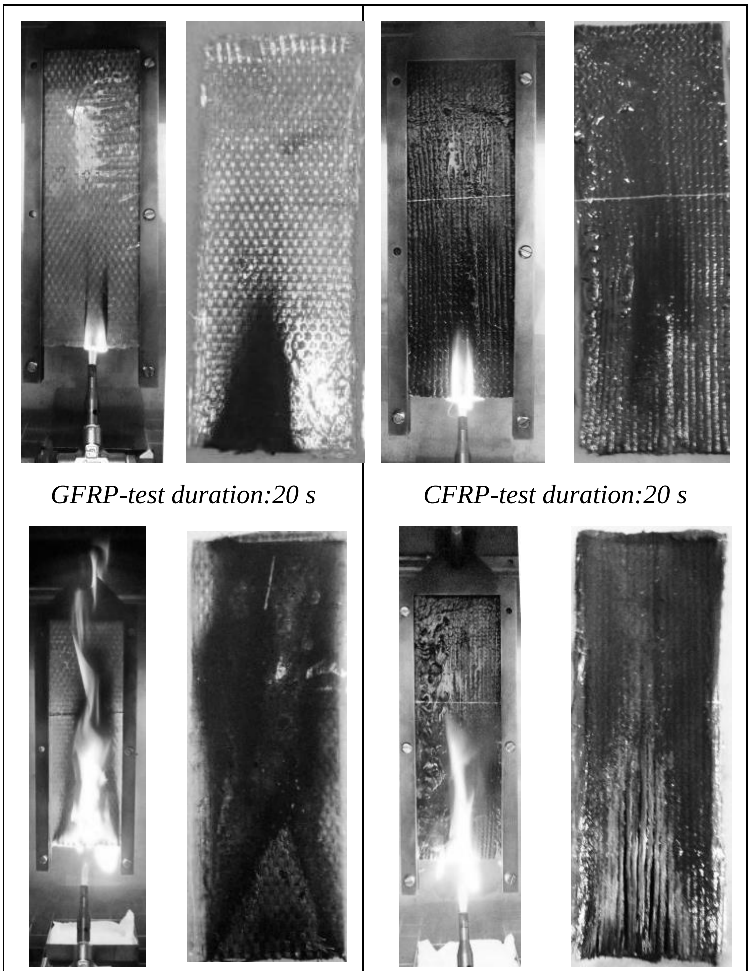
Cone calorimeter fire test

The bench-scale fire test was performed with cone calorimeter according to ISO 5660-1. The specimens were cut as 100 by 100 mm square samples. Two incident heat fluxes of 35kW/m^2 and 50kW/m^2 were set for evaluations. Three tests were carried out for each incident heat flux.

3. Discussion

3.1 Thermal aspects

At first a simple ignitability test were done on both samples. For both set of specimens, the flame tip did not reach the distance of 150mm during the test at 15s flame exposure. However, in contrary, when the tests were carried out at 30s flame exposure, the flame tip reached to a distance of 150mm before the end of the test duration. Thus, according to the test results and classification method of EN 13501-1, the tested FRP specimens met the reaction to fire class of E. Figure 1 shows the CFRP and GFRP specimens during the ignitability fire test.



GFRP-test duration:20 s | *CFRP-test duration:20 s*

GFRP-test duration:60 s | *CFRP-test duration:60 s*

Figure 1: GFRP and CFRP epoxy composites during ignitability fire test

Cone calorimeter tests were carried out at two radiation heat fluxes of 35kW/m^2 and 50kW/m^2. All of the specimens were ignited under these radiation heat fluxes in less than 1 min. The results showed a high flammability of tested materials. The PHRR values were high at both radiation levels (figure 2). In addition, TTI of the specimens were about 20s at 50kW/m^2 (table 1). The definitions of abbreviations are as following:

abbreviations	*Comment*	*abbreviations*	*Comment*
ρ (kg/m^3)	*Volumetric density*	*Av. SEA (m^2/kg)*	*Average of specific extinction area*
TTI (s)	*Time to ignition*	*TSR(-)*	*Total smoke released*

Mi (g)	*Initial mass*	t_{fo} *(s)*	*Time to flashover*
ML (g)	*Mass lost during the test*	*Peak CO (ppm)*	*Peak concentration of CO*
PHRR (kW/m^2)	*Peak of heat release rate*	*pk.COY (kg/ kg)*	*Peak yield of carbon monoxide*
THR (MJ/m^2)	*Total heat released*	*pk.CO2Y (kg/ kg)*	*Peak yield of carbon dioxide*
x=PHRR/TTI ($kW/m^2.s$)	*Flashover propensity*	*FED=pkCO/5000*	*Fractional effective dose*

Table 1: Reaction to fire thermal/smoke parameters in heat radiation levels 35kW/m^2 and 50kW/m^{2}in

Specimen / Parameters[1]	GFRP	CFRP	GFRP	CFRP
ρ	1230	872.5	1071	877.6
Heat flux	35 kW/m^2		50 kW/m^2	
Thermal parameters				
TTI	56	38	22	23
Mi[2]	41.0	26.4	34.7	27.8
ML[3]	16.9	18.7	18.5	20.9
PHRR	636.1	551.0	693.4	643.4
THR	59.1	52.7	49.3	54.9
x=PHRR/TTI	11.4	14.5	31.5	28
Smoke parameters				
Av. SEA	-	811.7	734.0	878.7
TSR	-	1723	1528	2090
Predicted time to flashover-conetools				
t_{fo}	-	-	81	74

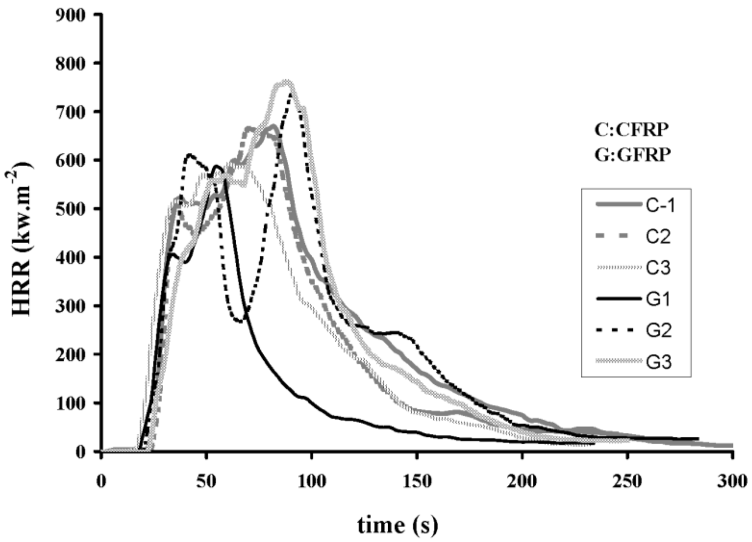


Figure 2: Heat release rates from GFRP and CFRP epoxy composites in heat flux 50kW/m²

The results shown in table 1 are the average values. Therefore, based on these results, these FRP materials would have a high contribution in growth of fire, if used without a protection layer. This shows that use of a protective layer for prevention of premature ignition and high contribution of materials in fire growth is necessary. Figure 3 shows the GFRP and CFRP specimens during cone calorimeter test in heat flux of $50kW/m^2$.

GFRP

CFRP

Figure 3: GFRP and CFRP epoxy composites during cone calorimeter fire test

The fire hazard of tested materials was analyzed with different methods. According to Petrella [4], the flashover propensity or x parameter is defined as ratio of PHR to TTI (in $kWm^{-2}s^{-1}$) and can be used for fire hazard classification of materials. In addition, he proposed a two-fold system consisting of the x parameter and total heat release (THR) for fire hazard evaluation, an attributed x parameter and THR to different fire hazard classes as following: x: 0.1-1.0 (low risk); 1.0-10 (intermediate risk); 10-100 (high risk) and THR: 0.1-1.0 (very low risk); 1.0-10 (low risk); 10-100 (intermediate risk); 100-1000 (high risk). Some researchers used this method for fire hazard assessment [5-6]. The x parameter of tested GFRP and CFRP specimens was calculated and compared with the method proposed by Petrella. The results are given in table 1 and as it can be seen both GFRP and CFRP showed high flashover propensities. An intermediate risk was acquired based on THR figures, which were in the range of 49-59 $MJ.m^{-2}$. Using test data from cone calorimeter, a time to flashover of 80s was acquired with conetools software for tested materials.

3.2 Smoke and toxic gases

The average specific extinction area (Av.SEA) and total smoke release (TSR) are reported. Attenuation of light (reducing incident intensity from I0 to I) by soot particles is proportional to the projection area (in m^2) of particles blocking the distance L (in m) between the light source and the receiver. SEA is a measure of this value normalized by the fuel mass [4]. Based on the values shown in table 1 this smoke parameter is relatively high.

The yields of toxic gases including carbon monoxide and carbon dioxide (COY and CO2Y) and the peak concentration of CO (pk[CO]) are given in table 2. CO concentration versus time is given in figure 4.

Table 2: toxicity aspects based on bench-scale cone calorimeter parameters in heat radiation level 50kW/m²

Specimen / *Parameters*	*GFRP*	*CFRP*
ρ	*1071*	*877.6*
Peak CO	*1153.4*	*888.3*
pk.COY × 100	*130*	*110*
pk.CO2Y × 100	*2440*	*2260*
FED=pkCO/5000	*0.23*	*0.18*

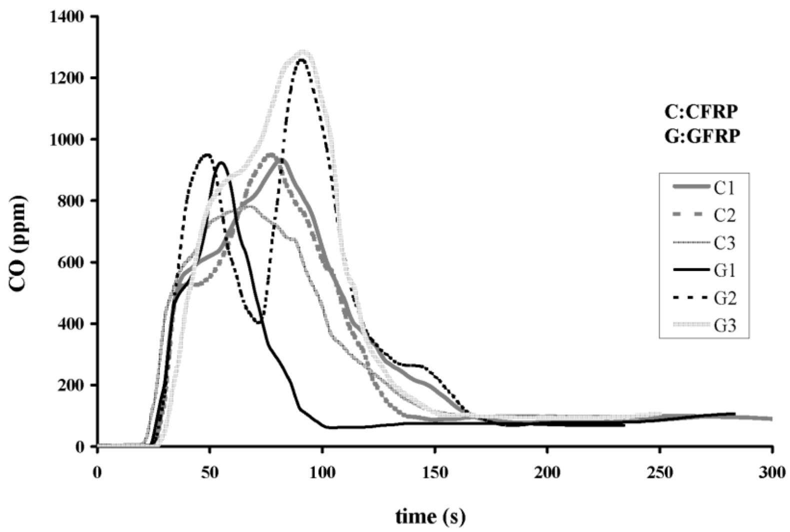


Figure 4: Carbon monoxide concentration of GFRP and CFRP epoxy composites in heat flux 50kW/m^2

It was observed that the value of pk[CO] was very high. It should be noted that the cone calorimeter is an open laboratory test and during the test about 24 lit/s fresh air is ventilated in the hood system. So the CO concentration is continuously diluted with the fresh air and it is not directly the CO concentration that can be expected in a real fire incident. In the other side, the integral of the area under curve of CO concentration might be a better index of the produced CO. As it can be seen from the figure 4, the CO concentrations of the tested materials were high.

A method of assessing toxic hazard in fire is fractional effective dose (FED). FED can be obtained from the ratio of the average concentration of a gaseous toxicant to its LC50 value [7]. Since CO and CO2 are measured in cone calorimeter and toxic potency LC50 for CO2 is much greater than LC50 for CO [8], FED was calculated [5] from pk[CO] in the cone calorimeter by:

$$\mathrm{FED} = \frac{\mathrm{pk}\,[\mathrm{CO}]}{5000}$$

The resulted FED was about 0.2 for tested specimens (table 2). Comparing with literature values for different materials [5] this can be taken as a relative high value. In the other side, as it was discussed in the above, the test is an open type with continues suction of fresh air. This is something again here that should be taken into account for interpretation of the results; and regarding this matter it can be said that the studied materials showed a high potential for producing toxic gases in case of fire, which is very important for life safety and evacuation of people from the building. Two factors including oxygen depletion and increasing of CO (and the other toxic gaseous) seriously affects survivability.

4. Conclusions

Fire behaviour of two types of fibre reinforced epoxy composites (CFRP and GFRP) was evaluated by reaction to fire tests including ignitability and cone calorimeter. Cone calorimeter tests were carried out in two different incidental heat fluxes of $35kW/m^2$ and $50kW/m^2$. Both FRPs Products showed relative dangerous behaviours in case of fire. They were highly flammable and their peak heat release rates were higher than $600kW/m^2$, which is a very high value.

Fire hazard assessments were done according to the method proposed by Petrella and also with use of Conetools software. The smoke and CO production of the materials were measured with cone calorimeter and then assessed using the related theories and methods. The results revealed that such FRP materials, used for external strengthening of concrete structures, are dangerous in case of fire, if they are used without a protective coating. In addition, the resin matrix would be rapidly molten, paralyzed and involved in combustion, if exposed to fire or high temperatures. So the mechanical strength of the system would be rapidly decreased and the system might be prematurely falls to a structural failure. Hence it is needed to protect the FRP system, due to both reaction-to-fire and fire resistance requirements. The results showed that high smoke and CO values from burning the FRPs. Furthermore, the obtained data revealed that there is a serious need for regulating the use of the FRP composite materials in building and other applications. Moreover, the study clearly shows the limitations of FRP composites applications should be determined based on the fire safety requirements in buildings especially widespread application for strengthening and rehabilitation of structures.

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Risk Assessment Impact on Landfill Structures Design

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Abstract

The purpose of this research was to investigate environmental permits of landfills with respect to the appropriateness of risk assessments focusing on contaminant migration, structures capable to protect the environment, waste and leachate management and existing environmental impacts of landfills. The objective of the environmental permit procedure is to ensure that the landfill owner has prepared a plan to protect the landfill environment using the Best Available Technique (BAT) and specialists with sufficient expertise. The plan includes structures for the protection of the environment with the help of which the environment, groundwater, surface water and the climate can be protected on a sufficient protection level during the whole life-cycle of the landfill according to the laws and regulations in force.

The directive admits of possible exceptions to the structural requirements if the protection capability of the deviations can be demonstrated to be corresponding with the help of risk assessment. Landfills risk assessing methods typically focuses on structural dimensions and harmful substances flux instead of focusing on local circumstances in Finland.

Several development needs were found in the risk assessments of the environmental permit decisions. The risk analysis equations used in the decisions did not adequately take into account all the determining factors like waste prospects, total risk quantification or human delineated factors. Instead of focusing on crucial factors, the landfill environmental protection capability is simply expressed via technical factors like hydraulic conductivity.

In this paper, it could be shown, that using adequate risk assessment approaches the most essential environmental impacts can be taken into account by consideration of contaminant transport mechanisms, leachate effects, and artificial landfill structures. The developed structural risk analysing (SRA) method shows, that landfills structures could be designed in a more cost-efficient way taking advantage of recycled or by-products. Additionally, the research results demonstrate that the environmental protection requirements of landfills should be updated to correspond to the capability to protect the environment instead of the current simplified requirements related to advective transport only.

Keywords: landfill, contaminant transport, geological barrier, environmental protection, Structural Risk Analysing method (SRA).

1. Introduction

The Landfill Directive defines explicit and unambiguous requirements for the structures that can be realized without a need for separate risk assessment. In the case of deviations, the risk assessment is obligatory. However, the directive does not define unambiguous requirements or procedures for it. Based on the literature, the risk factors affecting the landfill bottom structure can be divided into factors related to the landfill operational environment and to the waste content (Guyonnet et al. 2009; Cossu et al. 2003; Katsumi et al. 2001; Giroud et al. 2000; Korkka-Niemi & Salonen 1996; Christensen et al. 1994; Othman et al. 1994; Shackelford & Daniel 1991). Figure 1 presents the division of the most common identifiable factors related to the landfill operational environment and waste content, which affect the environmental protection crucially.

Based on the inadequate results of landfill risk assessment, it can be stated necessary to introduce further developed landfill risk assessment methods (Pollard et al. 2006). Risk assessing helps to define the risk factors, which have been identified in the designing phase and how their impact has been taken into account. The Structural Risk Assessment (SRA) method is introduced in this paper and is a tool for a sustainable landfill designing process. The SRA method gives substantially more information for landfill management, risk management and risk identification compared to the risk assessments conducted in the environmental permit processes.

The SRA method has been verified in the environmental permit processes of two landfills. The first verified case was an innovative surface structure and the second one a hazardous waste bottom structure. These verified structures used local products, by-products or recycled materials as much as possible to supplant natural materials and offer a substitute to expensive materials, such as sand bentonite. Also, these materials have to fulfil environmental regulations; otherwise authorities may not issue an environmental permit.

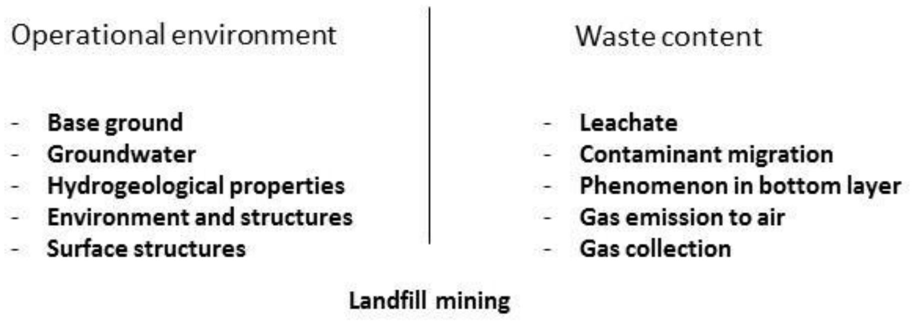

Figure 1. Effects of the most common identifiable factors related to the landfill operational environment and waste content on the landfill life-cycle information management and environmental protection (Ortner et al., 2014; Laner et al., 2012).

2. Materials and methods

2.1 Landfill surface structure

The risk assessment process was to find a solution for a lightweight structure that fulfils the environmental protection demands and is cost-effective. The incinerator has been activated recently and the surface structure should be possible to open for landfill mining purposes. The life expectancy exceeded 50 years because of the incinerator, landfill mining and the separation of waste (Pivato & Morris 2005). Landfill gases generate undesired odours in the vicinity of the landfill, and this could be avoided after the surface structures have been installed. Near the landfill site is a moraine area that has been tested during the landfill site construction, and the material could be used in the sealing structures. According to measurements by the Finnish Meteorological institute, the average drainage capacity is 548 mm/year. The temperature is below 0 degrees Celsius for 158 days a year.

The study was initiated with laboratory tests, calculations of gas emissions and water migration through porous media in a partly saturated situation. The risk quantification for uncertain assessment calculations had to be at least 1.5. The exposure assessment demands were set to control the water migration and electrical conductivity measurement results outside the landfill site in real time. The significance of electrical conductivity measurements is to control and secure that surface structures do not affect the surrounding environment. Electrical conductivity was chosen because the measurements easily indicate if harmful substances increase in the landfill areas, and comprehensive advance material is available as a reference (Grellier et al., 2006).

The hydrogeological properties, drying and shrinkage factors, insulation properties, frost resistance and mechanical properties of till were tested in laboratory conditions. The calculations of mineral layer hydraulic properties were simulated according to the Van Genuchten equation for partially saturated soils, the drainage system capacity according to unit gradient method and the bearing capacity with the general shear failure method. A drainage core was included in the gas collection layer. Table 1 illustrates the laboratory tests.

Table 1. Till's laboratory tests results.

Property, [unit]	test 1	test 2	test 3
Hydraulic conductivity [m/s]	2.2 E-8	1.7 E-8	6.6E-9
Effective stress [kPa]	26	40	20
Water content [w %]	5.2*	5.0*	9.5*
Dry unit weight [kN/m^3]	20.11	20.49	21.26
Volume shrinkage [%]	0	0	0
Compression strength [kPa]	73	75	72
Shearing strength [kPa]	36.5	34	37.2

2.2 The bottom structure of a hazardous landfill

The risk assessment process was to find a solution for a sustainable structure that fulfils the environmental protection demands and the life-cycle expectancy exceeded 50 years. The structural dimensioning was partly based on meteorological background information. Also, the result of the absorption tests was essential.

The average drainage capacity, founded on the precipitation statistics of the Finnish Meteorological Institute, is 513 mm/year. By 2012, the maximum precipitation during the preceding 40 years was 900.5 mm/year. The air temperature was below 0 degrees Celsius for 108 days and the soil temperature 217 days.

The background research included laboratory tests, a site investigation by boring drill holes into the solid base rock, taking samples from the drill holes, and absorption tests of water sludge made from existing landfill leachate. The objective of the absorption experiments was to examine the absorption capacity of water sludge and leachate, the impact of leachate on electrical conductivity, pH, and the chromium, molybdenum and nickel liquid-solid content. The risk quantification for uncertain assessment calculation had to be a minimum of 1.5 or at the same level as the frame of reference values. The exposure assessment demands were to control the electrical conductivity measurement results outside the landfill site in real time.

One of the primary principles was to make sure that the HDPE membrane does not include any holes after installation. There are several methods to confirm the integrity of the membrane. In this case, the electrical tension difference method has been used. The integrity of the membrane was crucial for structural dimensioning.

2.3 The Structural Risk Assessment method

The SRA method is useful to all landfill stakeholders: owners, designers, authorities and residents in the vicinity of the landfill. However, its most essential task involves design. The SRA method a tool for landfills risk assessment, which can be divided into three main categories (Fig. 2):

* Human factors

* Environmental factors

* Technical factors.

In the first phase, the identification of the current operational environment begins by evaluating source information, i.e. by comparing monitoring information, which can be called reference data, and test results. The second phase concentrates on the impact of various mechanisms, local conditions and phenomena in the design phase in relation to the required environmental protection level. In addition, during the design process, the initial conditions in the current operational environment and their impact on the environmental protection requirements will be taken into account. In the third phase, the achieved total result of the design phase will be compared to the minimum environmental protection requirements that are based on laws and decrees. In the last phase, the planned landfill life-cycle length will be examined in relation to the monitoring system with the help of which the changes or damages in the structures can be predicted, along with their environmental impacts. Also the risk quantification safety factors and the ranking between the risk assessment factors have to be defined.

Each category item has been further divided into sub-categories. The risk quantification can be identified more easily in the design phase with the help of the classification. In the risk analysis, the selected factors are examined based on the hypothesis that unidentified risk management does not exist but only identified risks could be accepted. The method emphasises the observation of every single factor, but examines analytically whether the factor is identified as a risk or not. Based on the reference data, it can be analysed whether the important factors have been identified in the design phase. Also, the identified factors impact the life-cycle information from the management perspective. In addition, the classification would have indicated how much and what type of essential additional information would have to be produced with the help of the evaluation procedure.

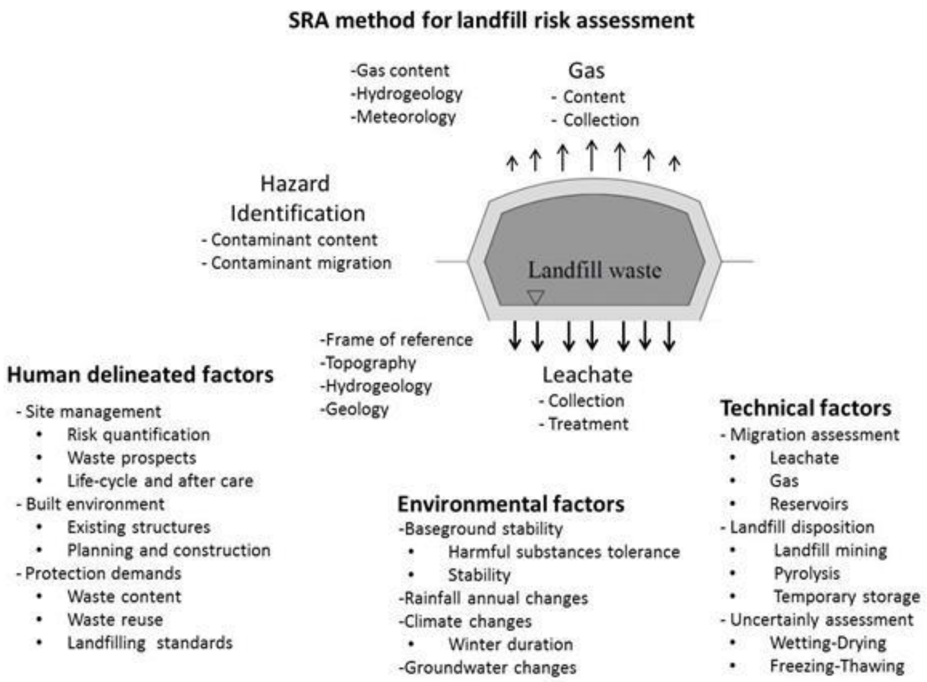

Figure 2. Risk assessment according to the SRA method.

The SRA method begins with the identification of the source data out of each entity of affecting factors, based on which it can be confirmed in the designing phase that there is enough source data available for decision-making in the design process. The minimum amount of source data depends on the target: is the landfill new or old, will the risk assessment being full or partial?

Typically, the source data would be more reliable if statistics could be calculated or the frequency of the data could be evaluated.

Unidentified risk factors will not necessarily cause risks during the whole landfill life-cycle, but the risk assessment is challenging if a risk has not been identified and its impacts have not been acknowledged in the design phase. The method does not guarantee risk-free environmental protection at the chosen risk level, because it is mainly a tool for the design phase. Errors during the construction phase may result in deviations in the selected life-cycle information management risk level and cause problems to the environment. For this reason, monitoring information should be utilised in the life-cycle information management after the design and construction phases.

Risk factors have to be ranked (P_x) after identifying them from the source data. P_x is the ranking value of an identified risk factor. Also, the landfill management or the designer has to determine the acceptable total risk level (R_{total}). The total risk level includes identified risk factors (R_{id}) and unidentified risk factors R_{ud}. The risk factor ranking depends on the structure protection demands, regulations, protection environment and human factors. This will lead to the situation that every risk assessment process has to be determined case by case. In addition, all the dominant risk factors are not included in regulations and environmental permits. Landfill management must identify the risk level (R_{ud}) of these unidentified risk factors.

The total risk level calculation is shown in Equation 1:

$$R_{total} = \sum_{x=1}^{n} R_{id} + \sum_{x=1}^{n} R_{ud} \qquad (1)$$

The identified risk level (R_{id}) can be determined by using Equation 2:

$$R_{id} = \sum_{x=1}^{n} P_x * Q_x \qquad (2)$$

Q_x is the probability coefficient of the identified risk.

The unidentified risk level (R_{ud}) can be determined by using Equation 3:

$$R_{ud} = \sum_{x=1}^{n} P_x * \beta_x \qquad (3)$$

β_x is the probability coefficient of the unidentified risk.

The probability coefficient Q_x of identified risk factors is always higher than demanded in regulations or environmental permits. The probability coefficient of unidentified risk factors could vary because increasing the reliability of the other risk factors could compensate for it. For example, the drainage layer risk probability is due to the fact that the soil is not being able to protect environment by increasing contaminant migration. Furthermore, the total risk level has to fulfil the demanded risk level. Figure 3 presents an example of a landfill risk assessment with the SRA method.

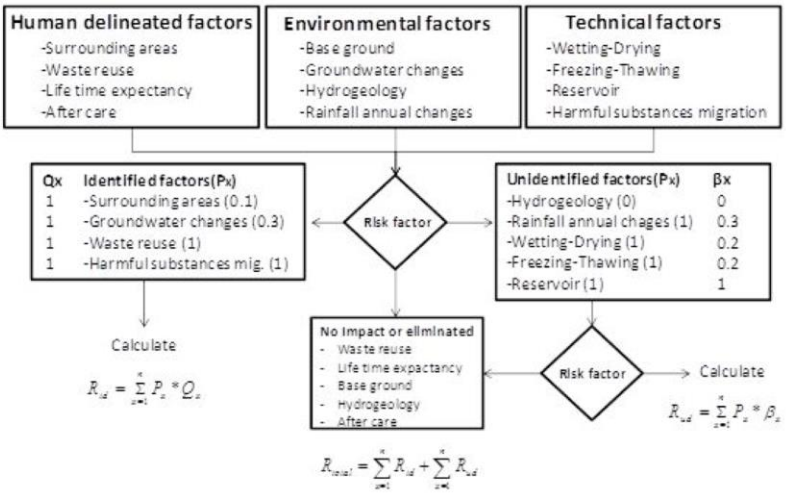

Figure 3. An example of landfill risk assessment with the SRA method.

3. Result and discussion

3.1 Landfill surface structure risk assessment with the SRA method

According to calculations, the surface structure environmental protection capacity of a mineral layer with a thickness of 0.09 meters could meet Government recommendation if fully saturated. Laboratory tests substantiate that the mineral layer could not reach full saturation in any meteorology condition (Henken-Mellies & Schweizer 2011). Consequently, partial saturation is a relevant calculation principal. Tammirinne et al. (2004) have made a model for surface structure drainage, but this model assumes that the temperature above 0 degrees Celsius throughout the year. The assumption is meteorologically irrelevant, but the model has been modified to be more realistic and relate to weather conditions in the landfill area. Tables 2 and 3 include mineral layer calculation results of dimensioning and safety factors. The dimensioning is calculated including and excluding safety factors.

Table 2. Dimensioning and risk factor calculation results for a surface structure mineral layer.

Property,[unit]	Including safety factor	Excluding safety factor	Risk factor
Hydraulic conductivity[m/s], (partly saturated conductivity)	$4.6\ 10^{-11}$	$1.3 \cdot 10^{-11}$	3.5
Effective stress [kPa]	26	13.7	1.9
Saturation degree [%]	40	30…50	---
Mineral layer thickness [m]	0.2	0.09	2.2

Table 3. Dimensioning, risk factors and total risk factor for the structural dimensioning of the surface structure drainage layer.

Property,[unit]	Including risk factor	Excluding risk factor	Risk factor
Flow rate [l/m^2s]	$2.38\ 10^{-1}$	$7.26 \cdot 10^{-2}$	3.3
Effective stress [kPa]	20	13.3	1.5
Gradient [-]	0.25	0.14	1.8
Structural dimensioning and total risk factor	2.05	1.5	**2.4***

*Note: * Total risk factor of the SRA method.*

The layer thickness has been increased form 0.09 meters to 0.2 meters because of construction and dimensioning problems. A very thin-layer construction over the angle slope would be challenging to excavate. Under Finnish regulations, the maxi-mum fraction size of soil material, such as till, has to be at least five times smaller than the constructed structure thickness. The maximum fraction size of till is 32 mm. Based on these factors, the 32 mm fraction size is a good reason for the thickness of the layer. According to frost resistant tests, water sources could not determine the freezing-thawing phenomenon for the mineral layer structure. The calculated total risk factor value was 2.4. The total risk factor value is the sum of the identified risk factors, and the ranking of the risk factors of this structure is the same (1).

The cost-efficiency of the structure compared with Government recommendations is 14% more affordability per hectare. The cost-efficiency will increase if the structure is opened in the future, because the structures are thinner and easier to excavate.

The limit conditions stated in the EC Landfill Directive should be developed further by means of structure life expectancy calculations, which can be implemented using various methods, such as the conversion factor method, statistical measuring and limit state of fatigue measurements, and the risk assessment safety factor.

3.2 Risk assessment of the bottom structure of a hazardous landfill with the SRA method

The structural dimensions of the geological barrier, water sludge, are shown in Table 4. The barrier is 1.2 meters thick, and the calculated risk level is 1.78. Hydraulic conductivity determined by 100 kPa effective stress, which is 1/6 of the final situation when the landfilling is finished. The porosity could be much lower in the last few years of landfilling because the effective stress increases and causes loading. The hydraulic conductivity will decrease impact on porosity and also affect the transport equation.

Table 4. Geological barrier's structural dimensions, calculation coefficients, porosity and contaminant transport times for three layer thicknesses.

C/C_0 =0.1 [Years]	Layer thickness [m]	Hydraulic conductivity [m/s] *	Hydraulic gradient [-]	Diffusion coefficient [m^2/s] **	R [-]	Porosity (-)
63	1.0	$4.5 \cdot 10^{-10}$	1.5	$2.0 \cdot 10^{-10}$	1	0.4
89	1.2	$4.5 \cdot 10^{-10}$	1.42	$2.0 \cdot 10^{-10}$	1	0.4
118	1.4	$4.5 \cdot 10^{-10}$	1.33	$2.0 \cdot 10^{-10}$	1	0.4

*Note: * The hydraulic conductivity value was determined by 100 kPa effective stress that is 1/6 of the final situation when the landfilling is finished. ** The diffusion coefficient is based on calculations by Katsumi et al. (2001).*

The HDPE geomembrane will be installed above and under the water sludge layer, also called the geological barrier. A double layer geomembrane could secure the migration of harmful substances of water sludge to the soil. The drainage layer and the leachate will be collected separately when the HDPE geomembrane is installed. This enables the control of the leachate source and content in both layers. Leachate is conducted to the reservoir and further to water treatment.

The uncertainty of the risk assessment has been estimated by determining the content of the drilled ground samples. The sample test results have been compared with the Government decree limit values and natural values (VNa 214/2007). Table 5 shows the reference values for soil.

The total risk value is the sum of the identified and unidentified risk factors and the ranking of the risk factors of this structure is the same (1). The total risk factor (R_{total}) was 1.79. The cost-efficiency of the structure compared with the Government decision is 43% more affordable per hectare. The total cost-efficiency is influenced most by the possibility to use by-products as a part of the structure.

Table 5. The examples test results compared with Government decree limit values and natural values.

Substance	Unit	Frame of reference	Limit value	Natural content	Lower reference value	Upper reference value
Chromium (Cr)	mg/kg	30*(25-48)	100	31(6-170)	200	300
Molybdenum Mo)	mg/kg	<1*	-	<1	<1	<1
Nickel (Ni)	mg/kg	10*(8-13)	50	17(3-100)	100	150
pH	-	7*(6.2-7.8)	-	-	-	-

Note: * Outside of the bracket is the mean value of 12 measurements and inside of the bracket are the lowest and the highest determined values.

Typically in environmental protection structures, attention is paid mainly to the hydraulic conductivity of the mineral layer. The landfill structure analysis should take into account the leachate management, and in leakage situations the leachate content, human-related factors and waste prospects in the risk assessment. Essential factors for the securing of the landfill barrier structures' operation are the functionality of the drainage layer and the intactness and life-expectancy of the artificial barrier. If it is possible to conduct the leachate from the bottom structure through the drainage layer into treatment during the whole life-cycle, the hydraulic gradient to the bottom structure is not significant. This reduces the leachate stress on the mineral layer including all transport mechanisms. From this example, the effect of the hydraulic gradient is eliminated because the artificial layer will be controlled to avoid damage after installation. Therefore, during the active phase the artificial and drainage structure will eliminate the effect of the hydraulic gradient.

Factors related to material transport and retention and contaminant migration have been discussed above. Based on them, it can be concluded that an unambiguous correspondence between the materials and structures is not easy to determine. The definition of reference materials or structures is also difficult because some materials may be better than others in some respect. Instead, materials and structures can be compared in relation to functional requirements. Dominant factors may in some applications be the amount of penetrating water and in some applications the penetrating contaminants or their concentrations or the time needed for their accomplishment. In structural analysis, the identification of the dominant factors and the setting of boundary conditions are essential and significant. According to the results of this thesis, the boundary condition setting has to be based on landfill-specific requirements, which may vary significantly depending on e.g. the location of the landfill, hydrogeology, meteorology and topography.

The SRA method is the most suitable for materials like these, that is, industrially by-produced materials for which the manufacturer can provide a serviceable life estimate for comparison. Statistical measurements support the SRA method for measuring structure dimensions, since the measuring equations are presented as a fatigue parameter and a response parameter so that the parameters are time-dependent. One example of this is the contaminant migration equation in which a concentration differential forms as a function of time due to the effects of fatigue caused by different loads.

4. Conclusion

The overall aim of this research was to provide further information on how the landfill risk assessment process has to be focused according to human-related, environmental and technical factors while evaluating the possible risk assessment to the environment. The technical requirements of the present landfill protection structures cannot achieve sustainable protection by focusing on the landfill life-cycle risk assessment information. The most essential problems in the design period are the unidentified and unrecognised risk factors and their effects on the landfill's environmental protection capability. The most significant factors are the inadequacies in the contaminant transport modelling and in the identification of the factors affecting it. Another essential factor is the identification of the factors affecting the environmental protection structures' capability and their life-cycle. In addition, the impacts of the existing structures or infrastructure on landfills have not been identified.

The directive should be developed to include complete guiding principles for the risk assessment scenario. The inconsistency in risk assessment leads to overly optimistic solutions and does not observe crucial requirements such as the local climate and weather. Unfortunately, it seems that numeric goals are missing in the directive. The directive only defines hydraulic conductivity and layer thickness, enabling different interpretations.

The results of this study emphasise the importance of utilising risk assessment like the SRA method for designing landfill structures. The design parameters should be based on true technical and environmental factors, human influence, waste prospects and risk quantifications for the final result to acknowledge the existing hydro-geological environment. In the future, demands concerning landfills will change because of reuse, recycling and using landfills as a material source. In consequence, landfills will be used as temporary storage in the future. Therefore, tools such as the SRA method will be needed to evaluate the life-cycle of landfill structures from different angles.

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Minimizing Risk through Performance Rather Than Warranties

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Abstract

Many problems are caused by owners specifying project technical requirements to expert vendors, then picking the low price vendor, assuming that all the vendors are providing the same quality of product. Research in the last 20 years has identified that when working with highly technical areas, this practice brings high risk to the owner because the vendors do not have the expertise to understand the requirements. The Alpha sprayed polyurethane (SPF) roof system has brought the Dallas Independent School District (DISD) high value but also occasional risk caused by the low price vendor. The authors are proposing that DISD's effort to buy the Alpha SPF roof system through the low price competition will cause DISD risk. A new approach is proposed to DISD, that the Alpha SPF roof system only be used as an alternate value added option. This approach assumes that the only way the Alpha SPF system can be procured is if it is in the best interest of the owner due to dominant value. This approach minimizes the risk that DISD has encountered from low price contractors who have not been able to minimize risk through the use of expertise and experience because their low price was directly related to a lack of experience and expertise.

Keywords: roofing, Alpha Program, Sprayed polyurethane, Best Value, performance

1. Introduction

Sprayed polyurethane foam (SPF) roof systems have been installed since the early 1970s. SPF roof systems have the following characteristics:

1. Have the highest insulating factor of any roof insulation systems.
2. Have the lowest weight of any roofing system [0.50 PSF (3 PCF)].
3. Monolithic.
4. Has a very technical application utilizing an exothermic reaction that transforms two liquid components into a rigid three pound density SPF.
5. The industry has changed the insulating refrigerant material numerous times to meet EPA standards, causing applicators to change their temperatures and process details.
6. It is a sustainable and green roof system [renewable, minimizes the need to remove the existing roofing system and lightweight].

7. The SPF industry has had difficulty regulating itself, resulting in many SPF roof failures.
8. Properly installed SPF roof systems have performed very well. The industry has always remained less than 3% of the roofing industry due to their inability to regulate the performance of their contractors.
9. SPF roof systems require a coating system to protect it from UV degradation.
10. Confusion on the performance of different coating and SPF roof systems [hail resistance, UV degradation and ability to sustain roof traffic].
11. Warranties are used by sales/marketing personnel to attempt to identify performance.
12. Warranties are used as marketing and are not related to performance.
13. In 2001, when coated SPF systems failed at DISD, and the manufacturers did not honor the warranty, DISD stopped using coated SPF roof systems.

An example of illogical warranty and marketing information was provided by Factory Mutual, [one of the two largest building insurance groups], who put out a report that all coated SPF systems, offer hail protection against 1-3/4 inch size hail based on their hail testing. PBSRG testing in 1996 could not verify their results. There published results identified silicone coating as the most hail resistant, and urethane coatings as offering the worst protection. PBSRG tests found it was the exact opposite [Kashiwagi & Pandey 1996]. FM testing was done only on new coatings and coating systems that were weathered using artificial weathering. When actual aged systems in the field were tested, the results verified that the Alpha urethane coating was the only coated SPF roof system that offered protection against 1-3/4 inch size hail. [Kashiwagi & Savicky 2003]

Only one SPF coating system has documented high performance in heavy hail areas. The Alpha system, made by Neogard, is the only coated SPF system with documented protection against hail. Other urethane coatings have not documented the same protection after being exposed to the elements.

DISD used the design-bid-build procurement approach to award contractors to install SPF roof systems. The resulting poor performance of SPF roof systems led to a DISD policy of “no SPF” roof systems on DISD roofs. It has not been proven that the price based approach can be used to utilize the value of the hail resistant Alpha SPF roof system.

2. Dallas Independent School District

From 1987-2001, DISD had a few high performance Alpha SPF roof systems, but the majority of the SPF systems failed. It was common for the coating and SPF manufacturers to offer warranties but not honor those warranties. Since DISD could not utilize their warranties and due to poor performing SPF roof systems, in 2002, DISD banned the installation of SPF roof systems.

DISD is in a heavy hail area, and is self-insured against hail damage. DISD identified that the Alpha roof system [with sufficient urethane coating] on the Casa View School roof showed 16 year performance with no maintenance. In 2002 DISD allowed the installation of the Alpha SPF roof system in a best value procurement test to identify if the same high performance could be duplicated. The results showed that the Alpha SPF roof systems were installed with high performance [Kashiwagi & Savicky 2003]. Due to the dominant performance results, DISD changed their policy and allowed the installation of the Alpha SPF roof systems.

In addition to the test results, the Neogard Corporation supported the Alpha roof system with a joint and several warranty, covering the performance of the SPF and the Alpha coating system. These warranties held the insured parties [Alpha coating manufacturer, SPF manufacturer, and the Alpha contractor] joint and severally, liable for any defects of the system. Defects included blistering and delamination. Defects that were not covered by the SPF industry were covered by the warranty [leaking was the only recognizable defect covered by warranties]. The joint and several warranty, along with the proven performance of the Alpha roof system in hail areas, differentiated the Alpha SPF roof system and help convince the DISD to continue to install the Alpha roof system.

In 2005 DISD had bond program to renovate their school buildings. The bond program eventually ran short of funding. Due to the shortage of funding, DISD did not utilize the Alpha SPF roof system and its warranty, but utilized a ten year SPF system, with a more traditional 10 year warranty. The ten year urethane coated SPF system [no joint and several warranty] was still at a much lower cost compared to the traditional built up and modified roof systems. The contractors bids were shopped, and one of the contractors used a SPF system that was not utilized in the Alpha program.

Table 1 shows the SPF roof performance of the Alpha roof systems at DISD based on the physical inspections of 98 roofs. Evaluating roof coverings using physical inspection and reporting the repair or replacement conditions to the owner have been used for other roofing systems [Coffelt et. al. 2010, Sharara et. al. 2009]. Table 2 compares the blisters and repairs at DISD for the last 4 years.

Table 1 – Overall DISD SPF Roof Performance

No	*Criteria*	*Unit*	*Performance*
1	*Oldest job surveyed*	*Years*	*22*
2	*Average age of jobs surveyed*	*Years*	*7*
3	*Age sum of all projects inspected*	*Years*	*675*
4	*Average total repairs on each roof*	*SF*	*348*
5	*% of roof repaired*	*%*	*0.79%*
6	*Average total existing blisters on each roof*	*SF*	*16*
7	*% of roof blistered*	*%*	*0.035%*
8	*Average blister size*	*In.*	*4”*
9	*Average job area (of jobs surveyed and inspected)*	*SF*	*43,128*
10	*Total job area (of job surveyed and inspected)*	*SF*	*4.3 M*
11	*Total number of jobs inspected*	*#*	*98*

Table 2: Blister and Repair Comparison at DISD

No	*Criteria*	*Unit*	*Year 4*	*Year 3*	*Year 2*	*Year 1*
1	*% of total roof area blistered*	*%*	*0.035%*	*0.038%*	*0.098%*	*0.131%*
2	*Total blisters*	*SF*	*1,525*	*1,599*	*3,915*	*4,117*
3	*% of total roof area repaired*	*%*	*0.79%*	*0.62%*	*0.38%*	*0.27%*
4	*Total repairs*	*SF*	*34,137*	*26,046*	*14,946*	*8,721*
5	*Total job area*	*SF*	*4.3 M*	*4.2 M*	*4.0 M*	*3.2 M*

Despite the low bidding and shopping of the Alpha roof contractors bids, DISD has received performance from the roofs that were installed. One of the reasons for using the Alpha roof system was the Alpha program required their contractors to maintain 98% customer satisfaction and roofs not leaking on an annual basis to continue to be allowed to install the Alpha roof system. This included all roofs that were installed by the roofing contractor. If they had issues that resulted in customer dissatisfaction, they were required to fix the roof. This resulted in many of the DISD roofs being maintained by the contractors, not as a warranty requirement, but as a requirement to get further work at DISD.

However, the following factors led to a degradation of the some of the contractor's roof system performance:

1. The Alpha roofing contractors are shopped for price through general contractors and traditional roofing contractors.
2. A relatively new contractor, who needed work, took the majority of the work due to their very low prices.
3. The low price contractor used substandard SPF due to a shortage of SPF material.
4. The low price contractor had an excessive amount of work and ended up cutting corners, such as installing SPF in marginal conditions.

In studying the defects of the Alpha system, it is clear that the majority of the problems were contractor generated. Requiring the manufacturers to pay for the repair of the defects under a ten year warranty, cannot be enforced. Once the contractor is paid, there has not been a way to force the contractor to fix the defects. If the defects are large, the contractor will go out of business. If the roofing system did not have a joint and several warranty, the roof owner has no recourse but to install another roof.

The low price contractor installed 62 out of the 98 roofs and there were 16 roofs which had defects that required maintenance. The contractor did not charge enough to maintain their roofs through the ten year warranty period [DISD expectation]. The roofing manufacturers [alpha coating and SPF manufacturer] continued to sell their materials to the contractor. DISD continued to hire and utilize the contractor. The contractor began to have issues with their roofs, and was not doing their maintenance work to keep the roofs performing. They ended up going bankrupt in

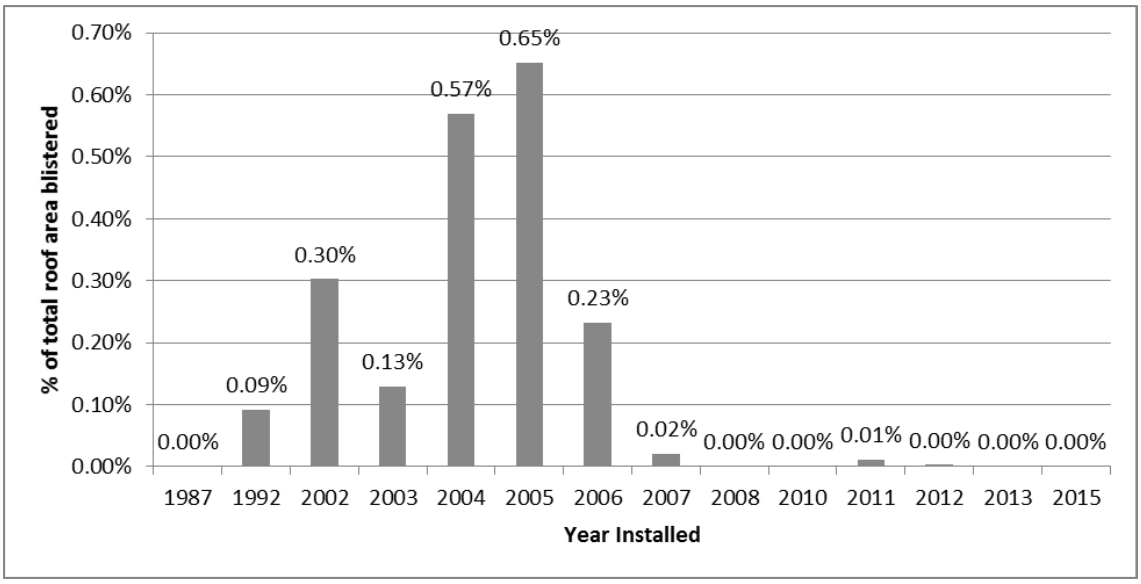
2015. DISD requested Neogard to cover the warranties, but with the ten year warranty, Neogard and their SPF manufacturing partner BASF, did not cover the SPF roof defects.

Table 3:# of Roofs Installed Yearly

Year	*# of roofs installed*	*Year*	*# of roofs installed*
1987	*1*	*2007*	*1*
1992	*1*	*2008*	*5*
2002	*3*	*2010*	*12*
2003	*1*	*2011*	*9*
2004	*15*	*2012*	*6*
2005	*28*	*2013*	*1*
2006	*11*	*2015*	
2007	*4*		

Another analysis of the roofs show that the majority of the problem roofs were installed in 2014 and 2015 during the beginning of the 2004/2005 bond program (Table 3). Ten years later the roofs show the problems which could have been avoided with more careful installation, and better materials. Despite a number of poor performing roofs, the number of performing roofs outnumber the poor performing roofs (Table 4). To identify the performance of a few nonperforming roofs due to extenuating circumstances in the bond program, with the performance capability shown on other roofs that are installed correctly would minimize the value that the DISD could receive from the Alpha SPF roof system.

Table 4: Roof Yearly Analysis



3. Problem

The warranties accompanying the coated SPF roof systems could not be enforced. The warranty is provided by the manufacturer to the buyer as a protection [Agrawal et. al. 1996]. Since the manufacturer provides the warranty it is written by their legal representatives [Murthy & Djamaludin, 2002] and contains exclusion that will void the warranty if encountered [Christozov et. al. 2009]. Hence warranties have no proven correlation to the actual performance of the product, however, contractors still use them for marketing purposes [Kashiwagi 2012]. Similar to the history of the SPF roof industry, where warranties were used as marketing tools to convince building owners that a longer warranty meant that they had a longer performing roof system with protection against defects, DISD found themselves with a few SPF roofs with problems which were not protected by the warranty.

DISD is aware of the value of the SPF roof systems when they are installed correctly. They are also aware of the impact of the "low bid" delivery system on the value and performance of the roof system. There were additional problems that DISD and the Alpha coating manufacturer (Neogard) encountered:

1. Neogard did not get the needed support from the SPF manufacturer that they had partnered with. The SPF manufacturer charged a higher price for the Alpha SPF, but offered no added support for the needed maintenance repairs.
2. Neogard no longer wanted to cover the liability for the correct installation of the SPF.
3. The contractors did not have the sufficient business acumen to take needed steps to minimize the risk of SPF roof defects.
4. The bonding companies were charging unaffordable rates to cover joint and several warranties. Due to this the contractors were not willing to sign the joint and several warranty.
5. DISD had 4M Sf of the Alpha system installed and had seen it was a good value proposition. However, DISD wanted a joint and several warranty, and none of the vendor parties were interested in taking on the liability.

The challenge to the Alpha coating manufacturer and DISD is:

1. To create a system that self-motivates the contractors to install a quality roof system.
2. Motivate the SPF manufacturer to take accountability of the SPF performance.
3. Minimize the risk of a non-performance at key points in the installation process, therefore minimizing and not transferring risk of non-performance to non-responsible parties.

Table 5: Roofs with High Damage (Over 1% Blistered)

School	*Roof Area in SF*	*Date Installed*	*Contractor*	*Total SF of Blisters*	*% of Total Roof Area Blistered*	*# of Blisters over 1 SF*	*# of open blisters*
Russell ES	*27,295*	*May-04*	*Alpha Contracting*	*1,050*	*3.85%*	*10*	*5*
Samuel HS	*147,500*	*Aug-05*	*Alpha Contracting*	*4,000*	*2.71%*	*27*	*0*
Spruce HS	*85,000*	*Aug-05*	*Alpha Contracting*	*2,150*	*2.53%*	*25*	*7*

Lincoln HS - Flat	*12,000*	*Oct-06*	*Alpha Contracting*	*230*	*1.92%*	*4*	*1*
Hawthorne ES	*45,200*	*Jul-05*	*Alpha Contracting*	*660*	*1.46%*	*6*	*3*
Russell ES - Old Admin Bldg.	*10,500*	*Aug-04*	*Alpha Contracting*	*150*	*1.43%*	*0*	*0*
Terry ES	*28,400*	*Dec-04*	*Alpha Contracting*	*320*	*1.13%*	*4*	*3*
Peabody ES	*32,600*	*Aug-05*	*Alpha Contracting*	*350*	*1.07%*	*7*	*4*

*All the high damaged roofs were installed in 2004, 2005 and 2006 and account for 66% of all blisters at DISD.

4. Approach and solution to the Problem

The steps to the solution of this opportunity must include the following:
1. Identify the DISD delivery system of construction and construction systems.
2. Identify the value of the Alpha roof system.
3. Identification of the source of risk caused by non-performance and create a new system that minimizes risk due to the structure of the approach and does not depend on a warranty to minimize non-performance [has not worked at DISD in the past ten years].
4. Create a best value structure that minimizes the risk of non-performance.
5. Create a transparent environment that clearly identifies expertise and the source of risk.

5. Description of the DISD Procurement/Delivery System

The DISD delivery system of construction is a design-bid-build (DBB) delivery system. The designers in the system do not have accurate information of the performance of different roofing systems and therefore do not have the expertise to select or design highly technical roof systems. They also do not have the legal liability or accountability of the roof system performance over the duration of the roofing system's lifespan. Due to the lack of information, the designer's decision making increases risk. The only party that does have the responsibility of roof system performance is the DISD roofing maintenance expert. He has the responsibility to resolve all roofing issues. Any change in roof system policy requires the DISD roofing expert's support.

The SPF roofing contractors and manufacturers in the DISD environment have shown the following characteristics:
1. There are vendors who cannot accurately price roof systems to accept the accountability of the performance of the roof for the duration of ten or more years. The Alpha SPF roof system should never be competed based on price.
2. Manufacturers of both the Alpha coating system and the SPF have not consistently exhibited leadership or control over the vendors pricing, installation and maintenance activities. Neither

have they consistently understood or supported the vendors at key times in the beginning of a project and at the end of the project to ensure the minimization of risk.
3. The Alpha SPF roof system has not consistently and successfully been competed among the SPF contractors. Rather than assume the cause of this lack of success, the Alpha SPF roof system should only be an alternate to the traditional modified or built up roof system, and should only be installed when the value to DISD shows tremendous value [cost savings of 30% or higher].
4. Warranties have shown minimal value in protecting the client against SPF defects and should not be used to protect the building owner. The more DISD depends on the warranties, the greater is DISD's risk.

6. Value of the Alpha SPF Roof System to the DISD

The DISD is in a heavy hail geographical area and is a self-ensured organization/entity. The Alpha SPF roof system has the following characteristics:
1. When installed correctly, proven 20 year history of performance in hail areas with the ability to withstand 1-3/4 inch size hail, it has been documented to resist larger hail, but due to the uniqueness of the hail shape and hail storm characteristics, expectations of hail resistance for larger hailstones must be tempered.
2. DISD documentation showing that the Alpha SPF roof system at DISD has exceeded 25 years [Foster Elementary and Casa View] and has the capability to be recoated for an additional 15 years [total of 40 years]. The aged Alpha SPF system's ability to withstand hail damage shows no degradation over time.
3. The Alpha SPF system does not require the removal of the existing Built-up Roof (BUR). Together with the BUR it forms a better waterproofing system. It does not require the throwing away of the existing roofing system which is environmentally friendly [Knowles 2005].
4. The Alpha SPF system is renewable through recoating.
5. The SPF is the highest known insulating material, and is monolithic which increases the insulation value.
6. The documented and observable value of the Alpha SPF system is 40 – 50% less that the price of the traditional BUR of modified roof system. This is established from the DISD base price of $16/SF for BUR vs the SPF pricing of Wattle & Daub [Tisthammer, identified as the best SPF performing vendor in the United States, 2015].

7. Risk of Defects in the Alpha SPF Roof System

Due to inconsistency in performance of the same roofing system, it has been observed that the craftspeople installing the SPF roof system, commit easily avoidable errors that lead to SPF defects. The industry expert [has been doing research for the longest duration, has help create the Alpha program for SPF roof systems, and has the most dominant performance in the SPF industry in the U.S.] stated that "the SPF system may exceed the planning and technical capabilities of the average SPF roofing manpower force." [Tisthammer, 2015] The defects observed over the past twenty years in the SPF industry are attributed mainly to applicator error [Bailey & Bradford 2005]. The number of occurrences that are due to material problems have been rare. The sensitivity of the chemistry of the SPF system when installed [temperature, ratio of the two components, not stepping on the cured system before it is cured, sensitivity to moisture, and not installing on a substrate with moisture], increases the need for expertise to follow specific installation instructions.

The defects require a system to assist installers to identify and mitigate risk that the installers may not instinctively do. This issue is not unique to the SPF industry, but is observable in the construction industry in general. Oftentimes, if the SPF installers have a discussion with the manufacturers' representatives, DISD roofing expert and other DISD involved stakeholders, many of the issues that cause risk can be eliminated. By observing the DISD Alpha SPF roof performance history, an on-site clarification meeting where the vendor's experts clearly articulate their concerns and challenges and then get input from the DISD and other stakeholders would have minimized most of the risks and defects encountered over the last 13 years at DISD.

The second observation of the DISD Alpha SPF roof history performance is that lab testing of the installed Alpha roof system must be performed, and the results analysed not only for the newly installed roof, but compared with the physical characteristics of all other installed SPF roofs at DISD. The results of the tests and analysis should be accessible to all stakeholders and to the industry. The current DISD environment has a lack of transparency of the technical metrics.

The third observation of the history of DISD Alpha SPF roof system performance is that any warranty documentation must be simple and the responsibility of the SPF and coating defects must be clearly stated. Once the Alpha coating and SPF physical metrics are checked and approved, the Alpha coating manufacturer is responsible for the coating defects, and the SPF manufacturer is responsible for the SPF defects. Another option is for the contractor to be responsible for all SPF defects. However, if the contractor is responsible, the risk is greater and the owner may require a performance bond due to the financial instability of roofing contractors.

8. Creation of a Best Value Structure for the Alpha Program

A best value structure is required for the DISD use of the Alpha SPF roof system. As previously identified, the Alpha program must have transparency, show responsibility and accountability and show expertise of the vendor to successfully install and maintain their Alpha SPF roof systems. This structure includes:

1. The inspection of a minimum of 50 performing SPF roof systems.
2. Have a 98% roofs not leaking and customer satisfaction of all SPF roof systems installed.
3. Annual surveys of all SPF roofs installed.
4. Every other year inspection of 25 or more roofs being installed.
5. Respond to a leak or customer dissatisfaction within a week, and fixing the defect with two weeks unless given more time by the owner's representative.

Any vendor who fails to meet any of these requirements at any time shall be suspended from the Alpha program. Re-entry into the program will require the above five steps to be redone.

9. Transparent Environment Built by the Manufacturers, Contractors and DISD

The best value environment is transparent. When an environment is transparent, the following characteristics are observable:
1. Consensus. All stakeholders will know the performance of any building system or vendor or system.
2. Metrics. All performance will be delivered in terms of relative number of years the roofs have been performing, initial and repair costs, number of leaks, was the leak fixed, the duration of time it took to be fixed and customer satisfaction.

The Alpha SPF roof system cannot be consistently and successfully specified and installed. The Alpha SPF system can only be selected and installed if the following is observed:
1. The budget for the traditional roof system is exceeded, and the Alpha SPF system can be installed within the constraints.
2. The Alpha SPF roof system is a dominant value [30% or more in cost savings of the specified system].
3. The alternative option which warrants all coating and SPF defects [with verifiable information that the manufacturer's system has been operational in covering defects]. The options that identify that the manufacturer will cover defects caused by their material has no value. It must state that the SPF manufacturer covers all SPF defects. This forces SPF manufacturers to cover the risk of applicators who do not respond to installation problems.

10. Conclusion

The Alpha SPF roof system has shown tremendous value for the Dallas Independent School District (DISD). However, the following are observations of the last 13 years of DISD attempting to deliver the Alpha SPF roof system using the low bid environment:
1. A few of the Alpha SPF roofing contractors have not been able to escape the low bid pressures that have led to occasional non-performance issues.
2. A high performance Alpha SPF roof system cannot be consistently delivered in the DISD low bid environment as lower performing contractors win jobs with low prices.
3. The Alpha coating and SPF manufacturers and DISD have not been able to regulate the contractor performance by proper quality control and the use of performance information.
4. There are Alpha SPF contractors who do not have the management and planning expertise and discipline to identify and minimize sources of SPF performance risk at the beginning of the project.
5. The Alpha SPF manufacturers have not provided the transparency that would have minimized DISD risk by testing for performance metrics at the end of the project, and continually comparing the project metrics to existing DISD Alpha SPF roof metrics.

Instead of using the traditional warranties which are difficult to enforce, the Alpha SPF manufacturers [Alpha coating and SPF] must create a new risk mitigation environment. The risk shall be minimized by identifying the sources of risk, and eliminating the sources of risk before the project begins instead of passing the risk to another party [traditional warranty system]. The DISD will also participate in the program by following simple rules of best value. The new environment will minimize risk sources regardless of who causes the risk.

The following are the risk mitigation mechanisms:
1. The SPF Alpha system should only act as an alternative to the traditional modified BUR system and can only be selected if it shows tremendous value for DISD [a minimum of 30% cost savings]. The Alpha roof system is already identified as an alternate roof system in the DISD approved specifications.
2. The SPF alternative proposal will be selected if the SPF manufacturer covers all SPF defects regardless of cause [and shows an operational process that has been in place] and still shows dominant value over the traditional specified system [minimum of 30% cost savings].
3. A clarification period will be held on every Alpha SPF project that is approved that requires the manufacturers' representatives and DISD stakeholders to attend. The Alpha contractor should clarify how they will install the Alpha system, present a list of risks and risk mitigation and have a schedule that will be tracked throughout the project.
4. The contractor will have third party inspection of the roof of coating thicknesses and SPF density, compressive strength and material stability. The testing metrics will be in a system that is accessible to all and easy to understand, creating transparency in the event that there are performance issues during the service period of the Alpha SPF roof system.
5. The contractors will show their level of expertise by belonging to an Alpha performance program that monitors the performance of all their SPF roof applications.
6. This Alpha program suspends the contractor if they do not follow any of the requirements of a high performance contractor [maintains their roof systems, maintains customer satisfaction and roofs not leaking to a 98% level of performance, and fixes any deficiencies within two weeks of notification].

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Improving the Resilience of Roofs: Lessons from Wind Damage Reports

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Abstract

As wind strengths increase in the future there will be requirements to assess the roof attachment strength of existing buildings. Improving the resilience of roofs to wind damage follows from an understanding of load transfer paths through the multi-layer roof systems.

Several case studies of wind damaged roof investigations in the UK and Ireland are presented, exploring alternative causation theories and identifying the weakest links in the roof attachment.

It is hoped that by sharing feedback from wind damage reports in an independent and constructive way we can improve our common understanding of failure mechanisms, enabling us to design and build more resilient building envelopes that are better able to withstand the extremes of changing weather patterns.

Keywords: roof resilience, roof reliability, wind damage

1. Introduction

Technical investigation reports on wind damage to roofing and cladding can provide a wealth of useful information relevant to designers, researchers, manufacturers, contractors and building owners. It is common to find multiple failures within roof systems and often the challenge is to identify which link in the assembly broke first. The forensic investigations demand a methodical approach, piecing together the available evidence of the initial point of failure, which is often hidden from view.

Several case studies of wind damaged roof investigations in the UK and Ireland are presented, exploring alternative causation theories and developing options for strengthening and repair.

This paper describes the method used for determining the attachment strength of a profiled metal roof construction under wind suction loading. Improving the resilience of an existing roof is dependent upon the identification of the weakest links and strengthening them.

2. Background

2.1 Extreme wind events

Situated on the edge of the North Atlantic Ocean, the islands of the United Kingdom experience storm force winds with gust speeds of 30 – 40 m/s occurring several times each season. Major storms can result in personal injuries and significant financial losses. In an average year 200,000 buildings are damaged by high winds, although the majority of insurance claims are for minor losses of ridge tiles on older properties. This was described by Blackmore (2003). The prevailing wind direction in the UK and Ireland is from the south west as frontal depressions track across the North Atlantic. Winds blowing from the north and east tend to be less severe and cause less building damage.

In recent years there have been several significant wind events where recorded wind speeds in isolated locations have been greater than could be expected to occur once in fifty years. If these events were to recur then our basic wind speed maps may need to be revised. However, at present no plans have been published to update the relevant standards.

It is understood that the increase in extreme wind events is related to changes in the paths of the jet stream, with broader meander patterns and increased velocities. Various explanations for these changes have been offered, although at present there does not appear to be a broad consensus. There is uncertainty in the longer term forecasting of weather patterns and predicting maximum wind speed data for future building design. What is predicted with a high degree of confidence is that more extreme weather events will occur.

2.2 Roof attachment strength

Wind suction forces acting on the outer weathering skin of a roof are transferred from layer to layer down through the roof construction into the structural framework. Each connection transfers the upward load to the next layer down. A useful analogy is that of a chain anchoring the upper weathering skin down to the support structure. If one link in the chain were to break, then potentially the outer sheets can become detached from the roof. As part of routine design calculations should be prepared to estimate the design wind suction loads acting on the different links in the chain and then compared with the characteristic strength of the fasteners to determine their factors of safety.

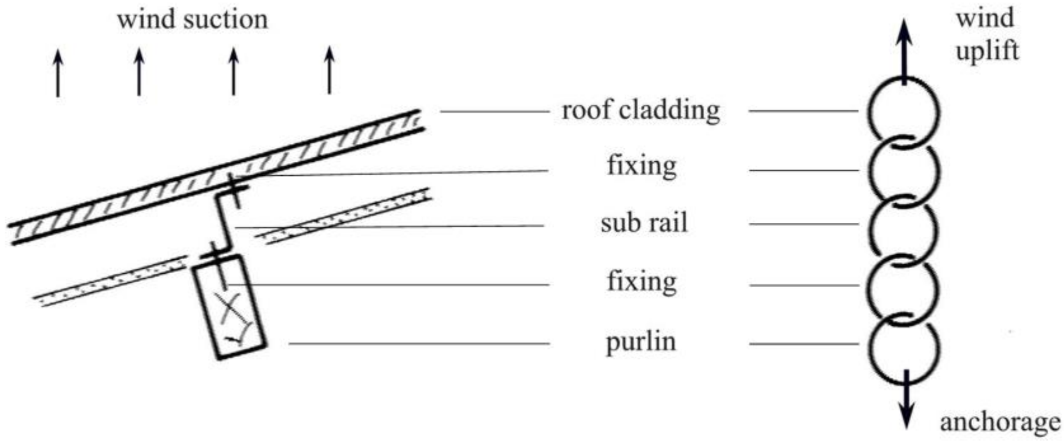

Figure 1: The chain analogy for the attachment strength of a multi-layer roof system

A protocol for the assessment of wind damaged roofs in North America is described by Smith (2013). Within the UK a permissible stress approach is still used for checking the attachment strength of a profiled metal roof, as described in BS 5427 (1996). The design wind pressures acting on the roof are calculated in accordance with BS EN 1991 Part 1.4 (2004). The permissible strength of the roof assembly needs to be greater than the applied pressure.

$$\mathbf{w} < \frac{\mathbf{f}}{\boldsymbol{\gamma}}$$

where: w = design wind load
f = characteristic strength
γ = factor of safety

The minimum factors of safety used in the UK for checking the attachment strength of profiled metal and single ply membrane roof fasteners, are 2.0 for pull-out from steel or aluminium, 3.0 for pull-out from timber and 4.0 for pull-out from masonry or concrete.

From the calculations for the roof assembly the greater the factor of safety, the greater the resilience of the roof.

3. Wind damage investigations

3.1 Case study A: standing seam roof

On New Year's Day 2005 a strong gale blew across southern Ireland resulting in an extensive area of lightweight aluminium standing seam roofing becoming detached from the windward verge and causing significant consequential impact damage to roof cladding and rooflights downwind. The aquatic centre and adjacent gym were evacuated safely without injury to members of the public or staff.

Location	Dublin, Ireland
Building use	Aquatic centre
Altitude, site exposure, topography	+74 m severe, rural
Roof area	5,700 m^2
Roof slope	Barrel vault 62 m wide, slope up to 20º
Roof type	Aluminium standing seam
Roof sub structure	Halters fixed to top hat rails, to saddles, through liner into purlins
Basic wind speed (hourly mean)	23 m/s
Recorded peak speed (hourly mean)	14 m/s
Design wind suction pressure in damage zone	-2.0 kN/m^2 ↑
Extent of detachment	300 m^2 of standing seam 60 m of parapet capping
Estimated financial loss	£10 million

Table 2: Basic data for Case A

An investigation was commissioned to examine the evidence relating to the wind damage and to identify probable causation. The instructions were received three months after the wind event such that on arrival on site much of the original roof construction and initial damage had been disturbed. Consequently the colour photographs taken immediately after the storm became a vital record. The site inspection confirmed the as-built arrangement of the roof assembly and the details of the fasteners used.

Figure 2: Detachment of aluminium standing seam roofing from windward verge

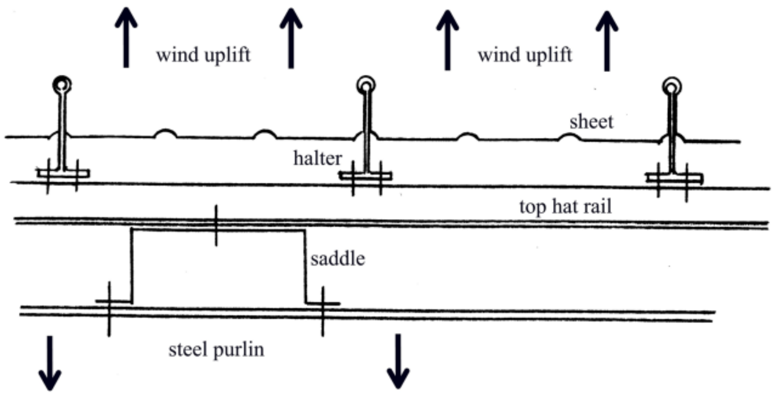

Figure 3: Roof assembly

The wind damage photographs showed that there had been a detachment between the steel top hat rail and the aluminium saddle at 900 mm centres. In addition there was upward distortion in the wide top plate of the saddle. Calculations were prepared to check the strength at each of the connections and the conclusions are summarized in Table 2 below.

<table>
<tr><th>Element</th><th>Material</th><th>Design wind pressure kN/m²</th><th>Area loaded m²</th><th>Number fasteners no.</th><th>Load / fastener w kN</th><th>Fastener strength f kN</th><th>Factor of safety γ</th><th>Satisfactory?</th></tr>
<tr><td>standing seam</td><td>0.9 mm aluminium</td><td rowspan="2">-2.0 ↑</td><td rowspan="2">-</td><td rowspan="2">-</td><td rowspan="2">-</td><td rowspan="2">-5.0 kN/m</td><td rowspan="2">2.5</td><td rowspan="2">✓</td></tr>
<tr><td rowspan="2">halter</td><td rowspan="2">aluminium</td></tr>
<tr><td rowspan="2">-2.0 ↑</td><td rowspan="2">0.64</td><td rowspan="2">2</td><td rowspan="2">0.64</td><td rowspan="2">3.35</td><td rowspan="2">5.2</td><td rowspan="2">✓</td></tr>
<tr><td rowspan="2">top hat rail</td><td rowspan="2">1.25 mm galvanised steel</td></tr>
<tr><td rowspan="2">-2.0 ↑</td><td rowspan="2">1.89</td><td rowspan="2">2</td><td rowspan="2">1.89</td><td rowspan="2">2.1</td><td rowspan="2">1.1</td><td rowspan="2">X</td></tr>
<tr><td rowspan="2">saddle</td><td rowspan="2">2.0 mm aluminium</td></tr>
<tr><td rowspan="2">-2.0 ↑</td><td rowspan="2">1.89</td><td rowspan="2">4</td><td rowspan="2">0.95</td><td rowspan="2">18</td><td rowspan="2">19</td><td rowspan="2">✓</td></tr>
<tr><td>purlin</td><td>10 mm steel flange</td></tr>
</table>

Table 2: Summary of factors of safety for the Competition Pool roof assembly

The calculations found that the local bending stress in the crown of the aluminium saddle was excessive and that the factor of safety against the top hat rail to saddle fixing pulling out was 1.1, significantly less than the recommended minimum of 2.0. This is the same weakest link as observed in the photos of wind damage.

The adjacent verge cappings also became detached in the storm and their means of attachment was closely examined. The aluminium capping had been held in place with rivets which had pulled through. The spacing of the rivet holes through the supporting cladding rail was measured and the distances found to be greater than the recommended 450 mm. This was a further weakness in the roof assembly.

The original roofing contractor undertook to replace the area of detached roofing, to make good the downwind isolated impact damage, and to strengthen the top hat rail to saddle and purlin connection by installing additional long screw fixings through the top hat rail directly into the steel purlin below. This repair scheme had a number of disadvantages, including puncturing the vapour control layer, although those advising the building owners considered the future condensation risks to be acceptable.

3.2 Case study B: single ply membrane roof

On 28th September 2013, St Jude's Day, a fast moving vigorous Atlantic depression brought very strong winds and heavy rain to south east England with winds gusting up to 36 m/s. One modern building that suffered wind damage was a hotel in Chelmsford, to the north east of London. Lengths of roof edging and single ply membrane roofing became detached from the western side of the second floor roof and peeled back, resulting in debris falling to ground level. This led to the closure of the public highway immediately to the east of the building for a period of several days.

Location	Chelmsford, England
Building use	Hotel
Altitude, site exposure, topography	+25 m, sheltered, urban
Roof area	2,000 m^2
Roof slope	Flat
Roof type	Single ply membrane, adhered
Roof sub structure	Mineral wool thermal insulation, screw fixed through vapour control layer into steel deck
Basic wind speed (hourly mean)	22 m/s
Recorded peak speed (hourly mean)	18 m/s
Design wind suction pressure in damage zone	-1.8 kN/m^2 ↑
Extent of detachment	200 m^2 of single ply membrane roofing and roof edges
Estimated financial loss	£1 million

Table 3: Basic data for Case B

An independent investigation of the roof was commissioned two months after the storm to inspect the evidence of damage, to identify causation and to advise on remedial works to remaining roofs. The roof system comprised of a single ply membrane that was adhered to a tissue faced mineral fibre insulation board, which in turn was screw fixed through the vapour control layer into a galvanized steel deck.

Figure 4: Roof membrane rolled back from western edge

At the time of the inspection temporary remedial works had been completed to enable the hotel to re-open. Much of the debris had been removed from site by the repair contractor and fortunately had been kept for examination in his local yard. The samples were closely examined to reveal an inadequate thickness and spacing of the adhesive bonding. Samples of the mineral wool insulation showed that the top tissue facing readily detached from the fibrous core and was not the specified insulation board with a 'single ply adhered facing'. The wrong product had been supplied which had not been identified by the roofing contractor, the supplier or the other surveyors initially inspecting the wind damage.

The wind damage photos also showed that the roof edge became detached. A short parapet had been constructed using two channel sections with an internal metal stud and no fixings joining the channels together. Under wind uplift pressure the capping and support could lift upwards. From this it was possible to determine the probable sequence of detachment along the western edge of the central roof in which a zed section flashing rotated upwards, increasing the wind uplift pressure acting on the underside of the flashing and entering the upstand detail. This in turn caused the perimeter channel and studs to lift upwards, causing the single ply membrane to peel back readily with the lack of adhesive restraint.

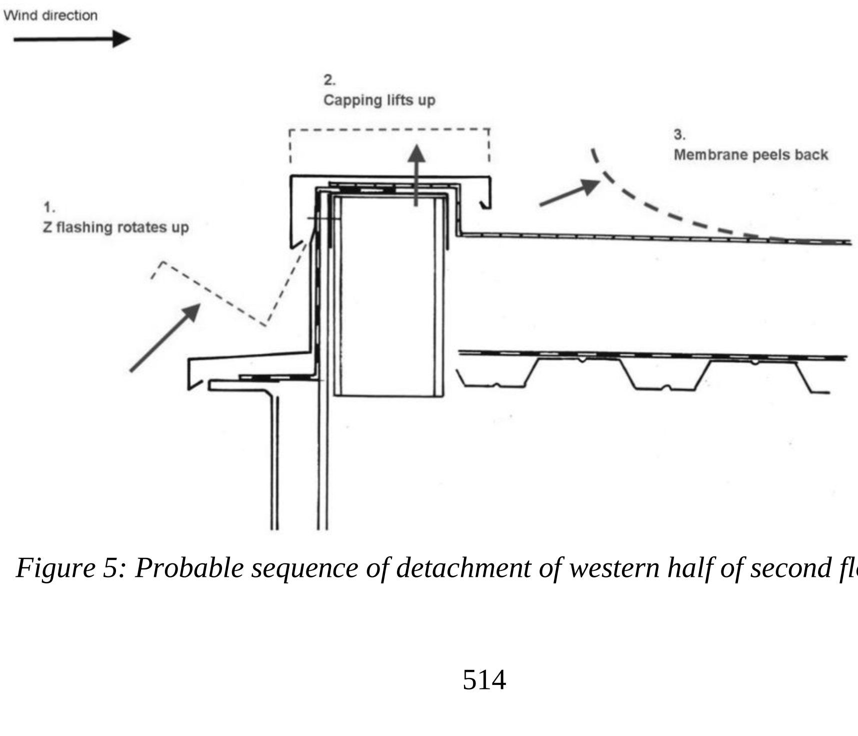

Figure 5: Probable sequence of detachment of western half of second floor roof

Within a month of the initial inspection the second floor roof was fully replaced with a new mechanically attached single ply membrane system. The third and fourth floor roofs were investigated and found to be of a similar construction, with areas of de-bonded single ply membrane adjacent to the western edge. It was recommended that a new mechanically fixed single ply membrane should be laid over the existing with a new secure perimeter detail developed. There were delays in carrying out this work during which the extent of the delaminated zone increased over a six month period, ultimately resulting in extensive ruckling. This evidence of further progressive damage persuaded the parties to mechanically fasten and overlay the third and fourth floor roofs, with works satisfactorily completed in the summer of 2014.

4. Conclusions

Identifying probable causation is rarely straightforward, often with multiple failures requiring an answer to the question 'what failed first?' A methodical approach is needed in gathering and recording the evidence of wind damage, in undertaking the desk study and then producing the factual report.

There is a need to learn from experience and to avoid repeating mistakes. In February 2014 the roof of another aquatic centre in southern Ireland blew off, suffering the same mode of failure as the aquatic centre in Dublin a decade before. The lessons from previous investigations had not been shared within the roofing community.

In the UK the Standing Committee on Structural Safety has established a scheme to improve structural safety and reduce failures by using confidential reports to highlight lessons that have been learnt, to generate feedback and to influence change.

It is hoped that by sharing feedback from wind damage reports in an independent and constructive way we can improve our common understanding of failure mechanisms, enabling us to design and build more reliable building envelopes that are better able to withstand the extremes of changing weather patterns in whichever country we practice.

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A New Demountable Seismic-Resistant Joint to Improve Industrial Building Reparability

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Abstract

In seismic-prone areas, post-event operability for steel warehouses can be considered an important issue for economic and social continuity during the recovery phase. Structures surviving strong earthquakes - even if designed with minimal probability of collapse - might suffer so much damage, that their repair costs would be prohibitive. Strategies for limiting the building's damaged zones to specific parts (or "fuses") can significantly reduce repair costs. However, the replaceable part is limited to a small portion of the structure, whereas the rest cannot be disassembled in a non-destructive way. This is an issue for steel warehouses, as their life span is more likely dependent on economics and technology rather than on their actual structural performance. From a sustainable design standpoint, making steel warehouses easily disassembled would be cognizant of their environmental footprint, not only in seismic areas but also in any industrialized area The aim of this paper is to explore the Design for Disassembly (DfD) approach to complement seismic design and to find a compromise between these two rather opposite approaches. Due to the complexity of this problem, one single type of structures was analysed (the moment resisting frame), focusing on the design of a seismic-resistant steel connection, capable of being deconstructed in a reversible way. The design process involved several design iterations until an “optimum” compromise between seismic design and DfD was met. It is worth noting that the assessment criteria for seismic design and DfD were different: the former required the compliance with building codes for each connection components; the latter implied to create new criteria, which had to be as accountable as possible. The results of this study show that a compromise between seismic design and DfD is possible. In this specific case, the compromise was achieved at the expenses of more complex design calculations and a number of components larger than that used in standard connections. However, this would be compensated for by a higher residual value for the entire structure. Moreover, this study has proved that a metric for assessing DfD steel connections is possible, but further structural analyses are needed to validate it.

Keywords: design for disassembly, sustainable structural design, reuse of steel structures

1. Introduction

Sustainable design as a research topic involves a wide range of disciplines. Since the development of one of its most commonly accepted definitions - in the “Brundtland Report” in 1987 – research on sustainable has increased significantly and expanded from general areas (i.e. construction sector) to specific fields (i.e. structural design). Studies aimed at investigating the impact of structural systems independently from the rest of the building (Cole and Kernan, 1996) stimulated research on sustainable design of structural systems – the so-called “Sustainable Structural Design” or “SSD.” Research papers pointing out the importance of teaching sustainability in Engineering Schools (Maydl, 2004 and Ochsendorf, 2005) raised attention on the responsibilities of civil engineers towards the environment, economy, and society.

Most of the discussions on SSD involve proper selection and usage of structural materials, as their extraction, manufacturing process and erection can be very carbon and energy intensive. Moreover, growing concerns about the depletion of raw materials (e.g. stone, iron, and bauxite), as well as construction and demolition waste management issues, encouraged researchers to develop SSD strategies. Some of them include “Minimizing Material Use, Minimizing Material Production Energy, Minimizing Embodied Energy, Life-Cycle Analysis/Inventory/ Assessment, and Maximizing Structural Systems Reuse” (Danatzko and Sezen, 2011).

Research projects carried out in countries using large quantities of structural steel (e.g. the United Kingdom) attempted to develop strategies for making the use of steel “greener.” The “Wellmet2050” project, carried out at the Cambridge University, identified four main themes to reduce the steel carbon footprint: “Reuse without melting”, “Less metal, same service”, “Longer, more intense metal use”, and “Supply chain compression” (Allwood et al, 2012). All these strategies aim allow reducing the use of new steel or the energy required to produce it. This translates into structural engineering design practises including the reuse of existing steel (without re-melting it), the optimization of steel profiles in order to use less steel, and the extension of steel structures’ design life by designing structures for future reuse. This paper focuses on this last strategy – also called “Design for Disassembly” or “DfD” – whose main benefit is to overcome the limits of traditional demolition, by obtaining valuable salvaged structural materials instead of scrap or debris (Crowther, 1999). This can be possible by considering a building structure as a kit of components and planning upfront all its assembly and disassembly steps.

Through a set of reversible operations, DfD can also facilitate the substitution or repair of damaged structural profiles. This feature simplifies not only regular retrofit operations but also a structure’s repair after hazardous events. In fact, if structural components are designed properly, those being damaged can be easily disconnected and repaired or substituted. This is a relevant benefit especially for buildings of “normal importance” such as steel warehouses. Yet, even if these structures are designed to withstand strong earthquakes with minimal probability of collapse, they usually suffer a high level of damage and, far too often, repair costs are so prohibitive that demolition is preferred. By reducing repair costs and facilitating the substitution of damaged components, DfD can provide a faster recovery from hazardous events.

Despite its great potential in achieving sustainable and resilient structures, DfD tends to be in conflict with current seismic-design practices, especially as far as concerns the design of connections. In fact, seismic-resistant connections can be barely disconnected in a reversible way, as they usually employ a large amount of connectors to provide adequate strength and stiffness. This practice is at odds with any reuse strategy.

The goal of this work is find a compromise between current seismic design practises and DfD, in order to ensure both post-earthquake reparability and ordinary deconstruction for industrial building. This work will focus on the critical aspect of connections design, with the following goals: a) to design a connection fulfilling both requisites for seismic resistance and deconstruction; b) to develop DfD criteria to assess if the goal is met.

2. Methodology

The design of a DfD seismic-resistant connection is a complex task, as it involves two quite distinct processes: a) the design of a steel connection for disassembly and b) the design of a seismic-resistant steel connection. Process a) is not supported by building codes but its achievement is rather predictable. In fact, construction experience shows what practices should be avoided and which ones should be reduced as much as possible. Conversely, process b) is regulated by codes, but its achievement needs to be proved by numeric analyses and testing. Besides being rather different, processes a) and b) tend to be in conflict, as mentioned in the Introduction.

In order to find a compromise between them, the connection design has been split into two phases. The first phase consisted in the conceptual design of a connection meeting both seismic and DfD goals and in the definition of criteria for a DfD steel connection. The second phase entailed the engineering design and the connection characterization, in order to provide the moment-rotation curves associated with the connection connecting a specific range of profiles. The first phase was carried out at The Catholic University of America and is the object of this paper, while the second phase is still on going.

More in detail, Phase 1) comprised a review of existing steel connection (paragraph 3), a selection of a structural layout in order to define the size of the profiles to connect (paragraph 4), and the actual design. This last phase consisted into two iterative processes, which started in parallel: on the one hand, the definition of criteria for DfD steel connections, and, on the other hand, the design of a connection meeting both these criteria and structural requirements.

Criteria for DfD were initially drafted based on the literature on DfD; these criteria were then refined through a survey (paragraph 5) to a group of "experts" (structural engineers with an expertise on DfD), where they were asked to evaluate some design concepts with these criteria. Eventually, experts were asked to grade and rank those criteria The outcome of this process led to the definition of general criteria to guide the following design iterations and of quantitative criteria for a final design evaluation. After many design-feedback iterations (paragraph 6), a final version of the "pre-design" roughly meeting structural requirements and DfD criteria was developed (paragraph 7) and eventually compared to existing seismic-resisting steel connections on the basis of such those quantitative criteria (paragraph 8).

3. Review of existing steel connections

A review of several steel connections (both traditional and innovative) helped identify the main features of DfD steel connections and seismic-resistant steel connections. The following sub-paragraphs will summarize this review, focusing on beam-to-column connections.

3.1 Traditional steel connections

Generally speaking, steel connections can be located either at the nodes of a structure or along structural members; depending on their structural behaviour, they can be simple, rigid, or semi-rigid; lastly, they can use welds and/or bolts. These very basic features do affect the disassembly potential of connections. In fact, connections placed at structural nodes can make the disassembly process complex, as their removal might compromise the structural stability. Simple connections are usually easier to disconnect than rigid or semi-rigid connections because they employ fewer connectors. Last, but not least, bolted connections can be removed in a reversible way, that is, without destructive operations. On the contrary, welded connections need to be destroyed, for instance by torch cutting. Figure 1 shows some of the most common types of beam-to-column steel connections.

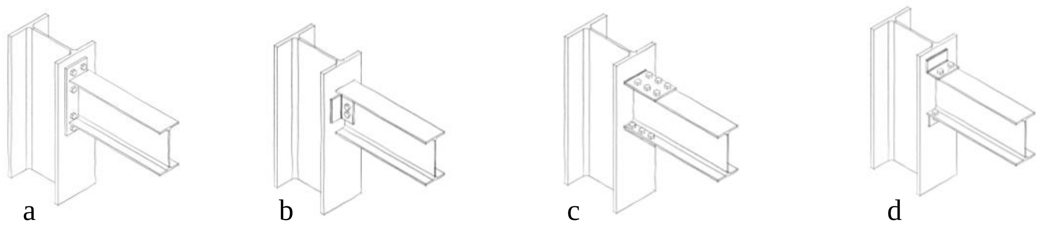

Figure 1: Traditional beam-to-column steel connections: a) extended end plate; b) double angle; c) flange plate; and d) seat connections).

Depending on their assets, steel connections require different degrees of accuracy for their assembly and disassembly processes. For example, being a field-bolted connection, the end plate connection needs that pre-drilled holes on the end plate match perfectly those on the column flange. Other connections, i.e. a double angle connection, may determine assembly issues such as the “knifing” of a beam, that is, the beam coping is needed to lower a beam into place. Eventually, connections, such as a flange plate connection, require tolerances, as a beam needs to fit the distance between the two plates that are shop-welded to a column flange. From a structural standpoint, both an end plate connection (in their extended version only) and a flange plate connection are moment resisting, while double angle and seat connections are can resist shear only.

3.2 DfD steel connections

DfD steel connections employ innovative technologies to facilitate both the assembly and the disassembly processes, in order to increase structural members’ reusability. Figure 2 shows three examples of DfD steel connections. Information on them has been taken from Cooper (2010) and relevant websites (see References).

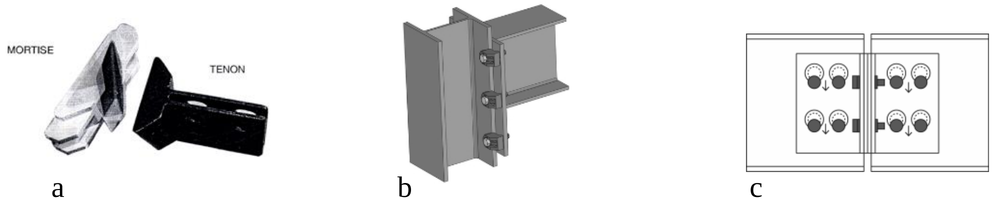

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Figure 2: DfD steel connections: a) ATLSS; b) LINDAPTER; and c) QUICON connections.

The ATLSS Connection (Lehigh University) comprises two cast pieces shaped to match each other: a tenon – both bolted and welded to the end of a beam - and a mortise welded to a column. In the erection process, the tenon is lowered into place and bolted with one bolt only. A limitation of this connection consists in the fact that shaped cast pieces are barely detachable from structural members and too non-standard to be reused in other structures.

Lindapter (Lindapter GmbH) beam-to-column connection employs "High Slip Resistance Clamps" to keep elements connected. Relying on friction only, this system avoids drilling holes in structural members, thereby maximizing their reusability. However, its moment-resisting application requires welding an endplate and a stiffener to a beam, so that the reuse benefits are limited to columns.

Quicon (Steel Construction Institute) comprises T-stub shop-bolted to a column's flange with k-holes slots on their other free terminal. Shoulders bolts pre-attached to a beam's web are lowered easily in the holes and tightened. This system allow speeding up the assembly process. Boltholes in structural members are the main barrier to reuse. Because of their structural weaknesses, all these connections are currently unsuitable for seismic applications.

3.3 Seismic-resistant steel connections

Seismic-resistant connections are designed to guarantee adequate strength and ductility in the case of seismic events. Some of them dissipate energy through specific components - called "fuses" - that are replaceable. Figure 3 shows three examples of seismic resistant steel connections. Information them has been taken from Cordova (2011) and relevant websites (see References).

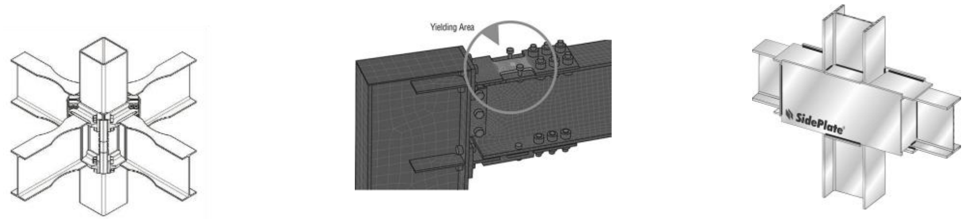

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Figure 3: Seismic-resistant steel connections: a) ConXL; b) Strong Frame Yield-Link; and c) SidePlate connections.

ConXtech's ConXL moment connection (ConXtech Space Frame Systems of Hayward) comprises a column's and a beam's "collar" with tapered terminals that should facilitate the erection process. Both the collars are shop-welded to structural members and mutually field bolted. Collars are expected to exhibit minimal yielding, while the Reduced Beam Sections (RBS) to lead to the formation of flexural hinging. From a DfD standpoint, this system presents some disadvantages, including a large number of bolts, which makes the disassembly operations long, the tapered terminals that limit structural members' reusability, and the possibility of using a single type of columns (HSS columns). Moreover, in the case of a fuse replacement, the entire beam should be removed.

Strong Frame Yield-Link™ (Simpson Strong-Tie Company Inc.) is entirely field-bolted. Its reduced-section plate, placed on a beam's top flange, is expected to dissipate energy during an earthquake and is designed to be replaceable. Despite its flexibility, this system uses a large number of bolts, which make it less reusable.

Sideplate (SidePlate) comprises a welded connection, with horizontal shear plates shop-welded to column flanges. The beam is lowered between the plates and welded to them. This solution avoids the formation of a plastic hinge at the beam-to-column interface by physically separating a beam end from a column face; however, its fuse is barely replaceable and its welds are almost impossible to detach.

4. Structural layout selection

Structural pre-requisites for a connection depend on the structural layout and structural elements connected. The moment resisting frame (MRF) was selected among those suggested by the Eurocode 8 because it has an inherent DfD potential. In fact, its lack of vertical bracings confers a great floor plan flexibility. This allows focusing on the connection issue.

Some important issues to consider in MRF connections design are: a) columns shall be stronger than their adjacent beams, so that the beam fails before the column; b) beam-to-column connections shall be moment-resting to guarantee structural stability; c) the connection must not fail, therefore the connection's shear and moment capacities shall be higher than the beam's shear and moment capacities; d) the seismic "fuse" shall be located as far as possible from the column, so that the risk of column failure is avoided.

The steel profiles to be connected were sized on the basis of common spans and widths for one-story one-bay steel industrial buildings (determined from previous research works): an IPE 300 section for the beam and a HEA 400 section for the column.

5. Surveys

In order to find a trade-off between structural prerequisites and DfD, a priority among DfD criteria should be determined. Criteria for DfD were initially listed based on the review of steel connections; then, these criteria underwent an examination from a group of "experts" (civil engineers/architects with an expertise on DfD), in the form of a semi-structured survey. This survey consisted in three sections: 1) an introduction; 2) a presentation of three connections designs, which the group of experts should evaluate on the basis of the listed DfD criteria; and 3) a section in which experts were asked to rank the importance of these criteria, by means of a “Likert Scale” (from Strongly Agree to Strongly Disagree).

Since the survey was an online-survey expected to take a limited amount of time, criteria for DfD were kept under the limit of seven criteria: 1) “Reduce the number of bolts” (with respect of traditional connections): the smaller the number of bolts to unbolt, the faster the disassembly process is; 2) “Use the same type of bolts”: the fewer the disassembly tools, the faster the disassembly process is; 3) “Adaptability of different structural members”: the more adaptable, the more reusable the connection is; 4) “Reduce the holes in the structural members”, increasing their reusability (too many holes require patching the holes – when not cutting off the bolted part); 5) “Ease of access for the disassembly operation” (a non-accessible connection cannot be disconnected at all); 6) “Reversibility”, so that the disassembly produces no or limited damage; 7) “Ease of assembly” (so that DfD and assembly are not in conflict). These criteria served to evaluate three design concepts (Figure 4) in terms of reusability and disassembly potential with respect to common beam-to-column moment resisting connection. It is worth noting that one inherent limit of this evaluation is the fact that there is no unique understanding of what a common moment resisting beam-to-column connection is; yet, the evaluation was deemed reliable purely on the basis of an the experts’ personal judgement.

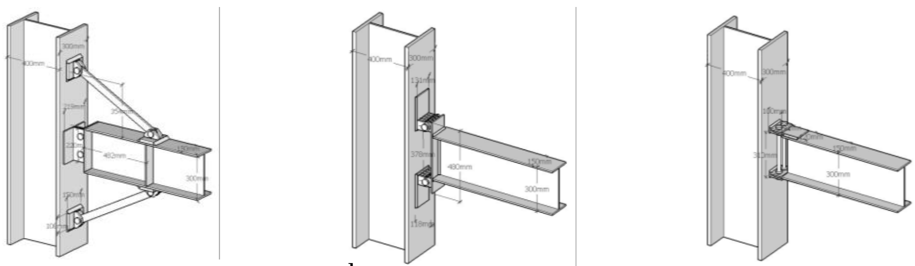

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Figure 4: Preliminary design concepts (design idea #1: diagonals; design idea #2: many shear plates few bolts; design idea #3: two long bolts)

In about one month, six experts took the survey providing an evaluation of both the design and of the DfD criteria. These surveys had two main outcomes: design idea #1 (Figure 4, on the left) turned out to be the best one under all the criteria; a general agreement on the criteria raking was not found, and this led to the conclusion that criteria should be refined so that they could be used as transparent tool.

6. Design iterations

Surprisingly, the most useful part of the survey was the section in which experts were asked to give an open feedback on the design. This helped identify design ideas strengths and weaknesses and guided following design iterations. Some of the interviewed experts offered to keep on providing feedbacks on new design ideas. Interestingly, DfD goals for the connection emerged naturally from this iterative process and can be summarized as follows: to avoid welds, to reduce bolts, and to be adaptable to different steel profiles.

7. Final design

The design process stopped when, in proximity of the end of the time available, the overall goal of avoiding welds and holes in structural members was met. Even if this paragraph is called “final” design, the design process did not stop there. During the second phase of this work, the design changed, even if these changes are not addressed in this paper. At the end of first phase, the connection incorporated some of the ideas developed at the very beginning of the conceptual design process: a) the use of clamps to avoid bolts and welds in structural members; b) the use of external connectors; and c) the increase of the number of section planes to reduce the amount of bolts. Among the three design concepts, the connection layout resembles design idea #1 the most: two diagonals deliver bending moment to a column, while a “shear tab” bears the gravity loads.

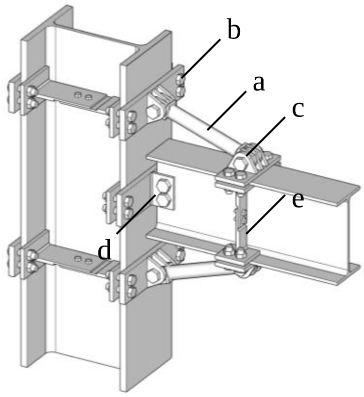

Figure 5: Final design

All the connection components were sized according to Eurocode 3 and 8. More in detail, these components are: a) two diagonals; b) slip-critical clamps; c) pins; d) a shear tab; and e) continuity plates. The diagonals serve to increase the moment arm, in order to reduce the entity of the horizontal forces applied to structural elements. The diagonals are also conceived as replaceable “fuses”. Therefore, they are designed with a lower steel grade (S235) than the rest of the structure (S275) so that they reach their yielding point before. The diagonals’ cross section is a tubular with a great thickness in order to impede buckling phenomena. The clamps serve to avoid boltholes and welds on structural members. High strength slip-critical bolts are used for this purpose. The condition upon which the clamps work properly is that the steel plates do not bend. To ensure it, steel plates are thick and stiffened by the steel plates forming the pins. The pins connect the clamps to the diagonals; they consist in a row of shaped plates that increase the number of shear planes, thus reducing the overall number of bolts. The “shear tab” is clamped to the column and bolted to the beam. These two boltholes at the beam end were considered an acceptable compromise, considering the fact that the beam web might have to accommodate another shear tab in future re-uses. The continuity plates are welded to the clamping plates and are secured through slotted holes. They are used instead of stiffeners - which are usually welded to the beam's and column's webs - and are meant to receive a portion of the vertical load off the beam's web.

8. Discussions

The main challenge for this design was to keep all the bolts and the welds of connection outside the structural members (with the exception of two boltholes on the beam web). This translates into two major benefits: the acceleration of both the assembly and the disassembly processes and a high degree of reparability/flexibility/reusability. Figure 6 synthetizes the first advantage: since most of the construction processes are carried out off-site, the erection can be faster and more accurate.

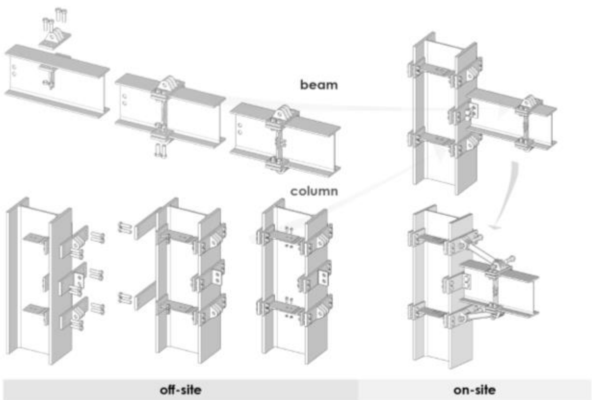

Figure 6: Construction operations

Figure 7 shows the second advantage. The substitution of damaged diagonals requires unbolting four bolts only. A minor change in the configuration requires unbolting more bolts but should be a very reversible process. If the entire system were disconnected, steel profiles would be easily reusable. Two other interesting advantages for this connection are its applicability to a variety of building structures (not only the industrial ones) and its potential for being a retrofit measure: the diagonals and the clamp system can be inserted in any existing connection to improve its moment capacity in a reversible way.

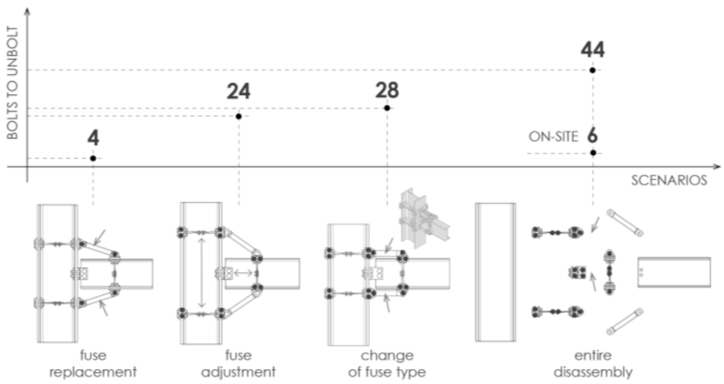

Figure 7: Reuse scenarios

Despite these relevant benefits, this design presents some issues. First, this connection is overall more complex than most of the other existing connections and employs more material. Secondly, this connection is likely a semi-rigid connection rather than a rigid connection, which puts some restriction to its use. However, all these drawbacks can be compensated for by a high residual value for steel profiles at a structure's end-of-life.

In order to evaluate if the goal of designing a seismic-resistant connection with a higher disassembly potentials than the existing ones, a new set of DfD criteria was developed. These criteria are an improvement of those used in the surveys, are accountable and fewer (four criteria), making the evaluation simple. Figure 8 shows a comparison between the design and two existing seismic-resistant steel connections, based on new DfD criteria: number of bolts to be assembled or disassembled on-site; number of holes in the structural members; length of welds in the structural members; ability of replacing the seismic fuses.

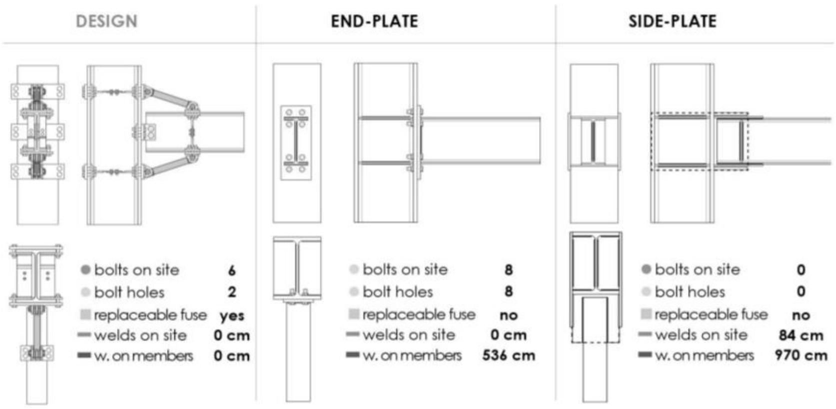

Figure 8: Comparison with a traditional and an innovative seismic-resisting connection

The existing connections were assumed to have the same capacity of the design connection and their capacity values were taken from the following literature: Ardeshir and Ashraf (2004) provided values for the end plate connection, while Dessouki et al (2013) for the side plate connection. It is worth noting, though, that the real capacity for the design connection was not determined yet and its design value was taken as the value of the connection capacity. As one can see from Figure 8, the design and the end plate connection have a similar number of bolts to be bolted (or unbolted on-site). However, the design entails a higher degree of reusability for the structural members because it is weld-free, has two bolts only and a replaceable fuse. Conversely, both the end plate and the side plate connections turn to be not as easily reparable (their "fuses" cannot not be easily replaced), reusable (either too many boltholes or too many welds) and reversible (the welds cannot be removed in a reversible way).

9. Conclusions

The results of this investigation show that, despite their evident conflict, seismic design and DfD can be combined to reach innovative solution. In this case, the compromise of having a DfD seismic-resistant connection implied complex design calculations and many connection components. However, this would be compensated for by a high residual value for the steel members, a potential waste reduction, and energy savings. This study has also demonstrated that it is possible to develop a metric for assessing DfD steel connections, but further structural analyses are needed to validate it. In fact, in order to compare the DfD potential of two connections it is necessary to know their real structural performances. This part is currently on going will be presented in future research papers.

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The Experimental Behavior of CFRP-Strengthened Reinforced Concrete Slabs with Fire Protection Systems Subjected to Standard Fire Exposure

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Abstract

Fire resistance of CFRP (carbon fiber reinforced polymer) strengthened concrete slab systems were evaluated in two forms of unprotected and protected against fire. In order to achieve this objective, an unstrengthened and two CFRP strengthened concrete slab (totally 3 specimens) were firstly subjected to increasing gravity loading until failure. The test results revealed that CFRP strips bonded to concrete slabs increased the load-bearing capacity considerably. So, this method can be suitable for flexural strengthening of concrete slabs. Subsequently, the unstrengthened concrete slab was placed on a furnace and was subjected to a constant service gravity load and then, the temperature of the furnace was increased according to a standard temperature-time curve until the failure of the slab occurred. This concrete slab was strengthened by CFRP with two different amounts and then, in two cases of unprotected and protected against fire (two different thicknesses) were tested with aforementioned method (totally 4 specimens). The results showed that because of more load-bearing capacity and subsequently increase in service gravity load, the strengthened concrete slab failed in a short time due to the lack of CFRP resistance against the fire. By contrast, the protected specimens resisted the fire in a considerable time. In addition, it was revealed that details of fire protective coating had an important effect on fire resistance duration and in flat large surfaces with thick fire insulation, the use of reinforcing mesh must be considered.

Keywords: reinforced concrete slab, strengthening, FRP, fire protective coating, fire resistance

1. Introduction

Fiber reinforced polymers (FRPs) are mainly used in civil engineering because of their advantages such as high resistance, light weight, and resistance against corrosion compared to available materials. Carbon fiber reinforced polymer (CFRP) strips are composite materials that currently used as external strengthening bonded to reinforced concrete members with epoxy resins (Hollaway 2010).

Although CFRP system has considerable advantages in concrete buildings, there are concerns about its behavior in high temperatures. In fact, the stiffness and resistance of FRP greatly decrease in relatively low temperatures (Dodds et al. 2000; Correia et al. 2013), i.e. when temperature reaches glass transition temperature (T_g) of polymer matrix that usually lies between 55 to 120 °C. Also, the bond strength between CFRP and concrete which is necessary for the effectiveness of the strengthening system is severely reduced in temperatures higher than T_g. Some researchers have showed that the bond strength between CFRP and concrete rapidly decreases, if the temperature of the epoxy resin increases to more than about 60-70 °C (Gamage et al. 2006; Leone et al. 2009; Ahmed and Kodur 2011a).

Fire resistance tests performed on CFRP strengthened reinforced concrete beams (Williams et al. 2008; Ahmed and Kodur 2011b; Palmieri et al. 2012), slabs (Williams et al. 2006; Lopez et al. 2013), and columns (Bisby et al. 2005; Chowdhury et al. 2007) revealed that when temperature of epoxy resin reaches T_g, composite action between CFRP and concrete will be weakened.

External strengthening using FRP composites are performed in various structural reinforced concrete members. Generally, external strengthening system with FRP sheets is used for three main objectives of flexural strengthening, shear strengthening, and confinement and increase in ductility of compressive members. Considering the subject of this study, flexural strengthening of reinforced concrete slabs using CFRP strips was only investigated here. When CFRPs are used in buildings for the retrofitting of reinforced concrete (RC) slabs, FRP-strengthened RC slabs have to satisfy fire resistance requirements specified in building codes. Thus, conducting fire tests on FRP-strengthened RC slabs is necessary to generate fire endurance ratings and study the response of them under fire conditions. In addition, there was a lack of data on FRP-strengthened slabs protected with domestic fire insulation system used in this research project.

First of all, a reinforced concrete slab is designed and then it is strengthened by CFRP strips. Subsequently, the fire resistance of reference concrete slab, CFRP strengthened concrete slabs as well as CFRP strengthened concrete slabs and protected by fire protective coating will be evaluated in a furnace according to the standard test method.

It should be noted that in the present study, only external strengthening of concrete slabs by CFRP materials has been investigated and internal strengthening by elements such as FRP bars has not been taken into account. Selection of carbon fibers in strengthening of concrete slabs was due to their high ratio of resistance to weight and widespread use of them in strengthening of different concrete structures. On the other hand, it should be considered that the amount of creep in carbon fibers is very low in comparison with glass fibers and so, they are more suitable for strengthening of concrete slabs against gravity loads (Hollaway 2010).

Also in this research, mechanical properties of materials used in the concrete slabs such as compressive strength of concrete and tensile strength of steel bars were determined according to the standard test methods.

2. Experimental Program

2.1 Design of test Specimens

In order to examine the fire resistance of CFRP strengthened concrete slabs as well as the performance of fire protective coatings, a total of 8 concrete slabs were fabricated as shown in

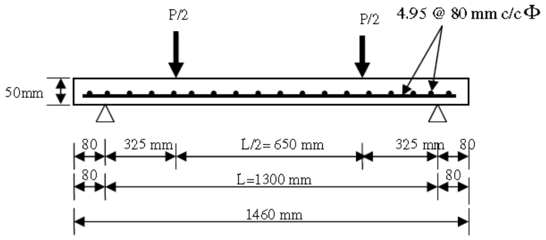
Table 1 at Road, Housing & Urban Development Research Center (BHRC). Test specimens were designed and made by considering the following parameters:

1. The effect of strengthening with CFRP; 2. Test temperature (room temperature as reference and exposure to furnace conditions for evaluation of fire resistance); 3. Width of strengthening strips; 4. Thickness of fire protective coatings.

Table 1: Specifications of test specimens

Row	Slab designation		Without strengthening	Strengthening with two one layer longitudinal CFRP strips		Without fire protective coating	With fire protective coating	
				30 cm width	15 cm width		2.6 cm thickness	1.6 cm thickness
1	Exposure to room conditions	CS-25	✔			✔		
2		FR1-25		✔		✔		
3		FR2-25			✔	✔		
4	Exposure to furnace conditions	CS-Fire	✔			✔		
5		FR1-Fire		✔		✔		
6		FR1-Fire-P1		✔			✔	
7		FR1-Fire-P2		✔				✔
8		FR2-Fire			✔	✔		

Because of existing dimensional limitations, the test specimens were scaled by scaling factor of one-quarter and fire resistance tests were performed in a one cube meter (1 m^3) furnace. Thickness, width, and length of these small-scale specimens were 5, 98, and 146 centimeters, respectively. Reinforced concrete slabs in two cases of unstrengthend and strengthened with GFRP, were designed as per ACI 318 (2011) and ACI 440 (2008) provisions. Test details including specimens dimensions, load places, and supports in two cases of unstrengthened and strengthened, are illustrated in Figures 1 and 2, respectively.



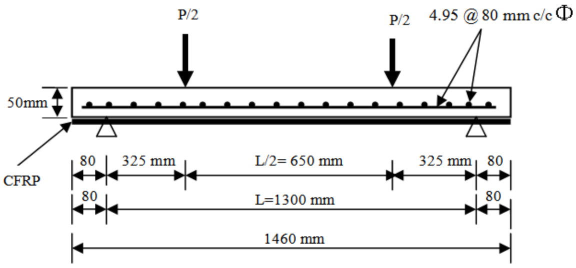


Figure 1: Geometrical properties of unstrengthened slabs and reinforcement details

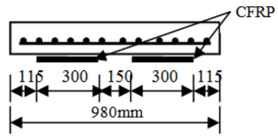


Figure 2: Geometrical properties of strengthened slabs with two one layer longitudinal 300 mm wide CFRP strips

As it is shown in these figures, the free length of flexural slabs is equal to 130 centimeters. As the specimens were scaled, tensile steel of the slabs was formed of a welded reinforcing bar mesh with a diameter of 4.95 millimeters and a distance of 8 centimeters from each other in both directions. For the case of unstrengthened concrete slabs, the section was low steel and so, the mode of flexural failure was ductile. In this case, firstly steel begins to yield and then, crushing of concrete in compression zone occurs. Also, for the case of CFRP strengthened concrete slabs, the amount of CFRP was selected in a manner to achieve tensile yielding of steel in flexure which is desirable and ductile. Namely, the tensile steel is yielded at the first time and then, crushing of concrete in compression zone happens before the rupture of CFRP strips.

2.2 Materials

2.2.1 Concrete

In order to make concrete for slabs, Portland cement type 1 and standard sands and gravels were utilized. Compressive strength of cylindrical concrete samples at 28 days age and on the day of the fire resistance test (6 months age) was 16 and 20 MPa, respectively. The mentioned data are the average of compressive strength of three samples for each time of test. The compressive strength of cylindrical samples was determined according to ASTM C 140 (2011).

2.2.2 Steel

With respect to scaling test specimens, welded wire mesh was used instead of reinforcing bars in concrete slabs. In order to determine mechanical characteristics of steel reinforcement used in construction of concrete slabs, one direction simple tensile test was performed on raw and welded steel wire samples according to ASTM A 370 (2011) and obtained results are given in Table 2. It is obvious that welding causes strain hardening, decrease in fracture strain, and increase in tensile and yield strength of the steel. Also, at the end of the tensile test of welded steel wires, it was observed that the fracture of samples did not occur at the welded locations.

Table 2: Mechanical properties of raw and welded steel wire samples

Sample	Wire type	Diameter (mm)	Yield strength (kg/cm^2)	Tensile strength (kg/cm^2)	Fracture strain (%)
1	raw	4.95	4158	5719	19
2	raw	4.95	4211	5823	18
1	welded	4.95	5700	6400	13.6
2	welded	4.95	5580	6800	12

2.2.3 CFRP

Carbon fibers together with epoxy resin were used to strengthen the concrete slabs. So, the composite material resulted from this mixture is a kind of CFRP composite which was applied for strengthening six reinforced concrete slabs. Geometrical and mechanical characteristics of this type of carbon fiber with commercial name of PANEX are presented in Table 3 based on specifications announced by the producer.

Table 3: Geometrical and mechanical properties of carbon fibers used in the study

Density (g/cm^3)	Thickness (mm)	Elastic modulus (GPa)	Tensile strength (MPa)	Elongation at break (%)
1.81	0.176	242	4127	1.5

2.2.4 Fire protective coating

The surface exposed to fire (bottom surface) of two slabs was protected by sprayed fire protective coating from type of gypsum-vermiculite (Vermifire-G) with two nominal thicknesses of 15 and 25 mm. After spray and when coating became dry, thickness in different locations were measured and actual values were 16±2 mm and 26±2 mm for two cases. Also, measured average density was 600 (kg/m^3). These measurements were carried out in accordance with ASTM E 605 (2011). For higher bond strength and according to the producer's instruction, a thin layer of primer was firstly applied on the slab surface. Also, a keying steel mesh was fixed between primer and coating layers when the primer layer was still wet.

2.3 Test setup and instrumentation

In this study, the fire resistance experiments were performed by an intermediate scale furnace (1 m^3) at Road, Housing and Urban Development Research Center (BHRC). In all the tests, the furnace temperature was increased according to the temperature-time curve of BS EN 1363-1 (2012). The mean temperature of furnace was measured by thermocouples installed inside the furnace. During testing, the mean temperature of furnace had been accurately maintained in the standard limit. In all the tests, vertical loading on the specimen was applied by a hydraulic jack statically. Considering the performance type of a concrete slab, fire resistance tests were continued until the failure of load bearing capacity criteria and the comparisons were fulfilled on this basis.

Flexural loading test on eight slab specimens were carried out according to ASTM E 72 (2010). Vertical displacements of each slab were measured by four LVDTs at midspan and support locations. Also, strain at tensile steel of the slab, extreme concrete compression fiber and outside surface of FRP were measured and recorded in each step by installed strain gauges.

For the fire test, the slab specimens were placed on the furnace. Quarter-point loading configuration was selected and two equal loads were applied on the slab specimens, each at a distance of one quarter of the span from the supports, toward the middle of the span. The total load for each specimen was equal to its calculated service load. After loading, when a steady condition (almost zero increase in deflection with time) was reached, the slabs were exposed to fire in accordance with the standard fire curve, with no additional load. The slabs were simply supported at the ends with a total length of 1.46 m, of which 1.3 m was exposed to the standard fire by the furnace. Each slab specimen was supported on an insulated edge along four sides of the furnace which did not make any restraint to the movement of the slab in its free edges. For this purpose, a ceramic fiber blanket insulation was placed between the slab and its supports and the edges of the furnace for the prevention of flame and heat exit (Figure 3). Also, for specimens FR1-Fire and FR2-Fire that CFRP layer did not have any fire resistant material, for protecting the strain gauges installed on the CFRP against the fire, they were covered by a ceramic fiber blanket insulation which was fastened to the concrete slab by means of a steel mesh.

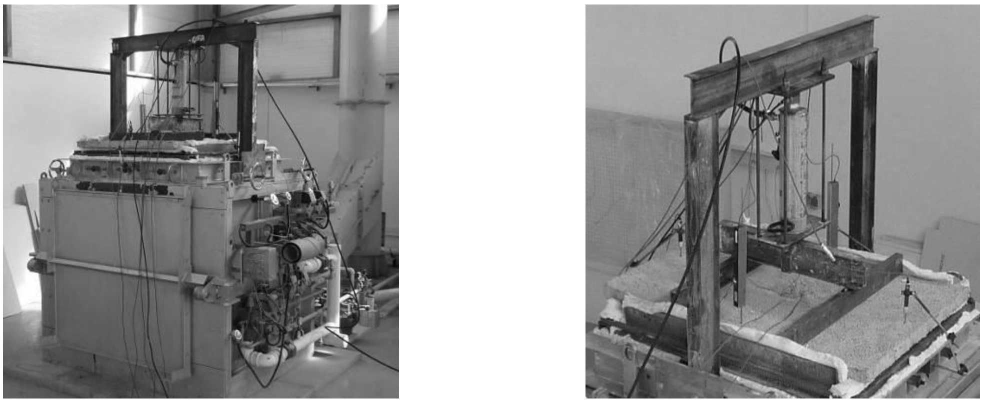


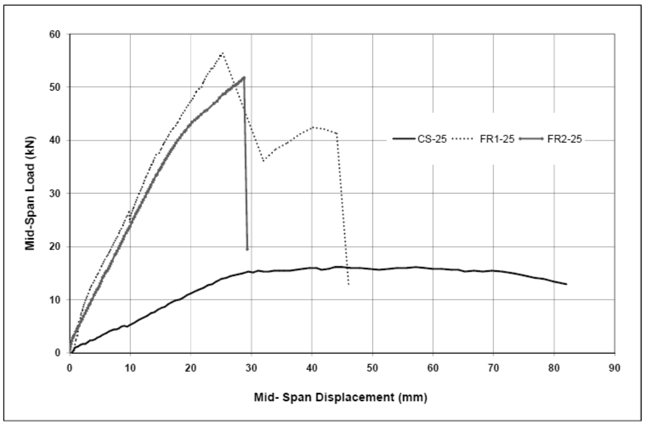
Figure 3: Test setup for the fire resistance tests

In these fire resistance experiments, two thermocouples were mounted inside each specimen to measure the temperature of the steel mesh (No. 2) and the specimen center (mid-thickness, thermocouple No. 1) at mid-span. In specimens FR1-Fire-P1 and FR1-Fire-P2, two additional thermocouples (No. 3 & No. 4) were places between the CFRP layer and the fire protective layer in order to measure the temperature of the CFRP layer.

3. Results and discussion

3.1 Gravity loading tests

Three slab specimens were tested under gravity loading in room conditions (almost 25 °C). One specimen (CS-25) was unstrengthened and two other specimens (FR1-25 and FR2-25) were strengthened with CFRP. In these tests, the applied vertical load was incrementally increased until the failure of the specimen was reached, i.e. reduction in the specimen strength after experiencing the maximum strength was at least 20%. Obtained load-deformation curve for these specimens is shown in Figure 4.



(a) (b)

Figure 4: (a) specimen CS-25 during testing; (b) Variation of load versus mid-span deflection for specimens CS-25, FR1-25, and FR2-25

In Figure 4, load-displacement curves of specimens CS-25, FR1-25, and FR2-25 are compared. According to this figure, the maximum flexural load-bearing capacity of strengthened specimens FR1-25 and FR2-25 is more than that of unstrengthened specimen CS-25 by a factor of 3.47 and 3.28, respectively, which shows the high efficiency of CFRPs in the flexural retrofitting of concrete slabs. On the other hand, as can be seen in this figure, the strengthening with CFRPs causes a reduction in the assembly ductility; since the stress-strain curve of CFRPs is linear up to failure (CFRPs have brittle behavior).

3.2 Fire resistance tests

A total of five slab specimens in accordance with Table 1 were subjected to fire resistance tests including one unstrengthened specimen (CS-Fire), two strengthened specimens without fire resistant material (FR1-Fire and FR2-Fire) and two fire protected strengthened specimens (FR1-Fire-P1, FR1-Fire-P2). In these tests, firstly the applied vertical load to each specimen was incrementally increased to reach the specimen service load. After loading, the furnace temperature was increased according to the selected standard temperature-time curve until the failure of the specimen occurred, namely the specimen was no longer able to resist the applied constant vertical load.

3.2.1 Specimen CS-Fire

A service load of 9.5 kN was obtained in accordance with ACI 440.2R-08 for the unstrengthened slab, which is corresponding to a stress of $0.8F_y$ in the slab tensile reinforcement, where F_y is the yield stress of the reinforcement. The mid-span displacement-temperature curve for this specimen is plotted in Figure 5. In this test, firstly, the load was gradually increased up to 9.5 kN which the corresponding displacement was equal to 13.5 mm.
After mechanical loading, the specimen was exposed to the standard fire. During the testing, the mid-span displacement of the specimen increased continuously. With the increase in the temperature during the test, a progressive cracking in the slab top surface developed. After the steel mesh temperature reached 550 °C, the slab mid-span displacement became suddenly 123.4

mm and the specimen failure happened. At that moment, the slab residual strength became lower than the applied constant load due to elevated temperatures. The test was stopped at approximately 79 min of fire exposure time because of the failure of the strength criteria. Figure 6 shows the temperature-time curve of the installed thermocouples in the specimen. For analyzing the slab failure at 79 min, the following explanation can be mentioned:

This unstrengthened concrete slab was under a constant load of 9.5 kN during the fire resistance test. Since the maximum load carrying capacity of this slab was 16.15 kN, thus the ratio of load to strength was around 0.6. At the failure time of the slab (79 min), the steel temperature was recorded as 550 °C by means of the installed thermocouple. In this temperature, the yield strength of the steel reaches 0.6 of its initial value in accordance with ANSI/AISC 360 (2010). Therefore, the slab flexural strength decreases about 40% and reaches from 16.15 kN to lower than the applied load of 9.5 kN that causes the slab to fail which agrees with experimental results. It should be noted that since the compression depth of this slab is small, the slab flexural strength is approximately related to the steel yield strength with a linear equation.

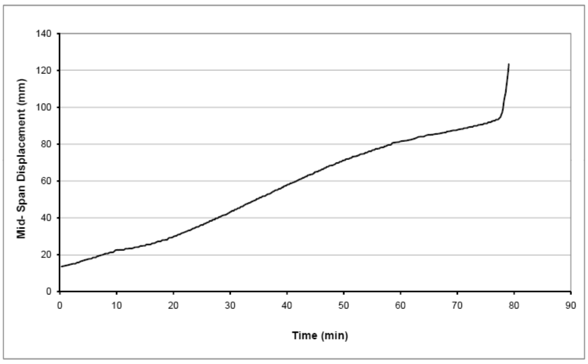


Figure 5: Measured mid-span displacement as a function of fire exposure time for slab CS-Fire

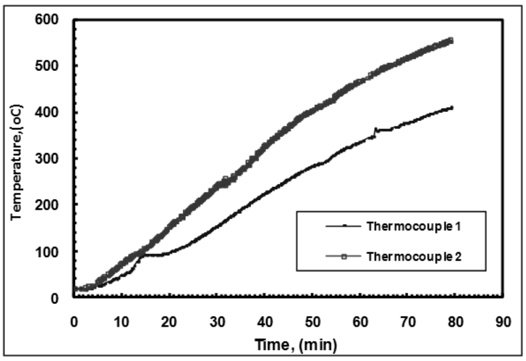


Figure 6: Temperature-time curve of installed thermocouples in slab CS-Fire

3.2.2 Specimens FR1-Fire & FR2-Fire

The service load of the strengthened specimens was computed based on the conditions that the service stress in CFRP sheets reaches $0.33C_DC_Ef_{fu}$ according to ACI 440.2R-08. C_E (environmental reduction factor), C_D (durability factor), and f_{fu} (tensile strength of fibers) were considered as 0.65, 1, and 4127 MPa, respectively. Finally, these service loads for specimens FR1-Fire and FR2-Fire were determined as 33 and 24 kN, respectively.

Variations of mid-span deflection versus time for specimens FR1-Fire and FR2-Fire are plotted in Figure 7. In specimen FR1-Fire, the load was incrementally increased until the calculated service load of 33 kN was obtained and the corresponding mid-span deflection was equal to 31.6 mm. Then, after the start of the fire test, this load was kept constant. With the increase in furnace temperature, the specimen mid-span deflection increased and when its value reached 43.3 mm, the debonding of CFRP sheets from the concrete surface in the fire-exposed span of the slab occurred. Then, anchorage failure and spalling of the concrete under a CFRP sheet in one slab end occurred (Figure 8) that resulted in a rapid reduction in the slab strength and so, the slab failed.

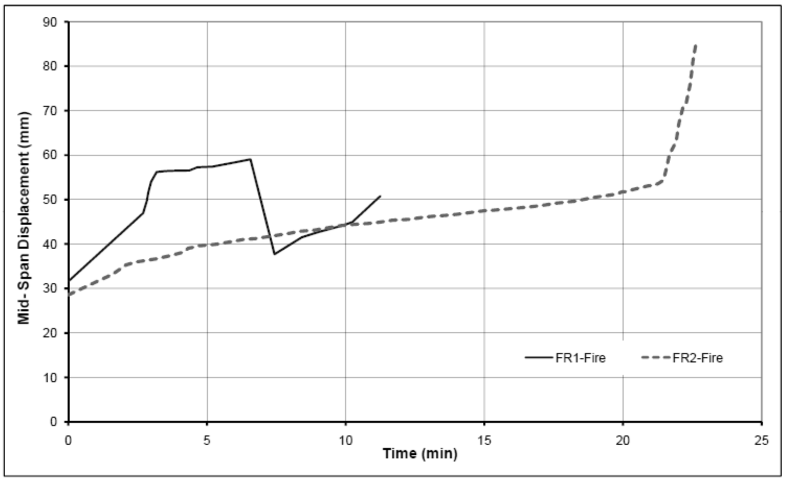


Figure 7: Mid-span deflection as a function of fire exposure time in strengthened specimens FR1-Fire and FR2-Fire without any external fire insulation

This test was stopped at 7 min due to the torsion of the transverse beams which the load was being applied to the slab by them. After the modification of the loading system, the fire test was performed again. After 4 min, the test was terminated because the slab was not able to carry the applied load any more. In other words, the strength of the slab at this time was lower than the applied load due to high temperatures. The fire endurance of this specimen was totally 11 min (Figure 7).

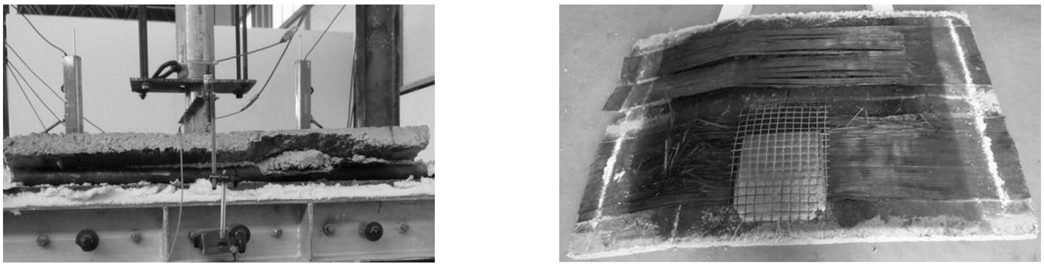


Figure 8: Specimen FR1-Fire at the end of the fire test

Visual observations were made for this specimen after the test. As can be seen in Figure 8, the epoxy resin of the CFRP strips in the fire-exposed span of the slab has burned. However, we can conclude that during the testing, in the absence of any debonding of CFRP within anchorage zones located outside the fire zone, the unbonded continuous carbon fibers at the slab bottom continued to contribute towards the tensile strength of the beam through the cable mechanism. Due to this cable mechanism, the collapse of the slab was delayed until the anchorage failure was reached and thus, the slab fire resistance increased. In practice, the use of mechanical anchors at both ends of FRP can aid the cable mechanism. It should be noted that in the literature, there is a lack of data on the contribution of this cable mechanism to fire endurance of FRP-strengthened slabs without any fire protection system.

It can be seen according to the temperature-time curve of the installed thermocouples in specimen FR1-Fire that the temperature of the steel was low and before reaching 100 °C, the test terminated. This is because the applied load to this strengthened slab was higher than that of the unstrengthened slab, due to the contribution of the CFRP sheets to the slab load bearing capacity. On the other hand, the epoxy resin in the CFRP is very vulnerable to high temperatures and after exposing to the fire, the strength of the CFRP-strengthened slab suddenly diminishes. Thus, FRP-strengthened concrete slabs that the FRP has not any fire protection coating, have very lower fire endurance as compared to that of the unstrengthened case in a fire event.

Similarly, in specimen FR2-Fire, the load was incrementally increased up to the calculated service load of 24 kN and in this situation, the corresponding mid-span deflection was equal to 28.6 mm. Then, after the start of the fire test, this load was kept constant. With the increase in the furnace temperature, the specimen mid-span deflection increased and when its value reached 53.6 mm, the debonding of the CFRP sheets from the concrete surface in the fire-exposed span of the slab occurred that leaded to a significant reduction in the slab strength. Then at mid-span deflection of 85.2 mm, the collapse of the slab occurred.

The fire test of specimen FR2-Fire terminated at 22 min because of the strength criteria failure. In other words, at this time the slab was not able to tolerate the applied load. Overall, the above explanation about the fire behavior of specimen FR1-Fire can be mentioned for this specimen again. However, due to the lower mechanical load in this case, the fire resistance rating and thermocouples temperature for specimen FR2-Fire are higher than those of the previous specimen.

Visual observations were made for this specimen after the test. Similar to specimen FR1-Fire, the epoxy resin of the CFRP strips in the fire-exposed span of the slab has disappeared and the continuous carbon fibers have separated from each other and debonded from the concrete surface in this region.

3.2.3 Specimens FR1-Fire-P1 & FR1-Fire-P2

The mid-span deflection as a function of time for specimen FR1-Fire in two cases of protected and unprotected against the fire is shown in Figure 9.

For the purpose of comparing the results of protected and unprotected slabs against the standard fire, the loading conditions was considered the same and the service load of specimen FR1-Fire (i.e. 33 kN) was applied to fire-protected specimens FR1-Fire-P1 and FR1-Fire-P2 similarly. The loading method for these specimens was similar to specimen FR1-Fire. That is the applied load was incrementally increased up to 33 kN and then, was kept constant during the fire test.

According to Figure 9, the fire test of specimen FR1-Fire-P1 terminated at 47 min due to the failure of the load bearing capacity criteria, that is the strength of the specimen reached lower than the applied constant load of 33 kN. However, the strength criteria failure for specimen FR1-Fire took place at 11 min that indicates the significant positive effect of the fire protective material. The temperature-time curve of the installed thermocouples in specimen FR1-Fire-P1 is plotted in Figure 10.

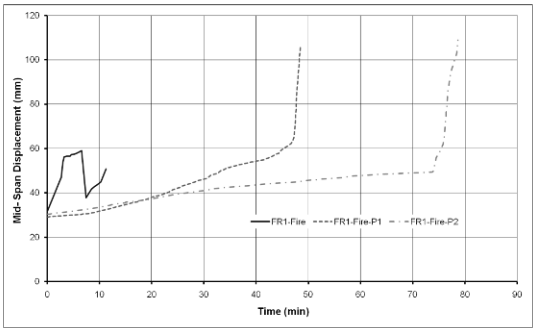


Figure 9: Variations of mid-span deflection versus the fire exposure time for specimens FR1-Fire, FR1-Fire-P1, and FR1-Fire-P2

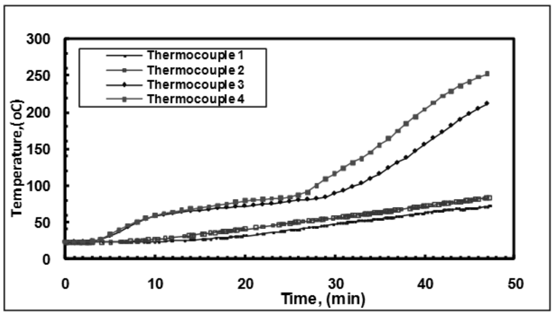


Figure 10: Temperature-time curve of the thermocouples connected to slab FR1-Fire-P1

During the fire test, cracking and spalling of the fire resistant coating of slab FR1-Fire-P1 occurred that leaded to faster transfer of the heat flow to the strengthened concrete slab (Figure 11a). In spite of the higher thickness of the fire insulation in specimen FR1-Fire-P1, the fire resistance of this specimen was lower than that of specimen FR1-Fire-P2 (Figure 9). This was due to the high thickness of the external thermal insulation and unsuitable details. In specimen FR1-Fire-P1, about 2 cm of the insulation was located outside the keying mesh. During the fire test, falling off some portions of the unreinforced protective coating happened as a result of high temperatures and slab deformations (Figure 11a). This phenomenon started at around 28 min and at 47 min reached its peak. Due to this phenomenon, the CFRP was exposed to high temperatures and subsequently, the CFRP failed and it caused the specimen to collapse rapidly. This event demonstrates that the details of fire protective coatings have important role on their performance and an increase in the insulation thickness without appropriate details can accelerate the spalling of the insulation and weaken the fire protection effectiveness. According to BS 8202-1 (1995), for high thickness insulations and or large flat substrates, the use of reinforcing mesh into the insulation may be required for providing integrity. However, where the insulation is locked in position by virtue of the shape of the element, for example I shape columns, the reinforcing mesh is not usually needed because of the encapsulation by the insulation.

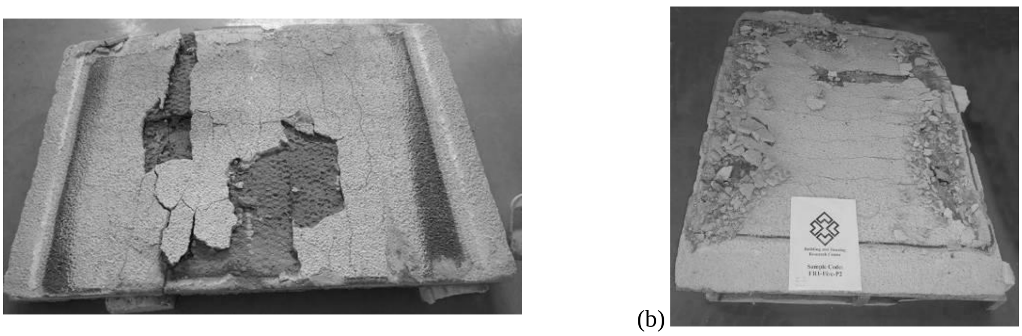
(a)  (b)

Figure 11: (a) Cracking and spalling of the fire protective coating in specimen FR1-Fire-P1 at the end of the test; (b) Specimen FR1-Fire-P2 after the fire test

The fire resistance test of specimen FR1-Fire-P2 terminated at 74 min because of the strength criteria failure; that is the specimen did not have sufficient strength to carry the applied load.

This fire endurance reveals the satisfactory performance of the fire protective coating as compared to that of specimen FR1-Fire-P1. According to Figure 11b, at the end of the test, the fire resistant coating in specimen FR1-Fire-P2 suffered many cracks; however, because of the presence of the keying mesh and its low thickness, any spalling of it did not occur. During the fire test of specimen FR1-Fire-P2, first, the debonding of the CFRP in the fire-exposed zone happened and the continuous carbon fibers transferred the load to the end anchorage zones. After the anchorage zones failure, the strength of the specimen decreased suddenly and subsequently, the slab collapsed.

At the end, the test results of all the tested specimens are summarized in Table 4.

Table 4: Fire endurance rating of experimental slabs based on strength criteria failure

Row	Slab designation	Slab properties			Fire resistance period (min)
		Width of CFRP strips (cm)	Thickness of Fire protection layer (cm)	Applied load (kN)	
1	CS-Fire	—	—	9.5	79
2	FR1-Fire	30	—	33	11
3	FR1-Fire-P1	30	2.6	33	47
4	FR1-Fire-P2	30	1.6	33	74
5	FR2-Fire	15	—	24	22

4. Conclusions

Based on this experimental research, the following conclusions can be drawn:

1. It was proved that the CFRP reinforcement is capable to increase the flexural strength of concrete slabs significantly. For the specimens tested in this experimental program, this increase in the load bearing capacity of the slabs was between 228% and 247%. However, the stress-strain curve of the CFRP up to the rupture is linear. As a result, the overall ductility and failure deformation of concrete slabs are reduced by the presence of the CFRP.

2. Strengthening a reinforced concrete slab with CFRP will increase the slab load carrying capacity and so, the applied service load to the slab can be increased. On the other hand, the CFRP is very vulnerable to high temperatures that the mechanical properties of its epoxy resin degrade at temperatures close to and above its glass transition temperature (usually is below 100 °C) which leads to the separation of the continuous carbon fibers. Because of these two factors, the fire resistance rating of a CFRP-strengthened reinforced concrete slab is much lower than that of the corresponding reference reinforced concrete slab. In this study, the fire endurance of the reference reinforced concrete slab was 79 min that reduced to 11 and 22 min for the strengthened slabs with different amounts of the CFRP. This issue reveals the intense need of fire insulation systems to protect the CFRP used in gravity retrofitting of reinforced concrete slabs.

3. The fire protection of the CFRP-strengthened reinforced concrete slabs with the gypsum-vermiculite material used in the study demonstrated that this type of materials is able to improve the fire resistance of the strengthened slabs significantly. In these experiments, a fire protection coating with 1.6 cm thickness could increase the fire endurance of the CFRP-strengthened

concrete slab from 11 min to 74 min. The reasonable thickness for the fire protection layer must be calculated to satisfy the mandatory fire resistance in accordance with building codes.

4. The installation method and details of a fire protection layer have a significant effect on its fire performance. In this study, in spite of an increase in the thickness of the spray-applied insulation from 1.6 to 2.6 cm, the fire endurance became lower contrary to our expectation. This result exhibits that for a large flat surface with a thick fire protection coating, a reinforcing mesh inside the fire protection coating is necessary to prevent it from detachment and maintain its integrity in high temperatures and large deformations.

5. In external strengthening of a reinforced concrete slab with CFRP strips, if a suitable external fire insulation or mechanical anchor can be provided at the ends of the CFRP strips, in a fire event, the continuous carbon fibers will separate from each other except the protected or strengthened ends. The bond of these fibers to the substrate at the ends will form a cable mechanism which will increase the slab strength and the slab fire endurance accordingly. This cable mechanism will fail at the time of the concrete cover detachment at the ends due to the high CFRP-induced tensile stresses.

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Knowledge Gaps in the Construction Industry to Increase Societal Resilience: A Local and National Government Perspective

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Abstract

Over the last decade, a series of increasingly devastated natural disasters have been witnessed across the world. The disaster threats were further aggravated due to various social, economic and environmental trends, such as, growing population, urbanisation, inequality and global environmental change. This demanded a more proactive approach to reduce the vulnerability and exposure, and to increase resilience. For proper implementation of resilience measures, various efforts are required from construction practitioners. Accordingly, construction practitioners are expected to play a key role at each stage of the disaster management cycle. However, recent literature concerning disasters has highlighted the inadequate engagement of the construction industry in reducing the risk of disasters. This emphasises the need to engage the construction professionals adequately, in achieving a resilient built environment. Therefore, it is of paramount importance to provide construction industries with the necessary capacity and capability to plan, design, build and operate in such a way that will reduce vulnerability and exposure, and increase resilience. In order to address this challenge, CADRE (Collaborative Action towards Disaster Resilience Education), which is an EU funded research project, intends to develop an innovative professional doctoral programme that addresses the career needs, and upgrade the knowledge and skills, of practising professionals working to make communities more resilient to disasters. Accordingly, the first phase of the research involved, capturing the needs of 5 stakeholder groups associated in disaster resilience and management as well as current and emerging skills and ultimately knowledge gaps, applicable to construction practitioners towards enhancing societal resilience to disasters. In this context, the paper aims to analyse the current and emerging knowledge gaps of construction practitioners as highlighted by the national and local government stakeholders. Accordingly, the paper provides an extensive analysis of knowledge gaps, which were captured via 20 semi-structured interviews with national and local government stakeholders. Knowledge gaps were analysed in relation to social, technological, environmental, economic and institutional factors and property life-cycle stages. Some of the key knowledge gaps identified in the study are, business continuation management; damage assessments and claims; financing, budgeting and estimating; building codes, regulations and planning; resilient buildings and infrastructure; community empowerment; stakeholder management; legal frameworks and compliance; disaster risk assessment; environmental impact assessment and management; and knowledge management.

Keywords: resilience, national and local governments, knowledge gaps, construction, disasters

1. Introduction

There is a growing recognition that those responsible for the built environment have a vital role to play in developing societal resilience to disasters. If construction researchers and practitioners are to be able to contribute to reduce risks through resilient buildings, spaces and places, it is important that capacity is developed for modern design, planning, construction and maintenance that are inclusive, inter-disciplinary, and integrative. In order to address this challenge, EU funded research project, CADRE (Collaborative Action towards Disaster Resilience Education) will identify knowledge gaps, and develop an innovative professional doctoral programme (DProf) that integrates professional and academic knowledge in the construction industry to develop societal resilience to disasters. Through the development of an innovative and timely curricular and learning material, the project seeks to update the knowledge and skills of construction professionals in the industry.

Before developing the proposed DProf programme, it was important to identify the knowledge gaps in the construction industry to develop societal resilience to disasters. Accordingly, the paper aims to present the knowledge gaps that have emerged as part of this research. Capturing knowledge gaps involved, capturing the needs of various stakeholder groups associated in disaster resilience and management, as well as current and emerging skills, applicable to construction practitioners towards enhancing societal resilience to disasters. The primary and secondary data generated a long list of needs and skills. Finally, the identified needs and skills were combined ‘like-for-like’ to produce broader knowledge gaps. The paper provides an extensive analysis on the knowledge gaps identified through this process.

The paper begins with a literature synthesis on disaster resilience knowledge and skills. The paper then presents the analytical framework of the study. The scope of the paper is limited to findings gathered from one stakeholder group, national and local governments and therefore the paper investigates the role of the government in developing societal resilience to disasters. The paper continues with an analysis of the data gathered through semi-structured interviews based on five resilience dimensions, economic, environmental, institutional, social and technological and concludes with a list of key classifications derived from government stakeholders in enhancing the knowledge and skills of construction practitioners serving them to increase societal resilience to disasters.

2. Disaster resilience knowledge and skills

Hazards cause various disruptions to the built environment. The damage to the built environment accounts for most of the economic losses of disasters and its failure often determine the amount of fatalities (Witt et al., 2014). As such, professionals related to construction sector are expected to play a major role in mitigating such impacts of disasters. At the same time, it is the duty of the professionals attached to the construction sector, to plan, design, construct and operate necessary risk reduction infrastructure and other services to protect the communities exposed to hazards (Malalgoda et al, 2015). As such built environment should be planned, designed, built and operated in such a way that it can withstand at a time of a disaster. Therefore it is clear that the construction industry and the built environment professions play an important role in contributing to society's improved resilience (Haigh and Amaratunga, 2010). Max Lock Centre (2009) developed a guide to demonstrate the value of using construction professionals in disaster risk reduction and response. This guide shows how the relevant professional skills and expertise can be applied at all stages of disaster management. Some of the key activities highlighted in this guide are, risk and vulnerability assessment; disaster risk reduction (DRR) and mitigation; emergency water supply and sanitation; logistical planning; relief and transitional shelters; project planning and management; design, construction and monitoring; physical condition surveys and audits; compensation packages; resource mapping; housing need assessment; land survey and acquisitions; physical planning; infrastructure planning and implementation; property rights and claims; financial planning and management; and advice on regulations and codes. Especially, poor urban planning and poorly regulated building codes have aggravated exposure to hazards (Bosher, 2014; Malalgoda et al, 2014) and as such utilising construction practices, building codes and technology that can withstand the exposure is of paramount importance (Ireni-Saban, 2012). As such it is clear that construction practitioners have a key role in DRR and management and their professional skills and expertise need to be deployed in disaster risk reduction and management. In addition to these, Norman and Binka (2015) highlighted the importance of soft skills such as leadership in building disaster resilience and response. A study conducted in Sub-Saharan Africa revealed that leadership capacities need to be strengthened through continual professional developments and formal education in order to build resilience and to improve response. It is important to understand that the disaster resilience requires efforts of various stakeholders and would require a multi-sectoral and inter-disciplinary approach (Haigh and Amaratunga, 2010). As such collaborative actions are required for a better resilience outcome (Ireni-Saban, 2012), which highlights the importance of knowledge and skills, related to collaborative working and community interactions.

Indigenous knowledge is another important aspect when it comes to DRR and resilience. According to Ireni-Saban (2012) local knowledge places a greater importance, including understanding communities at risk, including their practices, traditions, customs and beliefs. By understanding the indigenous knowledge, such as local skills and materials and how it can be successfully used and its success in coping with disasters over time (UNISDR, 2008) would undoubtedly benefit in the preparation for future disasters. However, according to Gaillard and Mercer (2012) there is a gap in integrating local and scientific knowledge because of the lack of trust between stakeholders operating at different level. As a result, contributions of local communities are often disregarded which lead to gaps between policy development at the national level and the practice at the local level. This emphasises the need of multi stakeholder approach, inclusion and empowerment.

As discussed above, various knowledge and skills are required to better perform the tasks associated with risk reduction. As such, knowledge plays a major role in disaster risk reduction and resilience (Weichselgartner and Pigeon, 2015). As a result of prominent gaps in knowledge, Sendai Framework for Disaster Risk Reduction (2015-2030) has identified the need of enhancing the capacities of relevant stakeholders and industries. The Framework provides recommendations regarding the creation and dissemination of knowledge (Weichselgartner and Pigeon, 2015). Accordingly, the framework suggest to “build the knowledge of government officials at all levels, civil society, communities and volunteers, as well as the private sector, through sharing experiences, lessons learned, good practices and training and education on disaster risk reduction, including the use of existing training and education mechanisms and peer learning” (UNISDR, 2015). Professionals attached to construction sector play an important role in disaster resilience and management. As such, construction professionals require continuous update of knowledge and education in order to effectively contribute to disaster management (Thayaparan et al, 2014). It is therefore important to design educational and training courses to enable them to successfully fulfil this role (Witt et al., 2014). Therefore as argued by Bosher et al. (2007), risk and hazard awareness training needs to be integrated systematically into the professional training of architects, planners, engineers, developers, etc. The next section presents the analytical framework and methodology of the study.

3. Analytical Framework and methodology

The initial framework of the study is a three dimensional framework consisting of the following parameters:

Built environment stakeholders: National and local government organisations; Community; NGOs, INGOs and other international agencies; Academia and research organisations; and Private sector.

Dimensions of resilience: Economic Resilience; Environmental Resilience; Institutional Resilience; Social Resilience and Technological Resilience

Stages of property lifecycle: Preparation Stage (PS); Design Stage (DS); Pre-Construction Stage (PCS); Construction Stage (CS) and Use Stage (US)

The framework was developed through an extensive consultation process with project partners and was refined throughout the first year of the project with the emerging literature findings and the opinion of stakeholders who has been interviewed to capture the labour market demands in construction industry to increase societal resilience to disasters.

The research discussed in this paper is focussed on analysing the market demands of one of the stakeholders, national and local governments. Accordingly, the paper analyses the semi-structured interviews conducted with national and local government organisations. Semi-structured interviews were conducted with a total of twenty respondents from the “national and local government” stakeholder group across different countries and continents. The respondents identified and interviewed in this category were individuals that were attached to national and local government institutions, involved in various activities related to disaster resilience and management. The interviews were aimed at capturing the needs as well as skills, applicable to construction professionals towards enhancing societal resilience to disasters. During the interviews, special interest and focus was given on the needs of national and local government organisations engaged in disaster resilience and management and the skills required from construction industry professionals serving them. Accordingly, the interviews were more of a discourse structured around the stages of disaster management cycle. The analysis was done using NVivo (version 10). The themes were presented under two main headings i.e. Needs and Skills. The category "Needs" covers the stakeholder requirements that emerged from the interviews as well as the demands specifically made by interviewees. Also, what the interviewees believe should be in place while professionals relate with them to enhance societal resilience were categorized under the heading "Needs" in the analysis. During the interviews, some set of skills were emerged; some were displayed by professionals while serving to reduce the threats posed by natural and human induced hazards and some that are desired by interviewees. These set of skills were categorized under the heading "Skills". All needs as well as skills were categorized into five dimensions of resilience (Social, Economic, Institutional, Environmental, Technological) and each of the dimensions of resilience is sub-headed with the five stages of property lifecycle, Preparation, Design, Pre-construction, Construction and Use stage. The interviews generated a long list of needs and skills with respect to the property lifecycle stages under the respective dimensions of resilience. Finally, the identified needs and skills were combined 'like-for-like' to produce broader level of knowledge gaps (themes).

3.1 Government as a stakeholder

A number of parties are involved in the process of increasing societal resilience to disasters, including community and citizens' groups, local governments, the private/corporate sector, the national government, civil society organisations, external actors, professional groups and the media. There should be adequate coordination among the interested parties in order to overcome the challenges posed by a disaster, successfully. Between these stakeholders, a government of a country plays a predominant role. All activities related to disaster management are usually centred at governmental level, and hence, governments can be identified as the principal stakeholder in disaster management (Moe and Pathranarakul, 2006). Usually the government assigns the responsibility for each task to different ministries or may form new authorities or committees and assign the responsibility for different tasks to these authorities or committees (Wolensky and Wolensky, 1991). To be successful, proper partnerships and cooperation are essential between local and national governments and civil society in order to reduce the costs of risk reduction, ensure local acceptance and build social capital (UN-ISDR, 2010). Recent literature highlight administrative shortcomings that prevent affected communities recovering from disasters (Ireni-Saban, 2012). In overcoming these challenges, government require professional services from the construction professionals to prevent, mitigate, prepare and recover from disasters. According to Bosher (2014) number of structural and operational obstacles does exist in making the built environment resilient to disasters and lack of knowledge and skills were key among others especially in developing country context (Malalgoda et al, 2014). Thus, it is very important to identify the knowledge gaps and develop educational programmes to cater the identified knowledge gaps. The next section analyses the data gathered through semi-structured interviews.

4. Data analysis and discussion

4.1 Economic Resilience

According to Seneviratne et al (2010) economic factors are two-fold, economic planning measures and financial measures. Aspects relating to production, distribution and consumption of goods and services are considered as economic planning measures and aspects relating to money and management of monitory assets are considered under financial measures. In terms of economic resilience, most of the interviewees identified the gaps in business continuity management. Some of the key highlights within this theme were business continuation strategies and business continuation plans. Having a business continuation strategy/plan is of paramount importance in order to make sure that business is up and running after a disaster. Local authorities have a responsibility to promote business continuity to businesses and the interviewees considered this as a key knowledge area within the domain of disaster resilience. Financing, budgeting and estimating was another key theme identified under economic resilience. This covers number of sub-themes such as, sourcing of funds, investment appraisals, construction budgets, cost control, contingency management, financial management relation to disaster resilience and, transparency and accountability. Damage assessments and claims is another important theme highlighted by the interviewees. Under this theme, interviewees highlighted the importance of knowledge and skills related to, property insurance, damage assessments, valuation, and compensation for damages. This include, assessing what damage has the disaster caused and what works need to be done to get back to pre-disaster condition and what further work could be done to prevent or reduce the risk of happening it again. Process and quality management was also categorised under economic resilience as it highlighted the importance of resource management and prioritising work. In particular, prioritisation of work is very much relevant in the context of disaster resilience due to the restricted budgets. Thus, identifying the most critical activities and prioritising projects is very important in implementing DRR projects. Resource management and prioritisation also has a link to the next theme, which is social and cultural awareness. Interviewees highlighted the importance of the use of local knowledge, skills and materials and emphasised the necessity of deploying economically feasible and socially acceptable solutions that would enhance societal resilience to disasters. Another theme was the contracts and procurement. Interviewees argued the importance of knowledge and skills with regard to different procurement strategies which facilitate rapid restoration; different forms of contracts such as nec3 option G which allows instructing task orders during incidents; framework contracts for incident management works; and rapid response of supply chain. All these are formed under the theme, contracts and procurement. Table 1 highlights all themes derived in relation to economic resilience and their relevance to different stages of property life cycle.

Table 1: Themes for economic resilience

No.	*Classifications*	*Property lifecycle stages*				
		PS	*DS*	*PCS*	*CS*	*US*
1	*Business continuation management*	*x*	*x*		*x*	*x*
2	*Financing, budgeting and estimating*	*x*	*x*	*x*	*x*	*x*

3	*Damage assessment and claims*	*x*			*x*	*x*
4	*Process and quality management*	*x*	*x*	*x*	*x*	*x*
5	*Social and cultural awareness*	*x*	*x*	*x*	*x*	*x*
6	*Contracts and procurement*			*x*		
7	*Construction and project management*	*x*	*x*	*x*	*x*	*x*
8	*Consultancy services in relation to constructions*	*x*	*x*	*x*	*x*	*x*
9	*Resilient buildings and infrastructure*	*x*	*x*		*x*	*x*
10	*Disaster management and planning*	*x*	*x*	*x*	*x*	*x*
11	*Disaster risk and need assessment*	*x*	*x*	*x*	*x*	*x*
12	*Knowledge management*	*x*	*x*	*x*	*x*	*x*
13	*Time management*	*x*	*x*	*x*	*x*	

4.2 Environmental Resilience

Factors relating to environment, ecology and sustainability were considered under environmental resilience. Similarly, analysis of semi-structured interviews facilitated deriving number of themes for environmental resilience. Each of these themes was derived from various needs and skills identified by the interviewees. One of the key themes identified under this category was the risk and need assessment. This theme was identified as a result of sub themes such as, preventive structures, identifying vulnerable population and properties, hazard and risk mapping, identifying suitable places for relocation and, forecasting and warning. In doing so, it is very important that community know that they are at risk, so that they will be more engaged and will be willing to take action. For an instance, they can equip with property level protection, for an example, in the case of floods, they can install floodgates for their doors and windows and flaps for inlets and vents into their houses. The theme, knowledge management arise based on interviewees arguments on the need for, access to related data and information and access to required software and technology such as GIS. Lack of data and information is a prevailing issue especially for more remote areas. These include, lack of hazard and risk maps, water tables, soil types, rainfall data, geological data etc. Under environmental management, interviewees highlighted the need of understanding and managing the environmental impacts, which trigger disasters, forecasting, early warning, weather and climate change, use of resilient designs, materials and construction techniques, environmental impact assessments and local topography. Materials and resource management also plays a role in environmental resilience. Accordingly, interviewees highlighted the importance of having the knowledge of resilient and environmentally friendly materials and other resources in order to enhance the environmental resilience. For an example, one interviewee highlighted the importance of selecting materials to match the location, climate, and soil types while another highlighted the importance of resource management to reduce the wastage. Sustainability and resilience is yet another important theme identified under environmental resilience. It covers number of sub themes such as, sustainable design solutions, selection and use of sustainable materials and technologies and ensuring sustainability of resilient solutions. Table 2 highlights all themes derived in relation to environmental resilience and their relevance to different stages of property life cycle.

Table 2: Themes for environmental resilience

No.	Classifications	*Property lifecycle stages* PS	DS	PCS	CS	US
1	*Disaster risk and need assessment*	*x*	*x*	*x*	*x*	*x*
2	*Knowledge management*	*x*	*x*	*x*	*x*	*x*
3	*Environmental impact assessment and management*	*x*	*x*		*x*	*x*
4	*Materials and resource management*	*x*	*x*	*x*	*x*	
5	*Sustainability and resilience*	*x*	*x*	*x*	*x*	*x*
6	*Building codes, regulations and planning*	*x*	*x*	*x*	*x*	*x*
7	*Resilient buildings and infrastructure*	*x*	*x*		*x*	*x*
8	*Disaster management and planning*	*x*	*x*	*x*	*x*	*x*
9	*Health and safety*	*x*	*x*		*x*	*x*
10	*Process and quality management*	*x*	*x*	*x*	*x*	*x*
11	*Social and cultural awareness*	*x*	*x*	*x*	*x*	*x*
12	*Teaching and research on disaster resilience and management*	*x*	*x*	*x*	*x*	*x*
13	*Time management*	*x*	*x*	*x*	*x*	
14	*Town and country planning*	*x*				

4.3 Institutional resilience

Institutional resilience, as defined in this paper refers to the political, legal and institutional factors. Aspects relating to government and policies are considered as political factors; aspects relating to law, accepted rules and regulations in managing disasters are considered under legal factors; aspects relating to an organisation linked to disaster management are considered under institutional factors (Seneviratne et al, 2010). As shown in Table 3, various themes were identified in relation to enhancing institutional resilience. One of the key themes identified was stakeholder management. Stakeholder management was derived from a combination of responses given by the interviewees. Some of these include, multi stakeholder engagement, appropriate institutional arrangements, clear definitions of roles and responsibilities, coordination between different organisations, collaborative working, relationship with other stakeholders and communities, commitment to disaster management and resilience. This theme further incorporated the interviewees' responses such as communication skills, team working and management and leadership skills. Legal frameworks and compliance is another key theme under institutional resilience. This theme incorporated sub themes such as, policies, plans and legal frameworks for disaster resilience, disaster risk reduction strategies, knowledge on prevailing laws and implementation of laws and regulations. Leadership and people management has been identified as a separate theme as it was a concern for most of the respondents. However, this has a close link to the theme, stakeholder management, and include, sub themes such as multi stakeholder engagement, understanding community needs, engaging communities, collaborative working, conflict management, leadership skills, people management skills, commitment for disaster risk reduction and proactive thinking. Governance is yet another important theme classified under institutional resilience. The theme was derived from number of sub themes, such as, institutional arrangements for disaster resilience;

commitment to disaster risk reduction; coordination between stakeholders; and policies, plans and legal frameworks for disaster resilience.

Table 3: Themes for institutional resilience

No.	Classifications	Property lifecycle stages				
		PS	DS	PCS	CS	US
1	Stakeholder management	x	x	x	x	x
2	Legal frameworks and compliance	x	x	x	x	x
3	Leadership and people management	x	x	x	x	x
4	Governance	x	x	x	x	
5	Building codes, regulations and planning	x	x	x	x	x
6	Business continuation management	x	x		x	x
7	Communication	x	x	x	x	x
8	Contracts and procurement			x		
9	Damage assessment and claims	x			x	x
10	Knowledge management	x	x	x	x	x
11	Resilient buildings and infrastructure	x	x		x	x
12	Disaster management and planning	x	x	x	x	x
13	Disaster risk and need assessment	x	x	x	x	x
14	Environmental impact assessment and management	x	x		x	x
15	Human resource management	x	x	x	x	x
16	Process and quality management	x	x	x	x	x
17	Project and construction management	x	x	x	x	x
18	Teaching and research on disaster resilience and management	x	x	x	x	x
19	Team working	x	x	x	x	x
20	Time management	x	x	x	x	
21	Town and country planning	x				
22	Transparency and accountability	x	x	x	x	x

4.4 Social resilience

Social resilience was defined based on Cacioppo et al (2011) definition for social resilience, which is revealed by capacities of individuals, or groups, to foster, engage in, and sustain positive social relationships and to endure and recover from disasters. Similar to previously identified resilience dimensions, number of themes was also derived under social resilience dimension. Community empowerment is the most noted theme under social resilience. In terms of community empowerment, interviewees highlighted the importance of community engagement and participation, maintaining or re-establishment of community relationships, working with the community, understanding community needs, empowering community and social cohesion. Especially in multi-cultural societies, communities aren’t always engaged or integrated, however after an incident community relationship grow stronger and participate more willingly. Team working is also an important theme identified under social dimension which includes, collaborative working, working with the community, understanding community needs, effective involvement of the community and team working. Communication was classified as a separate theme due to the importance placed by the interviewees on communication. Communication skills are especially required when dealing with disaster-affected communities, to understand their emotional and psychological conditions and to avoid any further harm. Sometimes it is difficult to convince the vulnerable population to take preventive action due to cost, time and other constraints. As such, good communication skills are of paramount importance to ensure that they understand the risk and act upon to reduce it. Another important theme derived under social dimension is the social and cultural awareness. This incorporated interviewees' responses such as the importance of the use of local knowledge and skills, use of local businesses for repairs and reconstructions, and selection of approaches suitable to local context. Table 4 highlights all themes derived in relation to social resilience and their relevance to different stages of property life cycle.

Table 4: Themes for social resilience

		Property lifecycle stages				
No.	*Classifications*	*PS*	*DS*	*PCS*	*CS*	*US*
1	*Community empowerment*	*x*	*x*		*x*	*x*
2	*Team working*	*x*	*x*	*x*	*x*	*x*
3	*Communication*	*x*	*x*	*x*	*x*	*x*
4	*Social and cultural awareness*	*x*	*x*	*x*	*x*	*x*
5	*Building codes, regulations and planning*	*x*	*x*	*x*	*x*	*x*
6	*Business continuation management*	*x*	*x*		*x*	*x*
7	*Consultancy services in relation to constructions*	*x*	*x*	*x*	*x*	*x*
8	*Damage assessment and claims*	*x*			*x*	*x*
9	*Resilient buildings and infrastructure*	*x*	*x*	*x*	*x*	*x*
10	*Disaster management and planning*	*x*	*x*	*x*	*x*	*x*
11	*Disaster risk and need assessment*	*x*	*x*	*x*	*x*	*x*
12	*Emergency shelter management*	*x*	*x*		*x*	*x*
13	*Environmental impact assessment and management*	*x*	*x*		*x*	*x*
14	*Financing, budgeting and estimating*	*x*	*x*	*x*	*x*	*x*
15	*Health and safety*	*x*	*x*		*x*	*x*
16	*Knowledge management*	*x*	*x*	*x*	*x*	*x*
17	*Leadership and people management*	*x*	*x*		*x*	*x*
18	*Legal frameworks and compliance*	*x*	*x*	*x*	*x*	*x*
19	*Post project audits*		*x*		*x*	
20	*Process and quality management*	*x*	*x*	*x*	*x*	
21	*Stakeholder management*	*x*	*x*	*x*	*x*	*x*
22	*Sustainability and resilience*	*x*	*x*	*x*	*x*	*x*
23	*Teaching and research on disaster resilience and management*	*x*	*x*	*x*	*x*	*x*
24	*Time management*	*x*	*x*	*x*	*x*	

4.5 Technological resilience

The final dimension of resilience was about technological resilience. This includes "application of scientific advances including any tool, technique, product, process and method to benefit disaster management" (Seneviratne et al, 2010). In terms of technological resilience, number of themes was identified and this section highlights the key themes identified under this dimension of resilience. The first theme identified was building codes, regulations and planning. This was derived from the sub themes, awareness of property related regulations and policy, knowledge of construction codes for different properties, knowledge on planning and building regulations and knowledge of planning permissions. In supporting this, one of the interviewees stated, “one of the things that put people and businesses at more risk than anything is permitted developments within flood plains and close to rivers”. Land next to rivers and next to water causes or flood plains are relatively cheaper, however, it is important to influence planners and decision makers to not to allow any developments within flood plains. The next theme identified under this was the resilient buildings and infrastructure. This theme covered a variety of sub themes such as, resilience planning, designing and construction, advice and guidance on design and construction of resilient structures, monitoring and supervising the construction and operation of resilient structures, use of resilient construction processes and techniques, development of resilient transport networks, identifying vulnerable population and properties, understanding impacts of disasters on the built environment, addressing disaster resilience in preparation and design stages, proactive approaches to disaster risk reduction or pre-disaster management, build back better and development of preventive structures and methods. There are so much that can be done to prevent or mitigate disasters, for an example, to manage flood risk, some of the things that can be done are, flood walls, embankments, storage areas and flood gates and vent protection to protect individual properties. Project and construction management is a combination of sub themes such as knowledge and experience of construction technology, knowledge of construction codes for different properties, resource management and monitoring and supervising the construction and operation of resilient structures. Table 5 highlights all themes derived in relation to technological resilience and their relevance to different stages of property life cycle.

Table 5: Themes for technological resilience

No.	*Classifications*	*Property lifecycle stages*				
		PS	*DS*	*PCS*	*CS*	*US*
1	*Building codes, regulations and planning*	*x*	*x*	*x*	*x*	*x*
2	*Resilient buildings and infrastructure*	*x*	*x*	*x*	*x*	*x*
3	*Project and construction management*	*x*	*x*	*x*	*x*	*x*
4	*Knowledge management*	*x*	*x*	*x*	*x*	*x*
5	*Disaster management and planning*	*x*	*x*	*x*	*x*	*x*
6	*Disaster risk and need assessment*	*x*	*x*	*x*	*x*	*x*
7	*Emergency shelter management*	*x*	*x*		*x*	*x*
8	*Environmental impact assessment and management*	*x*	*x*		*x*	*x*
9	*Materials and resource management*	*x*	*x*	*x*	*x*	
10	*Process and quality management*	*x*	*x*	*x*	*x*	
11	*Social and cultural awareness*	*x*	*x*	*x*	*x*	*x*
12	Sustainability and resilience	x	x	x	x	x
13	Teaching and research on disaster resilience and management	x	x	x	x	x

5. Conclusions

A number of needs and skills were identified in respect to various resilience factors and property life-cycle stages. Finally, labour market needs and skills with respect to resilience dimensions across property life stages were filtered to generate a total list of 33 knowledge gaps. 13 (out of 33) gaps emanated from labour market needs and skills under economic resilience with their respective property lifecycle stage. 14 (out of 33) gaps originated from labour market needs and skills under environmental resilience. 22 (out of 33) gaps emanated under institutional resilience. 24 (out of 33) gaps derived under social resilience, and 13 (out of 33) gaps produced under technological resilience. It is evident that more gaps were derived from social resilience, followed by institutional resilience. The paper analysed the knowledge gaps in the construction industry to develop societal resilience to disasters from the perspective of national and local government stakeholders. The paper was based on an EU funded project, CADRE (Collaborative Action towards Disaster Resilience Education) and as part of the project similar studies were conducted to obtain the views of other stakeholders, such as community, private sector, academia and non governmental organisations. Finding of all stakeholders were collated to derive a comprehensive list of knowledge gaps and at the next phase of the research it is expected to validate these findings through stakeholder seminars. Finally, it is intend to develop a professional doctorate to cater the identified knowledge gaps.

6. Acknowledgements

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Built Asset Management Climate Change Adaptation Model

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Abstract

Climate change continues to pose major challenges to those responsible for the management of built assets. Whilst mitigation is largely being driven by legislation and corporate social responsibility, adaptation has to compete alongside general built asset management needs. As such, adaptations to address longer-term building performance issues (such as those posed by climate change) rarely get prioritised above more immediate, short-term needs. However, failure to adapt a built asset to climate change could result in significant premature obsolescence if work is not programmed in a timely fashion. This paper will present the results of a case study of climate change adaptation of UK social housing.

The project reports the results of an in-depth participatory action research project with a London based social landlord to develop and test a 6 stage climate change adaptation framework and risk based model as part of its built asset management strategy. The project developed metrics to analyse the performance of the housing stock against climate change scenarios for current time and 2050. The project also examined the potential (options appraisals and cost/benefit analyses) for a range of adaptation solutions to close the performance gap and developed performance thresholds to prioritise adaptations into long term built asset management plans. These plans were developed against a range of futures scenarios through interviews and workshops with senior decision making stakeholders within the social landlord's organisation. This paper will present the practical results from this study along with a new theoretical model that integrates resilience theory, risk framing and performance management into built asset management (maintenance and refurbishment) planning. The paper will conclude with a 10 step asset management framework that was developed as an aide memoir to guide other social landlords through the climate change adaptation planning process.

Keywords: Adaptation, Built Asset Management, Housing, Risk, Resilience.

1. Introduction

The world’s climate is changing in ways that will have a significant impact on both human society and the built environment (IPCC, 2014a). These changes affect not only average temperature but also results in changed temperature patterns and in particular the severity and frequency of extreme weather events (ibid). Whilst the impact of climate change is different across the world it is urban centres that are likely to be at greatest risk and where action needs to be taken to improve resilience to climate change threats (IPCC, 2014b). To this end actions that accelerate adaptation of the built environment are required (ibid). In particular actions are needed that reduce the vulnerability and improve the resilience of urban systems (e.g. housing, buildings and infrastructure etc.) and provide the governance, policies and incentives to realise adaptive capacity (ibid). This paper reports the development of a built asset climate change adaptation model for social housing in London. The paper supplements a previous publication by Jones et al (2013) where the climate risks to London were discussed and the theoretical base to the risk framework model was presented. This paper provides details of a participatory action research project that integrated the risk framework model with built asset management theory and tested the resulting model against approximately 4000 housing units in London. The paper concludes with a 10 step approach to adaptation planning that should allow Facilities Manager’s to develop built asset management plans to reduce the vulnerability and improve the resilience of their built assets.

2. Background

Whilst in the UK the impact of a changing climate on new buildings can be accommodated through new design standards and planning guidance (CLG, 2007; CLG, 2009; Environment Agency, 2009), the same instruments are not universally applied to existing buildings. As such many existing buildings could be vulnerable to the impacts of climate change, and particularly extreme weather events (EWEs), requiring adaptation if they are to remain viable (Saunders & Phillipson, 2003). Further, in the UK adaptation to climate change is not generally considered part of routine maintenance/refurbishment and it is unclear whether the approaches used by the climate change community (UK climate projections, risk frameworks) can be effectively integrated into built asset management models. These issues are particularly acute in London where it is already apparent that the changing climate could have a significant impact on the ability of existing social housing to provide the quality environment expected by residents (Jones et al, 2013). This poses a problem for many landlords; how do they prioritise adaptation for an uncertain future climate over solutions that improve the immediate quality of their housing stock today?

The EPSRC Community Resilience to Extreme Weather (CREW) project studied the potential impact that a range of extreme weather events could have on the vulnerability, resilience and adaptive capacity of buildings in the SE London Resilience zone (Hallet, 2013). The CREW project used the UKCP09 probabilistic weather files to predict weather patterns across SE London and then superimposed these onto topographical and drainage information to generate extreme weather impact scenarios for 2020 and 2050. The scenarios were then used to investigate the risks to housing of overheating and flooding and to identify adaptation solutions that could reduce vulnerability and improve resilience. One of the key outputs from the CREW project was a risk based adaptation framework (Fig. 1) that sought to guide facilities managers through the climate change adaptation assessment process. In this framework future scenarios are used to predict the degree of change over current conditions that could occur to a building(s) as a consequence of climate change. For each potential impact a risk assessment is then performed to identify impacts and cost adaptations. These adaptations are then prioritised and integrated into contingency plans (Jones et al, 2013). The application of the adaptation framework forms the background to this project.

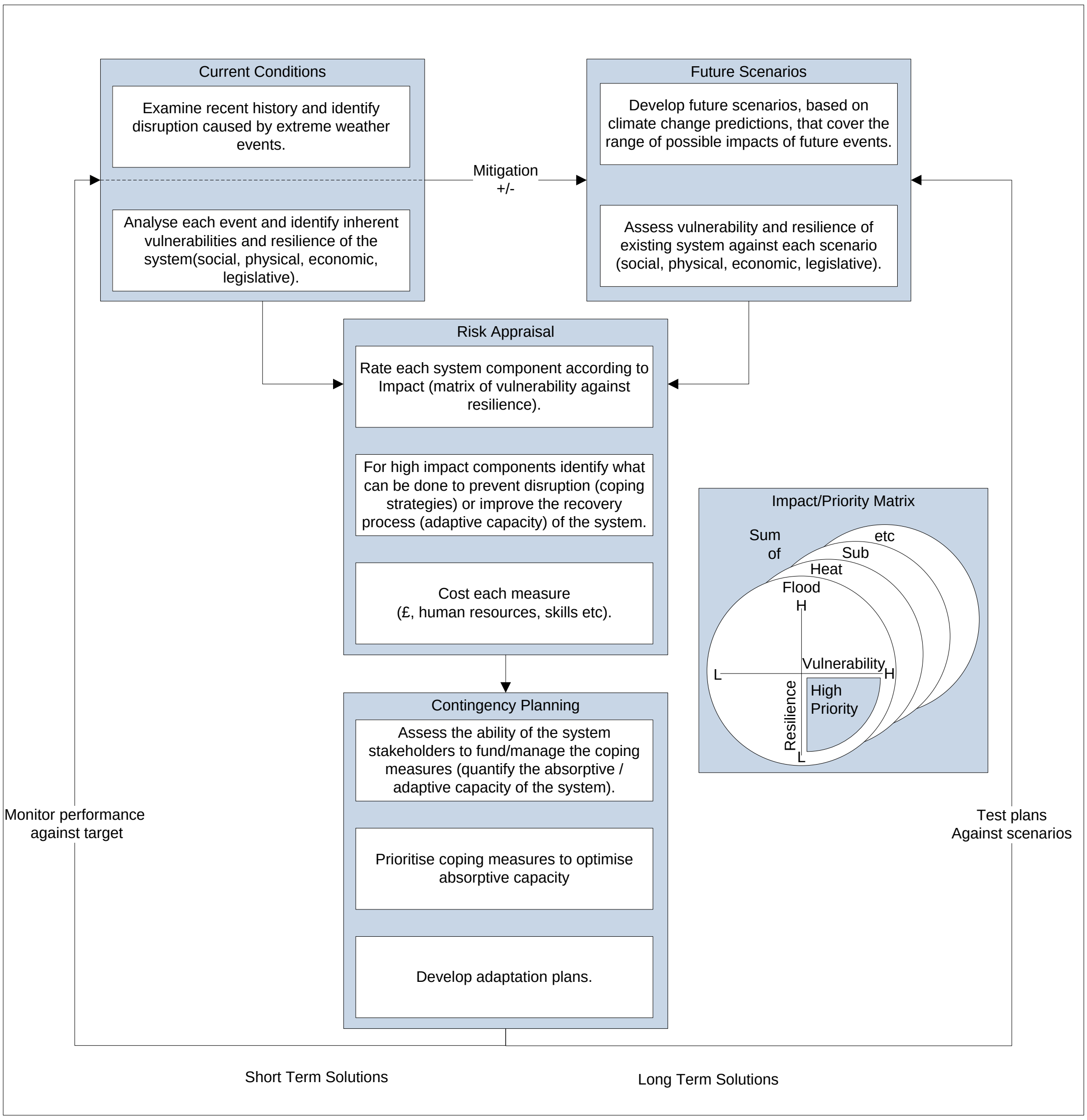

Figure 1: Adaptation Framework (Hallett, 2013)

In order to test the applicability of the adaptation framework to inform maintenance and refurbishment plans it needs to be integrated into a performance based built asset management model (Jones and Sharp, 2007) (Fig. 2). The performance model involves: identifying the critical success factors (CSF's) against which maintenance and refurbishment (including climate change adaptation) will be judged; establishing a series of performance toolkits that measure the performance-in-use of each property; establishing the underlying cause of any underperformance; developing action statements that describe the required improvements in performance; developing and evaluating adaptation solutions against the organisations CSF's; and evaluating the success of the adaptations and provide feedback to the organisation's climate change adaptation policy and strategies. This project developed the tools necessary to achieve this integration. This paper builds on work previously published (Jones et al, 2013) where the background to, and further details of, the factors that affect the vulnerability, resilience and adaptive capacity of UK social housing to climate change can be found.

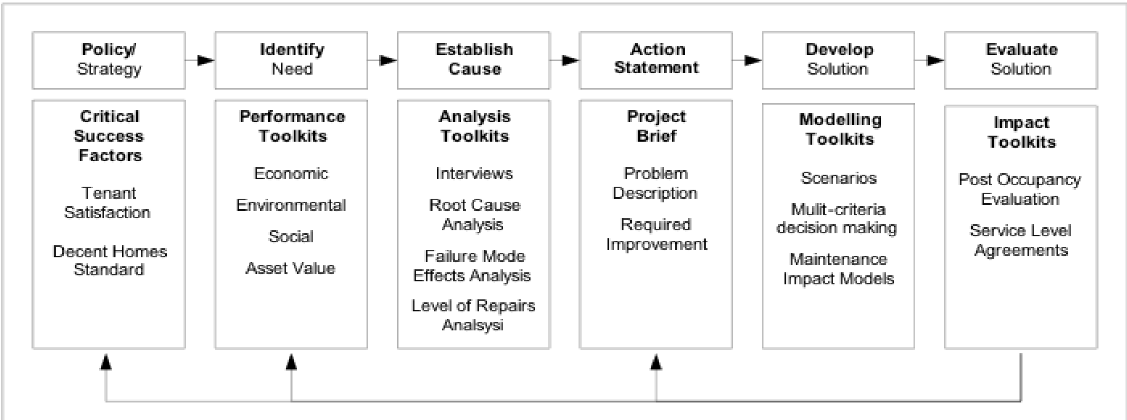

Figure 2: Performance Based Built Asset Management Model (Jones and Sharp, 2007)

3. Methodology

The focus of the project was a UK Registered Social Landlord (RSL) that owns and manages approximately 4000 homes, located mainly in inner London. The RSLs property portfolio was extremely diverse, ranging from large modern purpose built blocks, to Victorian street properties. Whilst he RSL owned few whole houses, more than 86% of its stock was made up of maisonettes and flats (the majority the result of the conversion of houses rather than purpose built blocks). Forty six percent of the stock were bedsits or one bedroom properties, 33% were two bedroom properties; 18% were three bedroom properties; and the remaining 3% were 4 and 5 bedroom properties. Forty nine percent of the stock was built before 1919; 8% between 1919 and 1944; 22% between 1945 and 1980; and 21% post 1980. A number of the RSLs properties were Listed Buildings and others were in Conservation Areas. At the time of the project the majority of the stock was in a reasonable state of repair, with the RSL spending approximately £11m per year on maintenance/refurbishment and a further £25m on new build. The RSL had a comprehensive asset management database, including an up to date condition survey of their stock, and had maintenance/refurbishment plans in place for general improvements over a 5, 10 and 30 year period. The RSL also had detailed contingency plans to deal with flooding events. For logistical reasons the fieldwork was limited to a sample of the RSL's housing, of 1255 properties or 31.46% of their total stock, located in a single London Borough.

A series of facilitated workshops, semi-structured interviews, building surveys of archetype housing units (undertaken by the RSLs consultants using standard UK guidelines), building simulation models and life cycle costing analyses were used to develop and test a range of practical adaptation planning tools that could be used to integrate climate change adaptation into the built asset management process. The field work for this project took place in 2012/13. Although the project examined both flooding and overheating for the sake of brevity only the flooding results are presented here.

4. Results

The following section describes the process that the participatory action research team went through to integrate the adaptation framework (Fig 1) into the performance based built asset management model (Fig 2).

Step 1 - Identify Policy/Strategy Drivers: The first task was to establish the Critical Success Factors (CSFs) against which current and future performance would be judged. This was done through discussion with senior managers and by reference to the RSLs strategic plan and operational documents. The RSLs approach to the quality of their housing was governed by their 'Performance Standard' that described expectations for the quality of the stock. Although the Standard didn't explicitly address the impact that climate change could have on a house it did establish the general principle that:

> *"Your home should be in good working order and fit for purpose - it should meet a certain set of standards, both inside and outside and in shared and private areas to make it a safe and healthy environment to live in."*

The Standard also implied that the RSL would adopt a proactive approach to ensuring that its homes meet the Standard. To this end the 'Standard' provided the basis from which CSF's were derived and against which the success of adaptation solutions would be measured. For flooding these were:

1) Reduce disruption to tenants from flooding events. Performance thresholds to relate to the degree of disruption that a flood event would cause to tenants.
2) To continue to maintain tenant confidence and trust in the RSLs ability to deal with climate change issues. Performance thresholds to be measured through the tenant satisfaction survey.

Once the CSFs had been established a set of performance toolkits were developed to help identify adaptation needs.

Step 2 - Identify Need: Toolkit 1 sought to identify those properties that were located in a potential (current and future) flood zone AND were vulnerable to water ingress. This toolkit involved superimposing the RSLs properties onto flood maps using geo-referenced data and a geographical information system to identify those properties that were at potential risk of flooding. Each property was then examined in more detail (using the RSLs asset management database, Google Street View, and external street surveys) to identify the potential for water ingress assuming a 0.5

m flood in the street immediately adjacent to the property. A combination of the potential flood risk and likelihood of water ingress into the property was used to determine the property's level of vulnerability (Fig. 3)

Toolkit 2 sought to quantify the impact that exposure to a flood would have on the performance-in-use of those properties at risk of such an event. Assessments of the potential impact of flooding events on a sample of those properties identified as highly vulnerable to such an event was used to identify their coping capacity. A combination of the potential damage that a flood event would cause and the recovery time it would take to return the property to its pre-flood performance level was used to categorise the properties coping capacity threshold as Low Medium or High.

		Likelihood of a flood event			
		No likelihood	Low	Medium	High
Likelihood of water ingress to the property / damage to critical infrastructure	No likelihood	Not vulnerable	Not vulnerable	Not vulnerable	Not vulnerable
	Low	Not vulnerable	Low	Low	Low
	Medium	Not vulnerable	Low	Medium	Medium
	High	Not vulnerable	Low	Medium	High

Figure 3: Typical vulnerability threshold matrix for flooding

The vulnerability and coping capacity for each property identified as 'at risk' of flooding was plotted onto a Resilience Matrix (Fig. 4). From this figure a number of properties were identified as highly vulnerable with a low coping capacity and these would be prioritized for early action in the asset management plan. Those properties that were highly vulnerable but had a Medium/Low coping capacity would be prioritized as short-medium term action in the asset management plan. Those properties that had a low vulnerability and high coping capacity would be reviewed at regular intervals as more climate change data became available.

Step 3 - Establish Cause: Internal surveys of 26 typical properties were undertaken to establish the root cause of flooding damage and to identify potential adaptation solutions. In all cases these solutions were affected by legacy design decisions made when the buildings were newly constructed or underwent major refurbishments.

Adaptation options in the form of resistance (preventing water entering the property) and resilience (increasing speed of recovery once the property has flooded) measures were considered for each surveyed property. From the surveys it was clear that it would be very difficult (if not impossible) to prevent water entering basement flats or basement floors of individual houses. Further, once water had entered the property it was likely to cause significant damage to both building components and fixtures & fittings that would require significant work in order to return the property to a habitable condition. Thus the best adaptation strategy for this type of property would be to let it flood but to improve the resilience of building components (non-structural) and fixtures & fittings to shorten the time it would take to return the property to a habitable condition. Similar analyses were undertaken for ground floor flats, houses and communal areas and a set adaptation principles (Fig 5) were developed in the form of an ***Action Statement (Step 4)***.

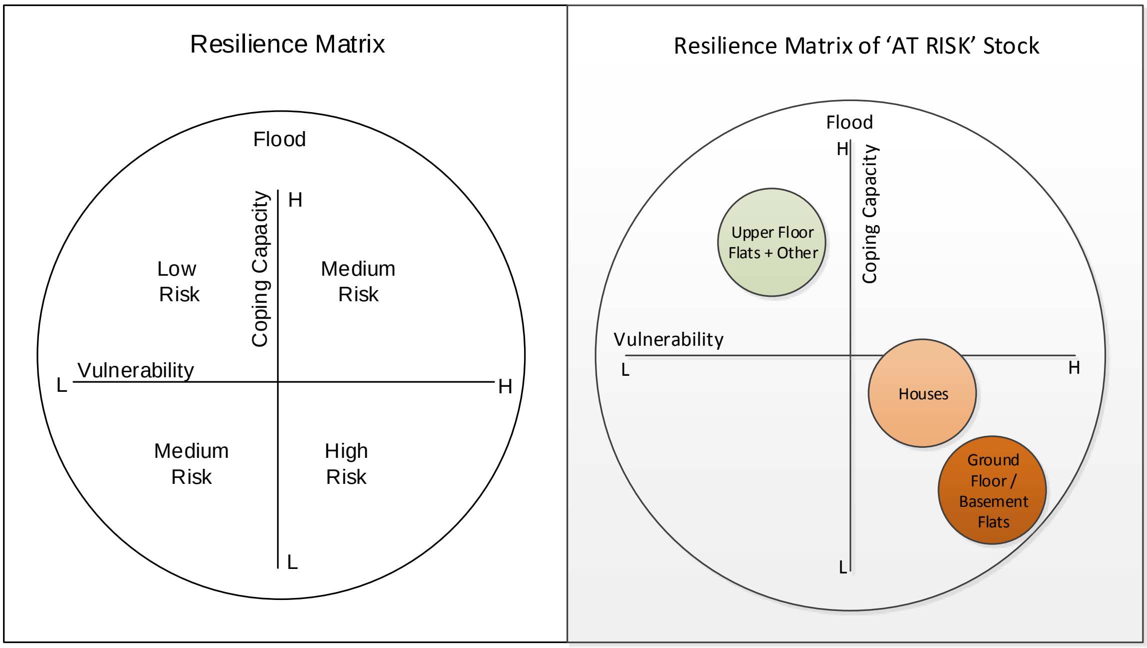

Figure 4: Generic resilience matrix and specific resilience matrix for flood risk properties

Adaptation Guiding Principles

- If it is economically feasible to prevent flood water entering a property then this should be adopted.
- Water resilient components, fixtures and fittings should be installed when flood ingress is likely.
- Ensure all essential services are resistant to a flooding event.
- Work with residents to prepare personal flood action plans.

Figure 5: Adaptation principles

Step 5- Develop Solutions: The potential (technical and cost/benefit) for a wide range of flood resistance and resilience measures were assessed for each archetype property. A set of triggers and thresholds were developed to allow potential adaptations to be prioritised for inclusion into the built asset management plan. At the strategic level these triggers and thresholds tended to be statements of intent or desire, rather than quantified metrics to instigate an action. These statements of intent were related directly to the RSLs 'Performance Standard' and were expressed as commitments for each quadrant of the Impact/Priority Matrix shown in Fig. 4 and summarized in Table 1.

In addition to the generic triggers and thresholds outlined above, specific action should be taken in Year 1 of the adaptation plan to address known, current problems. Where the problems are known, but the scale is unknown, action should be taken in the first 5 years of the adaptation plan to quantify the scale of the problem. Where there is uncertainty about the potential problem or a solution the situation should be regularly monitored. These thresholds and triggers are summarized in Table 2.

Table 1: Action trigger/thresholds for flooding adaptations

Resilience Quadrant	Action Trigger/Threshold
High Vulnerability / Low Coping Capacity	Take action to improve resistance and/or resilience in the next 5 years.
High Vulnerability / High Coping Capacity	Take action to improve resistance and/or resilience in years 6 to 10.
Low Vulnerability / Low Coping Capacity	Take action to improve resistance and/or resilience in years 11 to 30.
Low Vulnerability / High Coping Capacity	Take no action.

Step 7 - Adaptation Strategy: Once all the previous described steps had been completed an adaptation strategy was developed to address the potential impact of flooding both today, and in the future. A typical part of the adaptation plan is shown in Table 3.

Table 2: Thresholds and triggers for action in an adaptation plan.

Year to Action	*Threshold*	*Trigger*
1	Know scale of problem and solution	Known level of risk is high
2-5	Know problem exists but don't know scale or	Establish level of risk
6-30	Unsure if problem exists. Don't have a solution	Continue to monitor risk

Table 3: Example extracted from the adaptation strategy

Property Type	Vulnerability - FLOODING	Timescale for Action
Vulnerable Street Houses	Where ever possible floodwater should be prevented from entering the house. Depending on the depth of any water entering the house (will depend on floor level above the street, existence of a basement etc.) resilient fixtures and fittings should be used to ensure that the house can be returned to a habitable condition in the shortest period of time.	
	Undertake detailed surveys of the vulnerable properties identified in this report to identify the flood resistant actions required to prevent water entering the property (including the sealing of air bricks, appropriateness of door dams, non-return valves on drainage and foul water systems etc.). Identify the impact that any floodwater entering the property would have on the post-flood recovery period. These plans should include a detailed assessment of post-flood	Year 2-5

	building works and an estimate of the time to return the house to a habitable (or part habitable) condition.	
	Assess the potential of resilience measures to reduce the estimated time to return the house to a habitable (or part habitable) condition. In particular examine measures that improve the resilience of essential services, kitchen and bathroom areas. Undertake a more detailed cost/benefit analysis of these measures and implement those that are appropriate when next refurbishment is planned.	Year 2-5
	Ensure that the RSL is signed up to the environment agency early warning service and develop a communications strategy that informs its residents of an impending flood events and keeps them informed of progress through the clean-up and repair phase.	Year 1
	Engage with the residents living in these houses to ensure that they are as prepared as possible for potential flooding events. Consider providing labour to assist residents in the removal of personal and treasured items to the upper floors of the houses.	Year 1
	Ensure that arrangements are in place with alternative landlords to provide temporary accommodation for those residents displaced by a flood.	Year 1

5. Discussion

This project sought to test the theoretical adaption framework developed through the CREW project by developing a set of tools that could be used to integrate it into a performance based built asset management planning model. Through this process a new 10 step model for adaption planning for future climate change was developed. This model is summarised in Table 4.

Table 4: Ten step adaptation planning model

Step		**Actions**
1	Identify current climate related threats to your stock	Examine local histories for details of climate related impacts. This could involve reviewing national and local climate risk assessments (e.g. flood maps) and identifying previous extreme weather events that have affected the region where properties are based.
2	Develop future climate impacts scenarios that are relevant to your circumstances	Identify future climate impact change predictions for your area. This could include reviewing national climate change assessments where they exist and undertaking absolute climate change assessments where possible. In most cases individual organisations will not have access to the resources necessary to undertake absolute assessments so relative (step-up or morphing) assessments can be used as an alternative to predict the scale of potential future extreme weather events.

3	Map current and future climate threats to your property portfolio	Examine known vulnerabilities of your stock to the key weather impacts. This would include geo-mapping the location of each of your properties onto current and future climate change risk maps (e.g. flooding, overheating etc.) and identify the numbers of properties at risk and the level of the risk (e.g. flood type, flood depth, flood duration etc.) for each property. Review the ability of existing disaster planning to cope with any increased incidence of extreme weather events.
4	Identify the coping capacity of your properties to current and future climate threats	Assess the impact that a climate related event would have on your property portfolio. This would involve identifying typical property archetypes for a range of climate change events (flood impact assessments, overheating etc.) ensuring that the organisation have the data (either in their asset management system or through housing surveys) to assess the vulnerability and coping capacity of the property to each event. Develop organisation specific vulnerability and coping capacity thresholds for each property archetype against each climate change impact. Plot vulnerability and coping capacity onto a Resilience Matrix.
5	Identify possible adaptation solutions	Identify appropriate resistant and resilience measures. This will include modelling the effect of a range of adaptation options against each archetype for each climate change impact and assessing the technical feasibility of retrofitting adaptation measures.
6	Articulate required improvements to the performance of your properties	Identify performance expectations for your properties against each climate change impact. For example, • Let properties flood and ensure rapid recovery; or • Prevent water ingress where ever possible; or • Ensure at least one room in every property does not over heat; etc.
7	Identify priorities	Develop priority thresholds based on the performance expectations identified in step 6. Identify what types of adaptation should occur in years 1-5; 6-10; and years 11-30?
8	Develop adaptation strategy	Identify the actions to be taken for each vulnerable property archetype. This could include identifying known problems for immediate action in year 1; gathering missing data (surveys) for high risk properties in years 1-5; and monitor performance of medium risk properties in years 6-30. All other missing data should be collected as a part of the normal re-survey cycle.
9	Prepare adaptation plan	Identify individual properties requiring action in years 1-5 (steps 3, 4 and 8). This will involve detailed (property level) assessments of the potential for different adaptation solutions identified in step 5 to achieve the performance improvements identified in step 6. Use priority thresholds (step 7) to order adaptation actions. Cost each solution and select appropriate ones for inclusion in the adaptation plan. Develop an adaptation programme for the works over a 5 year period.

10	Implement and test plan	Monitor effectiveness of interventions and close the feedback loop. If you experience a climate related event how well did your plans work? If you don't experience an event then test your plans against a simulation. Review the effectiveness of your Disaster Management and Contingency Plans

Whilst the theories supporting the adaptation framework and the performance based built asset management complemented each other, and at the theoretical level integration was fairly easy to achieve, a number of issues were identified that limited its practical application.

Whist access to public data on past extreme weather events and potential impact of none climate change future events was generally available and suitable to inform step 1 of the adaptation planning model the data required for steps 2 and 3 wasn't. Whilst UKCP09 climate change projections provided a means of generating future weather patterns the lack of future risk assessments (e.g. future flood risk maps, local heat islands etc.) made it difficult to assess the future vulnerability and resilience of the housing stock. As such the project scenarios were based on possible relative changes to weather impacts rather than absolute risk projections. Whilst these scenarios worked well when introducing the problem and examining the generic vulnerability and resilience of the housing stock (see Jones et al, 2013 for further details), the lack of probability risk factors associated with the different scenarios limited their credibility when trying to prioritise adaptation actions. The lack of projected climate risk data must be addressed if real advances in adaptation planning are to be made.

Whilst the toolkits developed to assess the impact of flooding (and overheating) on a range of archetypal properties worked well, allowing 'potentially at risk' properties to be clearly identified and generic adaptation solutions to be evaluated, the level of data required by the toolkits was significantly greater than that which existed within the RSLs built asset management database (step 4). As such re-survey work (internal and external) had to be undertaken to identify the potential impacts that flooding (and overheating) would have on the performance of a range of property archetypes before indicative adaptation solutions could be identified and evaluated (step 5). Going forward the additional data needed for adaptation to climate change should be gathered as part of the routine stock condition survey process.

Whilst the RSL had a clear understanding of its performance criteria through its 'Performance Standard' translating this into generic adaptation principles (step 6) and strategic level thresholds that trigger inclusion of an adaptation into their built asset management plans (step 7) was more complicated than had originally been considered. For example the RSL had a number of basement flats that were at risk from pluvial flooding. Whilst the initial approach to adaptation (from the performance standard) was to make these properties resistant to flooding, it became clear through the study that such adaptations would be uneconomical to achieve. As such a compromise threshold was agreed for these properties to allow them to flood but improve their resilience to speed up recovery. Initially the RSL were very concerned that this approach would be interpreted by tenants as a 'don't care' attitude (contrary to the Performance Standard Principles) and as such they added a non-technical adaptation to work closely with tenants in the potentially 'at risk' properties to explain how they will support tenants through a flooding event. This included working with tenants to help them develop personal flood plans; providing support to allow tenants to protect valuable items; and having robust relocation plans in place.

The other problem with setting meaningful priority thresholds (step 7) and developing adaptation plans (steps 8 and 9) was the lack of quantifiable (probabilistic) projected weather impact data and the numerous gaps in building data meant that only the most obvious adaptations were prioritised for action with the vast majority of adaptations being put 'on hold' until better information is available or until the future risk became obvious. As such, the adaptation strategy can best be described as cautious and reactionary. This approach is at odds with the need to accelerate adaptation of the existing built environment (IPCC, 2014b).

6. Conclusions

This project sought to integrate a theoretical adaptation framework with a performance based built asset management model to provide an approach by which Facilities Managers could develop short, medium and long term climate change adaptation plans. The project has described how a series of performance toolkits can be used to identify potential impacts of climate change on the performance of a house and how triggers and thresholds based on an organisation's CSFs can be used to prioritise interventions as part of routine maintenance and refurbishment planning. Although developed for housing the 10 step model should be applicable to most property types.

Whilst the underlying theory and the assessment tools developed in the project worked well, some of the underlying data required to support the tools was lacking or incomplete. As such, working assumptions had to be made that reduced the level of detail and confidence that Facilities Managers had in the final adaptation plans. At the time of this project there was no consistent UK wide data on the future impact that climate change could have on physical performance of the building stock. Most flood maps that were available didn't accommodate climate change scenarios and, in the case of pluvial flooding, didn't map future rainfall predictions onto local drainage topology. As such the future flooding scenarios lack the currency associated with existing fluvial flood assessment. Where there are accepted climate change models, organisations asset management databases don't generally contain the level of building detail required to develop adaptation solutions. Whilst these issues do not undermine the development of the adaptation strategy, they will influence attitudes towards adaptation planning, resulting in a wait and see approach which is at odds with the needs to plan for the implications of climate change. Better national and organisational data sets are needed to address this shortcoming.

Finally, whilst the technical approach described in this paper worked well, it was developed within a mature (in climate change adaptation and mitigation terms) organisation that had previously assessed its vulnerability, resilience and adaptive capacity to respond to potential climate change threats (see Jones et al, 2013). The approach may not be as easy to replicate for organisations who have not gone through this process. Also, it should always be remembered that it is people who are ultimately affected by the impacts of climate change and more work does need to be done to understand the factors that affect an individual's vulnerability and resilience. In this study no account was taken of vulnerable people living in vulnerable houses.

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The Construction Project Manager’s OSH Responsibilities

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Abstract

The role of Project Manager is central to a successful safe and healthy execution of any construction project. While there are specific statutory obligations placed on various duty holders across the entire construction process, from the Client through to the worker, it is a core responsibility of the Project Manager to ensure that the hazards that exist in construction do not present harm to the workers and anyone else affected by the construction activity. There are ample sources of advice and guidance available. The Institution of Civil Engineers works closely with Health and Safety Executive in UK and in Northern Ireland to ensure that the highest possible standards of health and safety are developed, promoted and adhered to. This clearly should come within the ethics reasoning of any professional.

This paper introduces key aspects of safety, health and welfare in construction with particular emphasis on project management. The practice based paper examines how the project managers responsibilities developed under the previous (2007) CDM regulations and how these duties are impacted under the CDM 2015 and the proposed CDM (NI) regulations.

Keywords: Construction Design and Management (CDM), Operation Analysis and Control (OAC), Clients, Designers, Principal Contractors, CDM Coordinators, Health and Safety File

1.Introduction: Principles of Health and Safety

Robens (1972) in his report, presented to Parliament by the Secretary of State for Employment stated that “…the first and perhaps most fundamental defect of the statutory system is simply that there is too much law” and in an attempt to simplify the situation recommended a self-regulating system of safety and health provision, where industry and commerce are encouraged to address their own safety and health issues, supported by a single enabling act and a series of appropriate standards and voluntary codes of practice. Much has happened since then but Robens’ fundamental concept holds true. Self-regulation is crucial to good health and safety management and while the influence of Europe has resulted in the introduction of several regulations since the early 1990s the focus in the UK remains consistent.

The core legal requirement for employers is to ensure, so far as is reasonably practicable, the health, safety and welfare at work of all their employees. The parent law is supplemented by regulations, approved codes of practice and guides that provide specific details on how that duty may be met in regard to particular work operations and industries. Across Europe the basic premise in construction safety legislation is that projects should be designed so that they can be built, used, maintained and demolished in a manner that does not cause harm to the workers or others who come in contact with them and that is the essence of the UK's Construction (Design and Management) Regulations (CDM). For many years legislators have been intent upon creating the conditions whereby risk in the workplace would be eliminated. However despite the existence of our present laws, the introduction of new laws such as CDM 2015, and the continuing implementation of supplementary regulations and codes of practice, workplace accidents continue to occur unabated, albeit with a decreasing rate of incidence. However it is not the standard of the law that causes accidents in the workplace. The state aims to eliminate workplace accidents and ill health and many safety professionals understand that to be the intent behind risk management. Yet the mistaken notion has grown up around safety that risk management simply means reducing risks to 'an acceptable level'. This is far from being the intent of legislation since the legal requirement is to secure the health safety and welfare of persons at work through the provision of safe working environments and products. Additional new laws are not needed to control the construction industry, but rather a reexamination of what exists with a view to managing things better. What is needed is a dynamic management model, focused on the elimination of or control of hazards that can produce significant improvements.

Failure to comply with statutory requirements is a criminal matter and the reverse burden of proof placed on a defendant (i.e. the need to prove your innocence), a peculiarity of H&S legislation, emphasises the importance of being able to identify and control hazards throughout the construction process and of being aware of and implementing guidance and good practice (Metherall 2015). This approach is broadly similar across European Union (EU) member states, since much of the present day H&S legislation is derived from EU Directives. A more detailed discussion of H&S law and how it relates to the construction industry is given in the ICE Manual of Health and Safety in Construction (McAleenan and Oloke, 20105).

2.Safer and Healthier Workplaces

It is not just the law that requires that employers and employees have due regard for the potential for harm, inherent in work activities. One of the three paradigms in the Seoul Declaration (ILO et al 2008) refers to the 'prevention culture' indicating that "...it needs to be supported and sustained by shaping and implementing OSH policies, strategies and programs fully reflecting preventive measures". Furthermore the OECD Principles of Corporate Governance state "…boards are expected to take due regard of, and deal fairly with … stakeholder interests, including those of employees, creditors, customers, suppliers and local communities". Therefore there is a moral, legal and principled obligation to manage construction projects in a manner that will not only prevent harm or injury but also protect others from it and this obligation extends to design quality; that combination of functionality impact and build quality that incorporates the key requirements of all the stakeholders, business and whole-life value in relation maintenance, management, flexibility, health and safety, sustainability and environmental impact (Office of Government Commerce, 2004).

Many workplaces are safer and healthier today not simply because of legislation but as a result of the efforts of workers, engineers, safety professionals, legislators and philanthropists. However with 2.3 million dying each year because of workplace accidents and ill health (International Labour Organisation (ILO) 2008) it cannot be asserted that work in general has become safer. There is still a way to go. It is now common in safer workplaces for risk and hazard assessment to be part of good work practices. Metherall (2015) stated that what matters "…is that construction work is organised and done safely" and it is here where the role and the focus of the Project Manager needs to dominate. Knowledge and understanding of the safety legal framework is secondary but that knowledge can help identify what steps must be taken. Metherall (2015) further indicated that the legal framework based on self regulation rather than prescription, has a tiered approach moving from the general obligation in the Health and Safety at Work Act 1974 (Health and Safety at Work (Northern Ireland) Order 1978) to provide and maintain plant and systems of work that are (so far as is reasonably practicable) safe and without risks to health, through to regulations, then to Approved Codes of Practice (ACoPs) and Guidance and finally to the development of good practice.

It is true that construction sites are hazardous environments, with high consequences should control measures be omitted or fail. The Health and Safety Executive (HSE) recognise the main causes of harm in construction as; falls from heights (33% of construction industry injuries), struck by object (13%), and slip, trips and falls (27%), (HSE 2015a, 2015b). Additionally there are health issues such as exposure to harmful agents (such as asbestos and silica), vibration, noise and manual handling (HSE 2015a). Gibb (2015) describes occupational health (OH) as "the poor relation of occupational safety" and goes on to describe OH as "a slow accident". Ill health continues to kill and disable significant numbers of construction workers and the delay in the outworking of the effects is one of the main reasons why the subject must be taken seriously. The major point of concern is that Project Managers are less clear in their understanding of their role regarding the prevention of ill health than they are about safety and this has got to be corrected. Gibb (2015) describes in great detail the various OH issues and the actions that designers and project planners can take to eliminate or reduce ill health effects from the construction process. But the existence of hazards does not make the industry dangerous. There needs to be a negative act or omission before the harm is realised. Every incident represents a loss of control of the work operation. Whether that loss of control can be attributed to the individual worker, or to a Project Manager, at the highest levels of the planning and design stage of the project is not so important as establishing how and why it happened and putting plans in motion to ensure that there isn't a recurrence.

The normal understanding of the word accident is referring to something specific that was unforeseen, unpredictable and/ or an unusual occurrence with no apparent cause. In construction where a Project Manager has a sound and thorough knowledge of the site, the project and the construction processes involved and having analysed the range of operations, identified the hazards and established the necessary controls it is not acceptable to contemplate unusual incidents with no apparent cause. At this point it is worth establishing that accidents don't just happen, rather they are the result of failures in the control process and that should never happen in a well managed project. But Projects Managers cannot deliver a safe and healthy project in isolation, it requires a team effort where they, their site supervisors and the workers control and influence safe and healthy progress, each according to their level of competence and authority, (Maharaj et al 2012, Postman and McArthur 2015).

3.Health and Safety Roles and Responsibilities

3.1.Health and Safety Executive

Great Britain and Northern Ireland's Health and Safety Executives are each "…an independent prosecuting authority who take action against those who put workers at risk of death, illness or injury" (HSE 2010). Among other things they;

- Advise on legislation,
- Produce approved codes of practice and guidance,
- Regulate and enforce compliance with health and safety legislation,
- Investigate workplace fatality, injury and illness incidents,
- Maintain workplace fatality, injury and illness statistics, and
- Carry out appropriate scientific research

3.2.Project Managers

Lingard and Rowlinson (2005) identified construction as a project-based industry and discussed the need for an appropriate structure to deal with the changing nature of the project. As it moves "...from design to construction to in-use phases, and as problems arise there is a need for rapid, decentralised decision-making, contingency planning and an appropriate, organic form of organisation". This engenders a free, independent spirit among construction site personnel and here Lingard and Rowlinson (2005) caution that this freedom could lead to "a disregard for authority and regulations". Such a warning is one that a Project Manager needs to be clear about since he gives both safety guidance and direction in the construction phase of any project. The lessons learned from safety failures in Nuclear Newbuild (e.g. Flamanville 3 NNB in Maharaj et al 2012) post to the need to establish project teams and high calibre managerial and engineering people … and led by a person with the authority to act, (Maharaj et al, 2012). The attitudes and behaviours displayed on construction sites are largely down to the drive and determination of the Project Manager to get the job done well and done safely. Project Managers are key to ensuring that corporate safety and health strategies are delivered at the site level and the culture is one of caring and support for the entire workforce. Therefore where accidents or incidents occur it is crucial that the safety health and welfare of the workers are uppermost in the considerations of the entire management structure, with work progress coming in behind, at a judicious interval.

3.3.CDM Roles

The CDM regulations define the roles and responsibilities of some, not all of the players in construction projects. In the legislation Clients, Designers, Contractors, Workers (and in Northern Ireland, CDM Coordinators) are all given specific legal duties. A short synopsis follows;

3.4.Clients

Clients are required to assess the competence of those they engage to execute a construction project, provide designers and contractors with pre-construction health and safety information (the information that will assist in determining inherently safer design solutions and construction phase safe working methods and resources), ensure that appropriate project health and safety management arrangements are in place before projects commence and where projects are notifiable (longer than 30 days or more than 500 person days of construction work) appoint a Principal Contractor and a CDM Coordinator.

3.5.Principal Designers

A principal designer must plan, manage, monitor and coordinate the pre-construction phase of a project, taking into account the general principles of prevention to ensure that the project pr ogresses without risks to health and safety. The PD must ensure that appropriate assistance is provided to the client in the preparation of pre-construction safety information that includes the identification and elimination or control of hazards likely to effect workers carrying out the construction phase. The PD has the additional duties to ensure the cooperation of all persons working on the project and to ensure that the designers are aware of and are complying with their duties under the regulations, this includes an on-going liaison with the Principal Contractor for the duration of the project.

3.6.Designers

Designers are required to check that project clients are aware of their CDM statutory obligations, be satisfied that they have the competence to undertake the design, consider the pre-construction information and design the project in a manner that it can be built, used maintained and eventually demolished without causing harm to workers or other affected by the structure or building.

3.7.Principal Contractor

The principal contractor is the Project Manager for the construction project and as such is required to plan, manage and monitor the construction phase to ensure that health and safety is appropriately delivered throughout. There can only be one principal contractor therefore ensuring that the other contractors and the workforce are engaging with and coordinating their project health and safety activities are his responsibility. The Project Manager, on behalf of the principal contractor should ensure that the construction phase plan is followed and that any information required for the Health and Safety File is collected and made available before the project hand-over. HSE (2010) describes the Health and Safety File as follows;

"...the file will contain information necessary for future construction, maintenance, refurbishment or demolition to be carried out safely, and is retained by the client or any future owner of the property. (Where a client gets non-notifiable work done, and a health and safety file already exists for the premises, it should be updated if necessary). The file should be a useful and valuable document for the client".

3.8.CDM Coordinator (NI only at the date of writing)

The CDM Coordinator is appointed where projects are notifiable. Their primary role is to give advice and assistance to Clients. Additionally they are to ensure that health and safety has been adequately addressed in the design phase, collect pre-construction information to be made available to the principal contractor and where there is more than one designer they are to check that they are cooperating and coordinating their design information. They do not have a role in site management and during the construction phase their involvement is limited to collection of information for the Health and Safety File and ensuring health and safety is considered, should any redesign take place.

Health and Safety Executive (2007) and Oloke (20105) describe the CDM roles in greater detail.

4.Effective Project Management

Effective project management is concerned with controlling the operation, the process and/ or the system in order to achieve its objectives. The extent to which it succeeds is directly linked to the degree of management effectiveness, which must be focussed on the outcomes rather than simply the processes and methodologies. It must recognise and respond appropriately to factors that impinge upon the outcomes and ensure that the desired outcomes are attained and the principal that management is solely concerned with outcomes falls short if the outcomes are defined purely in terms of product. They must be defined in the wider quality assurance terms that include quality of product, cost effectiveness of production, health, safety and welfare of and appropriate remuneration for workers, safety of customers, sustainability and organisational profitability. The correct activities are those that control the operation properly to achieve the right outcomes. However, where risk exists, control is weakened because risk means that there is a possibility that harm may result; in essence risk exists where there is ignorance of (or choosing to ignore) some or all of the facts and it isn't known with absolute certainty whether the operation will succeed or fail. Every action will therefore have an outcome that is either desired or undesired and a managed operation is one in which all of the hazards have been considered and the controls have been put in place so that the operation itself is free from risk. By effectively managing the operation, concern can then be focused on the reliability of the control mechanisms rather than the probability of exposure to the hazard itself (Gerry Ayers, Australian Construction Safety Professional, in private correspondence with the authors (2002))

Whereas 'risk' is a subjective measure of the possibility of danger being realised, management is the authoritative control of operations, a critical aspect of the Project Manager's responsibilities. The purpose behind the Operation Analysis and Control (OAC) model (McAleenan and Oloke, 2015) is to ensure that work operations are carried out in strict accordance with all relevant 'safe working' procedures. In this way, with high quality planning and implementation you can make sure that people, plant and property are protected from harm prior to, during and after the work operation, regardless of the nature of the hazards faced. Planning any project without reference to the safety requirements means that the project will fail, certainly and, often, spectacularly. Effective management requires that safety is considered as an integral aspect of the project, central to and fully integrated with the project objectives. What a good planning process delivers is consideration of the objectives as well as the means and the methods of achieving them. All elements of the project and every eventuality are considered, in advance and appropriate actions developed and scheduled. Anything that is left out, by accident or by design exposes the project and the company to risk and consequently the likelihood of an undesirable outcome. It is here where the twin survival objectives come strongly to the fore, that is; where workers safety (survival of the individual) and company profitability (survival of the company) co-exists (McAleenan and McAleenan 2010).

In defining the outcomes, and all the relevant considerations the OAC approach requires the identification of the principal actors necessary for the establishment, development and successful achievement of the project. The competence and expertise of a wide range of personnel are needed to input to the various aspects of the project, to establish the parameters of what is achievable within the constraints of finance, engineering & technical capabilities, environmental management, and human interaction before, during and after the project. There will be contradictions between the demands of the various elements that will require expertise to not only resolve them effectively, but to identify and define them in the first instance. The health and safety input will not be derived solely from Health and Safety professionals, but must also come from experienced and competent managers and supervisors, engineers, specialist experts and of course the workers and their representatives. Effective management and operation analysis and control require that those involved in the project will have a contribution to make to the elimination or control of hazards and this applies equally where a client engages a contractor. The client needs to ensure that all relevant H&S information is made available to the contractor and that time and resources have been suitably budgeted for. Similarly the contractor must demonstrate competence to carry out the work; such competence extends to having adequate funds, time and other necessary resources.

5.Discussion, Risk assessment – Process or Product?

In 1997 a NI government agency began the process of implementing the OAC approach to safety management, the underpinning assumption being that every work operation that was not fully controlled was heading for failure, whether in reduced quality or output, plant failure or worker injury. Their approach re-integrated H&S into the process, into individual competence and also required co-operative effort between all the various departments in order to achieve successful production. Crucially OAC took into consideration worker competence, recognising that the competent worker is one who is fully aware of the hazards and the H&S issues within their own sphere of competence and who is capable of assessing and making appropriate decisions with regard to their work activities. This shifted decision-making and control of work operations back into the hands of the worker and the competent team. Superfluous decision makers were removed from the process and those who were left co-operated in the achievement of the objectives, e.g. the production department determined the outputs, engineering the competency requirements, human resources recruited and trained competent workers, finance ensured that the activities were adequately resourced and the operational team determined the requirements of and carried out the work operation, (McAleenan and Oloke, 2015).

The risk assessment approach is not without its critics and opponents. The pre-2010 UK Government established a parliamentary committee (WPC 2008) to look into the problems caused by the risk assessment approach, particularly that aspect that led to the profusion of paper based assessments that workers seldom read much less adhered to, and also the claim that ridiculous decisions were being made, (e.g. councils banning hanging flower baskets for fear that they will fall on the heads of pedestrians). In his submission to the Work and Pensions Parliamentary Committee McAleenan (2008) identified that the risk-averse culture prevalent in Great Britain, stemmed from a misinterpretation of the statutory requirements, which had never been corrected. Now the 2010-2015 government, following a review by Lord Young (2010) to see if the H&S legislation is the cause of such nonsensical decisions appointed Professor Lofstedt to consider what changes may be made to the legislation to reduce the burden on employers (Löfstedt 2011). It is worthy of note that the now defunct CDM ACoP was ahead of such reviews when it stated "…paperwork which adds little to the management of risk is a waste of effort, and can be a dangerous distraction from the real business of risk reduction and management" (HSE 2007).

Some employers see the safety component of work as an additional cost, which can be jettisoned when business is suffering as a result of local or global economic downturn. This unfortunate situation occurs when H&S is perceived as an adjunct to rather than an integral aspect of worker competence. The defunct CDM ACoP (HSE 2007) held that the integration of health and safety into the management of the project is the key aim of the regulations. At the launch of the Seoul Declaration (ILO et al 2008) a number of the platform speakers and signatories highlighted this very point, namely that globalisation and (at that time) the looming economic crisis has serious negative consequences for the health, safety and welfare of workers. The negative health effects of the economic climates since 2008 has impacted most severely on psychosocial risks with mental ill health increasing throughout that period, (van Stolk et al, 2012). (In discussing risk averse companies and the potential consequences McAleenan and McAleenan (2010) introduced the concept of calculating a safe flight distance (Dawkins 2009) or the point at which it is safe to commence the work activity to health and safety, stating that;

"The risk-averse company faces extinction in the marketplace and for the company that ignores risk, their extinction comes at the hands of the courts. The successful company survives because it has evolved a balanced dynamic between productivity and hazard control in which the twin objectives of worker safety (survival of the individual) and profitability (survival of the company) co-exists".

Greenman, Fire Engineering instructor, Bates College, Tacoma, USA in a private correspondence with the authors (2010) commented that workers tend to think only in terms of food on the table, management on profits and so each forgets that their goals are dependent on each other's. The calculation of the flight distance must aim to achieve both worker's and manager's objectives, recognising that an acceptable risk is one that does not conflict with either, (Figure 1).

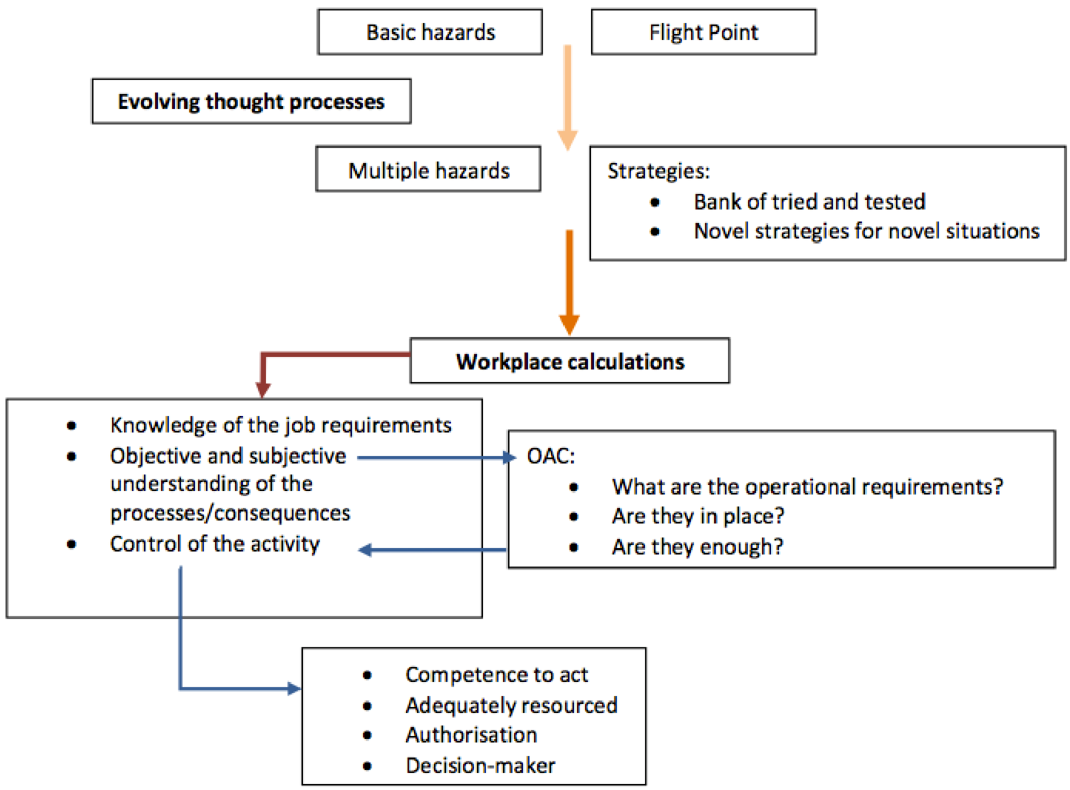

Figure 1: Calculating your Flight Distance (McAleenan and McAleenan, 2010)

6.Conclusions

Orr (ICE Past President, 2007-08) issued one strong piece of advice (in: McAleenan and Oloke,2010), which is echoed by all of the construction professionals who contribute to the ICE's body of health and safety expertise and specifically the Expert Panel on Health and Safety. As construction professionals we all have core values and an ethical position that demands we have a sound knowledge of health and safety within our chosen field of construction and maintain a high regard for the consequences of our professional activities on the safety of workers and others affected by our work, which means;

- Working with integrity;
- Tackling only the work we are competent to do;
- Acting always in the public interest; and
- Continually developing our knowledge.

Project Managers following these principles can ensure that health, safety and welfare is at the heart of everything that is done on a construction project.

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Investigating the Electrical and Mechanical Safety in Construction

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Abstract

Electrical and Mechanical (E&M) installations are indispensable to any construction projects. In the light of number of workers and companies involved, E&M works play an important role in the construction industry. The objectives of this study are to reveal causes of accidents of E&M works and provide recommendations to improve safety and health of E&M practitioners. A systematic approach with multidisciplinary inputs will lead to the formulation of a series of holistic and practical measures. An investigation in "WiseNews", a comprehensive newspaper search engine, shows that there were at least 60 E&M works related fatal cases between 1998 and 2014 in Hong Kong. Fatalities due to fall of person from height and contact with electricity account for over 70 % of all occupational fatalities in electrical and mechanical installations. The study also found that the proportion of occupational fatalities due to fall of person from height is occurred more frequently in air-conditioning installation trade. Focus group meetings with frontline workers and experts will identify the root causes of the E&M accidents. Structured interviews will solicit views of different stakeholders to formulate safety preventive measures. NVivo, which is a software package that supports qualitative and mixed methods research will be used to analyse the qualitative data obtained from the interviews. A questionnaire survey will validate and prioritize the causes of accidents and strategies for improving E&M safety. The proposed study will be useful in improving the safety performance of E&M practitioners in Hong Kong.

Keywords: Electrical and Mechanical, Safety, Electrocution, Fall of person from height

1. Introduction

Electrical and mechanical (E&M) installations are significant to most construction projects regardless of new construction works or repair, maintenance, alteration and addition (RMAA) works. E&M works consist of various specialist trades such as fire services installation, electrical wiring, plumbing and drainage, air-conditioning installation, and lift and escalator installation. With the presence of ageing buildings which lack of proper maintenance, the deterioration of fire services, water pipes and electrical wiring in old buildings commonly occurs. To uphold the ageing building stock properly and enhance public safety in a sustainable way, the Hong Kong SAR government has initiated the

Mandatory Building Inspection Scheme (MBIS) in 2012 to inspect and repair these ageing buildings on a regular basis. Around 2,000 target buildings would be selected by the government for inspection and for owners to carry out corresponding repair and maintenance works each year. The scope of inspection is not only limited to the structural elements of buildings, but also the fire safety elements and drainage system. Thus, it is expected that the volume of E&M RMAA works will continue to increase.

E&M installation involves a considerable number of workers. As shown in Table 1, the number of persons directly engaged in “building services installation and maintenance activities” in 2013 was 73,165, accounting for nearly 40% of the number of persons directly engaged in “all construction activities” (n=185,773) (Census and Statistics Department, 2014). The data are also plotted as illustrated in Figure 1. Statistics of number of persons directly engaged in building services installation from 2007 to 2013 also show that the employment of E&M workers has continued in an upward trend (Figure 1). The number of “building services installation and maintenance activities” establishments in 2013 was 7,075, accounting for 32% of the number of establishments of “all construction activities” (n=22,312) (Census and Statistics Department, 2014). The gross value of construction works performed (HK$'000) increased by 17% from 236,926 in 2012 to 278,175 in 2013 whereas the gross value of building services installation works (HK$'000) expanded by 25% from 50,567 in 2012 to 63,089 in 2013 (US$1=HK$7.8). The importance of E&M works to the construction industry of Hong Kong is expected to increase further.

Table 1. Statistics for building services installation activities in Hong Kong (Census and Statistics Department, 2014)

Industry /Group	Year	Number of establishments	Number of persons directly engaged	Gross value of construction works performed (HK$'000) (US$ 1 = HK$ 7.8)
Building services installation (including New works and RMAA activities)	2013	7,075	73,165	63,089
	2012	7 282(-10.1%)	73 828(+1.9%)	50,567,303(-6.2%)
	2011	8 096 (+16.1%)	72 434(+37.5%)	53,916,770(+36.2%)
	2010	6 976 (-13.7%)	52 664(+10.1%)	39,595,569 (+11.9%)
	2009	8 082 (-8.0%)	47 839 (-14.7%)	35,395,071 (-14.7%)
	2008	8 788 (+25.8%)	56 107 (+40.0%)	41,489,497 (+31.4%)
	2007	6 985	40 079	31,577,350
All construction activities (including New works and RMAA activities)	2013	22,312	185,773	278,175
	2012	22 309 (-4.7%)	184 563(+8.3%)	236,926,550(+10.2%)
	2011	23 417 (+14.2%)	170 345(+15.9%)	214,976,995(+19.5%)
	2010	20 506 (+1.4%)	146 958(+8.7%)	179,836,843 (+15.2%)
	2009	20 216 (+0.6%)	135 254 (-0.5%)	156,068,485 (-5.1%)
	2008	20 100 (+3.6%)	135 990 (+19.0%)	164,376,972 (+15.7%)
	2007	19 399	114 294	142,035,628

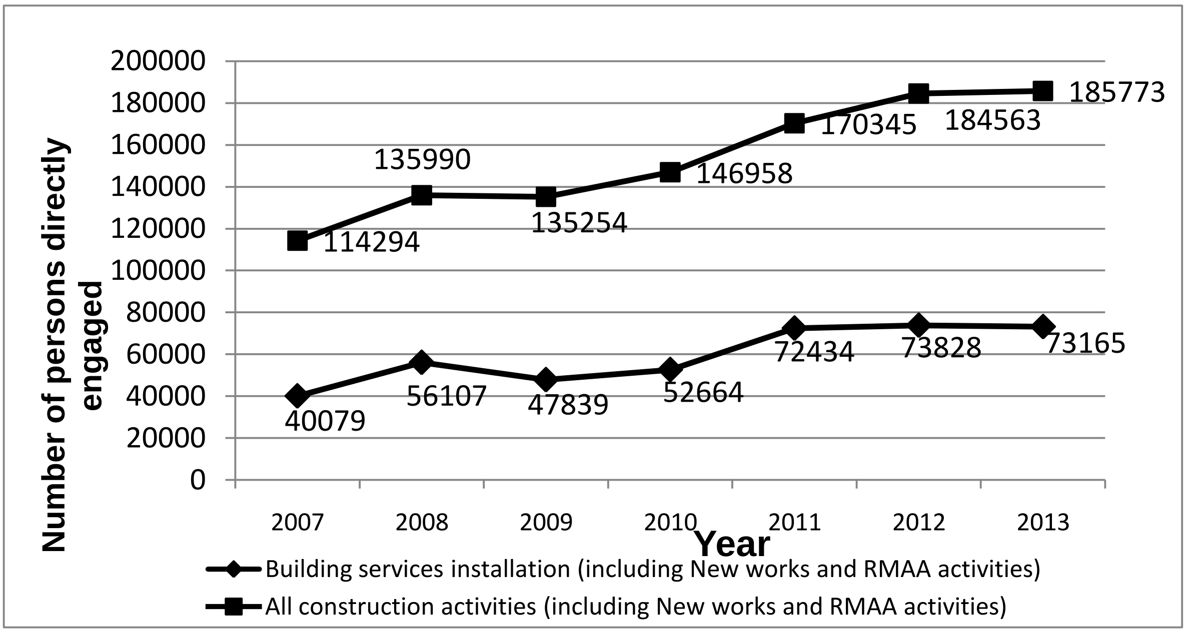

Figure 1. Number of persons directly engaged in construction activities and building services installation in Hong Kong (Census and Statistics Department, 2014)

2. Research Aim and Objectives

Safety issues of E&M works are critical in the construction industry because of the hazardous work nature, tight working schedule and complexity of work. Previous statistics have manifested that falls of person from height and electrocution are the top two killers on E&M works in Hong Kong. There are some detailed analyses of construction fatalities on fall accidents (Huang and Hinze, 2003; Chi et al., 2005; Chan et al., 2008; Hon and Chan, 2013), struck-by fatalities (Hinze et al., 2005), electrocution (Janicak, 2008; Chi et al., 2009) and crane related fatalities (Beavers et al., 2006; Tam and Fung, 2011) etc. Safety research focusing on E&M work installations has been scant. It has not received sufficient attention. The proposed research aims to reveal the causes of accidents on E&M works and provide recommendations to improve the safety and health of E&M practitioners, particularly for those two accident types. To achieve the research aim, four specific research objectives were set out as follows.

1. To understand the general practice and procedures in E&M installation.
2. To determine the causes of E&M accidents.
3. To identify effective measures to be implemented in order to reduce E&M accidents on construction sites.
4. To give recommendations to various stakeholders to enhance E&M installation safety.

3. Significance and Value of Research

The Hong Kong Federation of Electrical and Mechanical Contractors Limited (HKFEMC) which is a sizeable E&M works trade association, has long identified safety a key issue to address (Lam, 2006). HKFEMC has expressed serious concerns for safety of their member practitioners in different occasions. The safety of E&M works has not been given enough attention it deserves. Some hazards associated with E&M works are identified in activities that involve working at height, electricity, lifting, and lift or escalator machinery. Most of the maintenance activities for air-conditioning and plumbing & drainage need to be carried out at height outside the external wall of a building. This greatly increases the likelihood of fall of person from height. Moreover, there are some risks, like electrocution perhaps is significant at E&M works. The study will provide insights to root causes of both fatal and non-fatal accidents of E&M works. The overall aim is to investigate the major causes of E&M works related accidents and recommend a series of practical and holistic measures to reduce them. It is important to upkeep construction workers' safety and health. Improvement in the safety of E&M works will benefit not only the practitioners themselves but the industry as a whole.

4. Research Methods

A mix of qualitative and quantitative research methodology has been employed in this project. The whole research process comprises seven key stages: (1) literature review, (2) focus group meetings, (3) case studies, (4) structured face-to-face interviews, (5) questionnaire survey, (6) data analysis and (7) validation of the results. The research framework for the proposed study is shown in Figure 2.

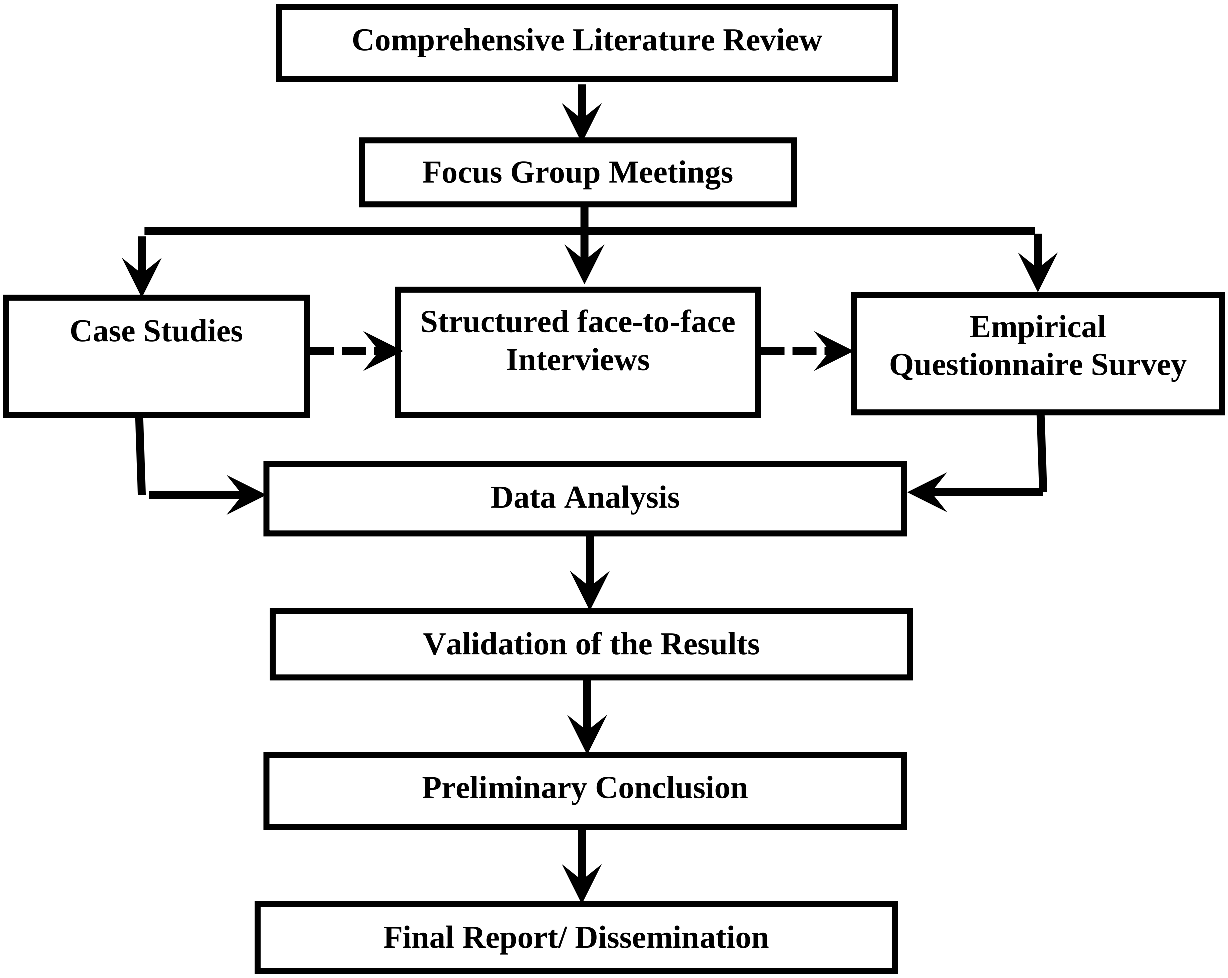

Figure 2. Flow of the Overall Research Framework

5. Research Progress and Preliminary Findings

Literature review

The research project began with a comprehensive review on general practice and safety procedures in E&M installation and common causes of E&M works related accident and safety research on E&M works from academic journals, industry report, research monographs, guidance notes, and newspaper, etc. An extensive review of related ordinance, code of practice, safety working guidelines from six government departments or organizations including the Construction Industry Council (CIC), Labour

Department, Occupational Safety and Health Council (OSHC), Buildings Department (BD), Hong Kong Housing Authority (HKHA) and Electrical and Mechanical Services Department (EMSD) has been launched to capture common types of E&M accidents, major causes of E&M accidents and recommendations on E&M works.

Accident statistical data in Hong Kong will be collected from government departments (including the Architectural Services Department, Census and Statistics Department and the Labour Department) and the volume, nature and the patterns of E&M works related accidents will be examined. The review will focus on safety problems and good practices of E&M installations which will form the foundation for the whole research.

Focus Group Meetings

Two focus group meetings were conducted with (1) trade unions' representatives and frontline tradesmen, and (2) representatives from the Hong Kong Federation of Electrical and Mechanical Contractors Limited (FEMC) in October and December 2014 respectively. It aims to examine the safety problems and the major causes of accidents. Focus group meetings are considered a convenient and effective way of collecting a large amount of information supplementing the traditional one-to-one interview (Haslam, 2003) because it generates synergism and stimulation among attendants (Vaughn et al., 1996). Their expertise has been drawn upon to give comments on safety issues on E&M works, to indicate the root causes of E&M accidents from their practical experience and contribute to the formulation of preventive strategies and measures. Focus group meetings provided a general picture of the safety problems of E&M works and also helped in developing templates for structured interviews and questionnaire surveys.

Case Studies

Both fatal and non-fatal E&M accidents will be retrieved and reviewed. Information on fatal cases will be solicited from relevant government departments and further supplemented by the "WiseNews" newspaper archive which is an electronic search engine containing key local newspaper clippings (Hon and Chan, 2013). These cases will be categorized according to characteristics and features. Key categories may include (1) year and month of accidents; (2) location of accidents; (3) type of work involved; (4) trade of work involved; (5) type of accidents; and (6) any other special features. Fatal cases collected from various sources will be triangulated and cross-referenced to ensure accuracy and reliability of the raw data. The study requires support of the industry. Sources of non-fatal accident cases for analysis could be obtained from member contractors of the Hong Kong Federation of Electrical and Mechanical Contractors Limited (HKFEMC), the Electrical and Mechanical Services Department (EMSD), the Architectural Services Department (ArchSD), and the Hong Kong Housing Authority, etc. Root causes of E&M fatal and non-fatal accidents will be identified respectively.

As official accident statistics on E&M works are not readily available in the public domain, an extensive search in "WiseNews", which is an electronic database of local newspapers in Hong Kong, was conducted. The results show that there were at least 60 E&M works related fatal cases between 1998 and 2014 in Hong Kong. Approximately two-thirds of the 60 fatal cases were related to RMAA works. There were 39 E&M works related accident cases occurred in RMAA works which far outweighed that of new construction works (*n=21*). Fatalities due to fall of person from height and contact with electricity account for over 75% of all occupational fatalities in the electrical and mechanical industry. Among various E&M trades, air-conditioning installation is the most common trades leading to fatality. This trade accounted for a total of 33% of all E&M works related fatal cases (Figure 3). This may be due to the fact that air-conditioning works extensively involve working at height outside the external wall. This greatly increases the likelihood of fall accidents.

With the consent of the Coroner's Court, 13 case files of E&M fatalities between January 2010 and July 2013 have been collected for detail analysis. Each case file include information on police investigation files, coroner's death investigation reports, fatal accident reports by the Labour Department, autopsy reports and medical reports. The advantages of referring to the coroner's reports are that the data is highly reliable for revealing the real causes behind an accident.

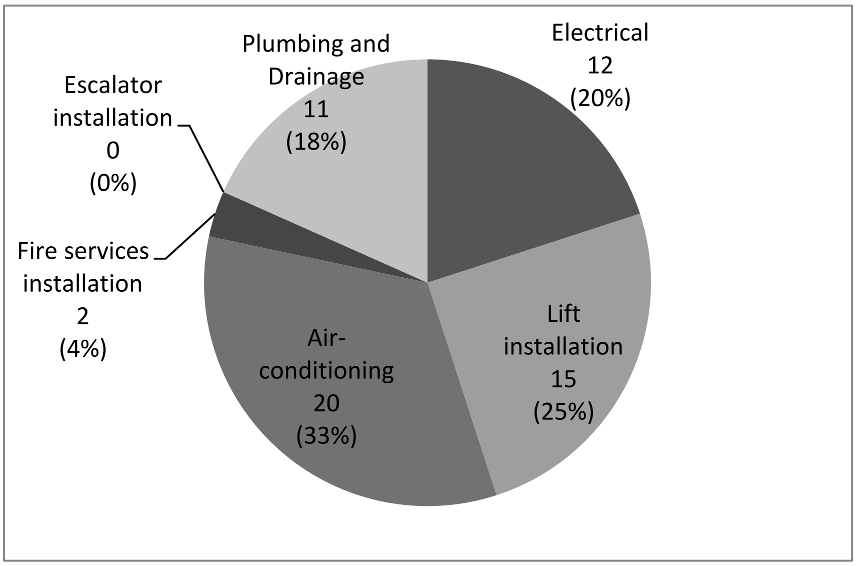

Figure 3. E&M works related fatal accidents from 1998-2014– analysed by Trades (Sources: WiseNews)

Structured interviews

Ten structured interviews have been conducted with key trades of E&M installations, including air-conditioning, fire services, plumbing, and electrical works. Interviewees include representatives from the government, quasi-government organizations, professional institutes, contractors' associations, and trade unions. Interview questions are compiled based on the literature review and also the results of the focus group meetings. It designed to identify the causes leading to common E&M accidents and strategies for improving safety of E&M work practitioners. The interviews results has been transcribed, coded and analysed in NVivo, a software system for analysing qualitative data. Mixed methods research qualitative data will similarly be collected, organized and analysed (Creswell, 2009). Basically, common interview narrative subjects and similar semantic meanings are first coded in individual category. After that, each identified category will then be compared with other categories and repeat this coding process for refinements to better arrive at distinct categorization.

Based on the ten structured interviews of E&M works practitioners, fall from height and electrocution have been identified as the top two killers in both new and repair, maintenance, alteration and addition (RMAA) E&M works in Hong Kong. The major causes of new E&M works and RMAA works are "Compressed working schedule & long working hours" and "Lack of facilities for safe access or improper design for maintenance" respectively.

Questionnaire survey

A questionnaire survey will be designed based on literature and findings from the case studies and structured interviews. The previous qualitative interviews can be used as an exploratory step before designing the questionnaire survey form. Respondents will be requested to prioritize the causes of E&M accidents and importance of recommendations for enhancing E&M works safety. About 200 number of completed questionnaires will be targeted to facilitate quantitative statistical analyses. Questionnaires will be dispatched via industry forum and presentations. The advantages of conducting questionnaire survey in this way are that respondents can get immediate assistance from investigators of the proposed studies and thus improving quality of their responses. Also, respondents attending the industry forum have interests in E&M safety. They are more likely to give reliable and informed responses based on their working experience and expertise.

Data analysis

An Excel template with predetermined categories will be decided for the analysis of case studies (Hon and Chan, 2013). The cases will be coded in the EXCEL template and analysed with SPSS. Descriptive statistics will be utilized in analysing accident records pattern. Key coded variables include year of accident, month of accident, type of accident and trade of E&M works etc. Some fatal and non-fatal accident cases will be selected for detailed analysed. Cluster analysis will be employed to classify types of E&M fatal and non-fatal accidents respectively (SPSS, 2001; Hon and Chan, 2013).

Descriptive statistics and multivariate statistics will be used for analysing questionnaire data using Statistical Packages for Social Science (SPSS). Kendall’s coefficient of concordance (W) will be adopted to measure the levels of agreement of experts (Siegel and Castellan, 1988). Spearman’s rho correlation (Norušis, 2008) will be calculated to assess the degree of correlation among the opinions expressed by groups of experts. The Kruskal-Wallis Test, which is regarded as a non-parametric test will be conducted to decide whether three or more independent groups are from distinct populations.

6. Conclusions

Hong Kong is a populous city with a multitude of ageing and deteriorated buildings. It is crucial to inspect and repair these buildings on a regular basis. E&M installations involve a considerable proportion of all practitioners in the RMAA sector. Repair and maintenance of air conditioning systems and water pipes are highly related to working at height. Fall injuries frequently happen when using ladders and majority of the injured workers are unskilled labourers working on a temporary basis. Electrocution is also a major type of E&M related accident. A person who has been electrocuted may be severely injured or even die. This research project provides an overview of E&M works related accidents in Hong Kong, identify underlying causes of accidents and practical recommendations through a series of research tools including focus group meetings, cases studies, structured interviews and questionnaire survey. The project has begun for about a year and is still ongoing. Case analysis, focus group meetings and interviews have largely been completed. The next step is to collect holistic opinions from E&M works practitioners by questionnaire for improving safety performance of the E&M industry.

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Evaluating the Safety Awareness and Behaviour of Construction Practitioners in Hong Kong

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Abstract

In Hong Kong, safety performance of the construction industry has substantially improved since the late 90s. However, this improvement in terms of accident rate and fatality number has slowed down and reached a plateau after 2006. The purpose of this study is to evaluate the safety awareness and behaviour of construction practitioners at various levels. Construction practitioners were classified into five levels as CEO, project management team, supervisors/foremen, trade-specific foremen, and frontline workers based on their different roles in construction site safety. Semi-structured interviews were conducted to assess the safety awareness and behaviour of CEO, project management team, and supervisors/foremen. Questionnaire survey was conducted to assess the safety awareness and behaviour of trade-specific foremen and frontline workers. A total of 280 construction practitioners participated in this survey, including 6 CEOs, 6 project management team leaders, 8 supervisors/foremen, 28 trade-specific foremen, and 232 frontline workers. It was found that construction practitioners across different levels possessed a satisfactory level of awareness and behaviour on safety with those at the frontline level having a comparatively lower score for safety awareness and behaviour. It is recommended that training, instructions, and remarks should be given for safety improvement at various levels.

Keywords: construction industry, Hong Kong, safety awareness, safety behaviour, safety culture

1. Introduction

Construction is a large, complex, and dynamic sector that generates employment for millions of people worldwide. However, this sector has high number of fatalities and non-fatal occupational injuries and illnesses (Hoonakker et al. 2005). Improving site safety is a top priority for construction companies throughout the world (Choudhry et al., 2007). Having a mature and positive safety culture is becoming crucially important to facilitate safety improvement (Choudhry et al., 2007).

The construction industry is one of the economic pillars which contributes about 4.0% of Gross Domestic Product (Census and Statistics Department, 2015) and 8.2% of total working population in Hong Kong (Labour Department, 2015). According to the occupational safety and health statistics of 2013, there were a total of 3,232 industrial accidents from the construction industry, 2.3 per cent up when compared to 3,160 in 2012 (Labour Department, 2014). Furthermore, the safety performance of the construction industry in Hong Kong lags behind as compared with nearby Asian cities, such as Singapore. The accident rate per 1,000 construction workers in Hong Kong was 41.9 in 2014 whereas the accident rate per 1,000 construction workers in Singapore for major injuries and minor injuries were 0.41 and 5.20 respectively (Legislative Council 2015). Although the Hong Kong SAR (Special Administrative Region, China) government has stipulated construction related safety and health legislation to reduce the accident and fatality rate, there are still a lot of rooms for improvement. Cultivating a good organizational safety culture is considered to be an effective way for further improvement (Zou 2011).

Safety culture is shaped by people working together in organizational structures and by social relationships in the workplace. It is recognized that leadership is important in the creation of a culture that supports and promotes a strong health and safety performance of an organization. Leaders play a key role in the creation of safety climate, which in turn influences workers to increase their safety behaviours, thereby decreasing their accidents and injuries (Hoffmeister et al., 2014). Managers and /or the team leaders are vital in inspiring employees to a higher level of safety and productivity, which means that they must apply good leadership attributes on a daily basis (Flynn and Shaw, 2010).

In Hong Kong, an annual Construction Safety Week (CSW) is organised by the Development Bureau (DevB) and the Construction Industry Council (CIC) to promote health and safety to all stakeholders of the construction industry. As one of the key initiatives of the CSW, the organizers commissioned the authors to undertake a research study to investigate and further enhance the safety awareness amongst the key stakeholders of the construction industry. The objectives of the study included: (a) classify the practitioners of the construction industry into a number of levels based on their different roles in construction site safety; (b) establish guidelines to enable the practitioners to become safety leaders in their corresponding levels; (c) monitor / gauge the enhancement of safety culture in the construction industry.

2. Five Levels of Construction Practitioners

Effective leadership can improve safety performance in hazardous and complex working environments (Flin and Yule 2004). An extensive literature review of construction practitioners' values, attitudes, perceptions, and patterns of behaviour at various levels were conducted. Previous studies related to this research are consolidated, thereby enriching the understanding of current knowledge. The literature was sourced from government/industry reports, books, and top-tier journals (Biggs et al. 2008; Choudhry et al. 2007; Clarke 2013; Conchie et al. 2013; Cooper 2000; Fernández-Muñiz et al. 2007; Flynn and Shaw 2010; Flynn and Yule 2004; Hoffmeister et al. 2014; Kines et al. 2010; Krause and Weekley 205; Koch 2013; Lu and Yang 2010; Martinez-Corcoles et al. 2011, 2013; Martin and Lewis 2014l Mohamed 2003; O'Dea and Flin 2001, 2003; Ostrom et al. 1993l Wamuziri 2006, 2013; Wu et al. 2008, 2011; Zou 2011). As illustrated in Table 1, construction practitioners are classified into five levels according to their roles in construction site safety. The roles of construction practitioners at each level are shown in Table 1:

Table 1 Five (5) levels of construction practitioners

Level	Position	Role
1	CEO	drive strategic decision
2	Project Management Team	involve in all project related issues
3	Supervisors and Foremen	supervise and arrange the construction materials and the labors at project level
4	Trade-specific supervisors	supervise and arrange the construction materials and the labors at trade level
5	Frontline worker	operate specific task

3. Data Collection

Semi-structured interviews and questionnaire survey were conducted to assess the current level of safety culture in the Hong Kong construction industry. Construction practitioners at various levels (i.e. CEO, project management team, supervisors/foremen, trade-specific foremen, and frontline workers) were invited to participate in this study. Face-to-face interviews were conducted with construction practitioners from Level 1 to 3, including 6 CEOs, 6 Project Management Team Leaders, and 8 Supervisors/Foremen. Questionnaire survey was conducted with trade-specific supervisors and frontline workers. A total of 28 valid questionnaires from Level 4 and 232 valid questionnaires from Level 5 were collected respectively. The participants were asked to evaluate their safety awareness/consciousness and actions/behaviours in day-to-day operations. They were asked to rate the level of agreement on the awareness/consciousness based on a 5-point Likert scale (i.e., 1 represents "strongly disagree" and 5 indicates "strongly agree"), and the actions/behaviours based on a 5-point Likert scale (i.e., 1 represents "always don't" and 5 indicates "always do"). The participants from Level 1 to 3 were also asked to rank the relative importance of factors contributing to positive safety culture. The factors contributing to positive safety culture were identified in the literature (Biggs et al. 2008; Feng et al. 2014; Wamuziri 2006, 2013; Chen et al., 2013; Choudhry et al. 2007; Zhang and Gao 2012; Zou 2011). All the data collected are treated in strict confidence by the research team. Both quantitative and qualitative analyses were employed to analyse the empirical data in this study.

4. Results and Discussion

4.1 Level 1 CEO

Ratings on safety awareness and safety behaviour in Level 1 are illustrated in Table 2. The respondents are strongly realize the importance of safety. Only the mean score on "all accidents can be prevented" is less than 4.5. Regarding the safety behaviour, the mean scores are between 4 and 5. It is found that "proactive action will bring about changes in safety behaviours and performance" is relative low with the score of 4.17.

Table 2 Ratings on the safety awareness and safety behaviour in level 1

Safety awareness	Rating
Everyone shares a responsibility on safety	5
The company shoulders a social responsibility on safety	5
All accidents can be prevented	4
Safety is an integral part in business performance	5
Safety behaviour	
Establish a clear mission, safety responsibility system and goal in order to set standards of behaviour for employees	4.83
Work with subordinates to reinforce the corporate safety commitment	4.83
Be clear and transparent when dealing with safety issues	4.67
Ensure statutory compliance with government health and safety regulations	4.67
Share the beliefs of the project management team	4.33
Proactive action will bring about changes in safety behaviours and performance	4.17

The participants were asked to rank the relative importance of factors contributing to positive safety culture. It is found that "provides resources to support safety", and "formulates safety policies to reflect the beliefs" are the top two important factors contributing to positive safety culture at Level 1 CEO.

4.2 Level 2 Project Management Team

Ratings on safety awareness and safety behaviour in Level 2 are illustrated in Table 3. Regarding the safety awareness, the mean scores on both "Shares the CEO's belief" and "worker safety is first priority" are 4.67. The mean score on "proactive action will bring about changes in safety behaviours and performance" is 4.33.

The mean score on "positive and proactive action will bring about changes in safety behaviours and performance" is 4.33. Regarding the safety behaviour, the mean scores on most items are between 4 and 5. It is found that the respondents performed worse in the "drive for the flexibility and adaptation of safety management" with the score at 3.67.

Table 3 Ratings on the safety awareness and safety behaviour in level 2

Safety awareness	Rating
Shares the CEO's belief	4.67
Safety is a core element of project management	4.67
Positive and proactive action will bring about changes in safety behaviours and performance	4.33
Safety behaviour	
Motivate the workforce to participate in safety activities in order to increase their awareness of safety and acceptance of safety responsibility	4.5
Allocate resources to safety management commitment	4.67
Reinforce/support subordinates' safety activities	4.5
Organize safety training and promotion	4.83

Keep safety rules and regulations updated regularly	4.83
Promote ‘Safety Behaviour’ campaigns	4.83
Establish effective incentive schemes and reward systems to reinforce safety behaviour	4.5
Express appreciation and respect for good safety behaviour	4.83
Encourage the workforce to rectify the risky behaviour when they disobey safety rules	4.83
Emphasize the interests in acting on safety policy	4.67
Apply the rules and company safety policy consistently	4.83
Address safety system flaw, be willing to admit mistakes and correct them	4.67
Drive for the flexibility and adaptation of safety management	3.67
Communicate with the subordinates on safety behaviours	4.33
Advocate and communicate safety values to subcontractors	4.33
Review safety process and take feedback seriously	4.17

The participants were asked to rank the relative importance of factors contributing to positive safety culture. It is found that “enhance safety knowledge”, and “instil respect and commands authority” are the top two important factors contributing to positive safety culture at Level 2 Project Management Team.

4.3 Level 3 Supervisors/Foremen

Ratings on safety awareness and safety behaviour in Level 3 are illustrated in Table 4. Regarding the safety awareness, the mean scores on both “shares the beliefs of the project management team” and “worker safety is first priority” are 4.67. The mean score on “proactive action will bring about changes in safety behaviours and performance” is 4.33. Regarding the safety behaviour, the mean scores on most items are between 4 and 5. It is found that “provide subordinates with a flow of challenging and innovative ideas for improving safety” is relatively low with the score at 3.67.

Table 4 Ratings on the safety awareness and safety behaviour in level 3

Safety awareness	Rating
Shares the beliefs of the project management team	4.67
Worker safety is first priority	4.67
Proactive action will bring about changes in safety behaviours and performance	4.33
Safety behaviour	
Consider the hazards and risks before and during the execution of any task	4.5
Take necessary precautions to mitigate these risks	4.5
Review safety process and take feedback seriously	4.5
Provide safety equipment to the workforce	5
Explain the concept of safety and good practices clearly	4.67
Stop any unsafe activity or operation	4.83
Be consistent and fair in dealing with workers against safety issues	4.67

Listen to workers' concerns with regard to safety and act on them	4.50
Be willing to admit mistakes and correct them	4.67
Report all unsafe conditions, practices and all injuries and illness	4.67
Report the risk assessment regularly	4
Conduct safety site-walks and report and rectify any irregularities	4.33
Detect and correct errors based on monitoring subordinates' safety behaviour or being reported by the subordinates	4.33
Coach, mentor, and provide feedback promptly	4.33
Build strong relationship with frontline workers	4.33
Provide subordinates with a flow of challenging and innovative ideas for improving safety	3.67
Deliver the established incentives and punishments as part of the daily routine	4
Lead investigations into injuries, accidents and high potential incidents	4
Provide feedback and follow up near-miss and post-accident reports	4.17

The participants were asked to rank the relative importance of factors contributing to positive safety culture. It is found that "carry out risk assessments before work", and "give safety instructions and information along with work instructions" are the top two important factors contributing to positive safety culture at Level 3 Supervisors/Foremen.

4.4 Level 4 Trade-specific Foremen

Ratings on safety awareness and safety behaviour in Level 4 are illustrated in Table 5. Regarding the safety awareness, the mean scores on "worker safety is first priority" at 4.75, which is higher than that on "proactive action will bring about changes in safety behaviours and performance" and "shares the beliefs of the project management team" at 4.39 and 4.18 respectively. Regarding the safety behaviour, it is found that the respondents performed worse in "provide inputs for design for safety", "report the risk assessment to superiors regularly", "deliver the established incentives and punishments as part of the daily routine", and "provide subordinates with a flow of challenging and innovative safety ideas", with the score at 3.73, 3.90, 3.90, and 3.90 respectively.

Table 5 Ratings on the safety awareness and safety behaviour in level 4

Safety awareness	Rating
Shares the beliefs of the project management team	4.18
Worker safety is first priority	4.75
Proactive action will bring about changes in safety behaviours and performance	4.39
Safety behaviour	
Consider the hazards and risks before and during the execution of any task	4.20
Take necessary precautions to mitigate these risks	4.03
Provide safe equipment to workers	4.43
Detect and correct errors based on monitoring subordinates' safety behaviour or being reported by the subordinates	4.13

Stop any unsafe activity or operation	4.43
Coach, mentor, and provide feedback promptly	4.20
Carrying out safety induction/familiarization training	4.40
Ensure that plants and equipment are being licensed, registered, and maintained regularly	4.13
Report all unsafe conditions, practices, near-misses, injuries, and illness	4.33
Comply with all safety policies, procedures and rules	4.37
Ensure workforce to obey/enforce safety rules	4.20
Monitor worker's awareness of safety instructions regularly	4
Trust and respect frontline workers	4.33
Be consistent and fair in dealing with workers against safety issues	4.30
Be willing to admit mistakes and correct them	4.3
Provide inputs for design for safety	3.73
Report the risk assessment to superiors regularly	3.90
Deliver the established incentives and punishments as part of the daily routine	3.90
Provide subordinates with a flow of challenging and innovative safety ideas	3.90

4.5 Level 5 Frontline Workers

Ratings on safety awareness and safety behaviour in Level 5 are illustrated in Table 6. Regarding the safety awareness, the mean scores on "safety is everybody's responsibility and each one has a part to play" and "personal safety at work is utmost concerns to one's family and friends" at 4.46 and 4.43 respectively, which are higher than that on "all accidents can be prevented" with the score at 4.20. Regarding the safety behaviour, it is found that the respondents performed worse in "make suggestions and initiate new ideas to supervisor proactively", "participate in safety activities", and "communicate with fellow-workers on health, wellbeing and safety issues regularly" with the score at 3.91, 3.94, and 3.97 respectively.

Table 6 Ratings on the safety awareness and safety behaviour in level 5

Safety awareness	Rating
Safety is everybody's responsibility and each one has a part to play	4.46
Personal safety at work is utmost concerns to one's family and friends	4.43
All accidents can be prevented	4.20
Safety behaviour	
Commit to use safety equipment provided	4.23
Perform work in accordance with safety practices and safety procedures	4.25
Report all injuries, illnesses, near misses, equipment damage, unsafe conditions, and practices to the superiors promptly	4.16
Advise and remind fellow-workers who deviate from safe working practice or misbehaves in safety	4.11
Reinforce and influence safety behaviour in workplace constantly	4.26
Work with management to identify safety problems and find solutions	4.03
Keep abreast of new knowledge	4.07

Participate in safety activities	3.94
Communicate with fellow-workers on health, wellbeing and safety issues regularly	3.97
Make suggestions and initiate new ideas to supervisor proactively	3.91

5. Conclusions

In Hong Kong, the safety performance of the construction industry has substantially improved since the late 90s. However, this improvement slowed down and reached a plateau after 2006. Having a mature and positive safety culture is becoming crucially important to facilitate such an improvement. This study aims to evaluate the performance of safety leadership scheme in the Hong Kong construction industry. Construction practitioners were classified into five levels as CEO, project management team, supervisors/foremen, trade-specific foremen, and frontline workers based on their different roles in construction site safety. Beliefs, initiatives, guidelines on being a "Safety Pioneer" for each level of construction practitioners were established. Semi-structured interviews and questionnaire survey were conducted to assess the safety culture in the local construction industry. A total of 280 construction practitioners were participated in this survey, including 6 CEOs, 6 Project Management Team leaders, 8 Supervisors/Foremen, 28 Trade-specific Foremen, and 232 Frontline Workers.

Findings of the research study indicated that: (a) construction practitioners at all levels possessed a satisfactory level of awareness/consciousness and actions/behaviours on safety; (b) construction practitioners at lower level tended to have a comparatively lower score for safety awareness and behaviours; (c) areas for further improvement includes: (1) "drive for the flexibility and adaptation of safety management" at Level 2 Project Management Team, (2) "provide subordinates with a flow of challenging and innovative ideas for improving safety" at Level 3 Supervisors/Foremen; (3) "provide inputs for design for safety", "report the risk assessment regularly", "deliver the established incentives and punishments as part of the daily routine", and "provide subordinates with a flow of challenging and innovative ideas for improving safety" at Level 4 Trade-specific Foremen; and (4) "participate in safety activities" "communicate with fellow-workers on health, wellbeing and safety issues regularly", and "make suggestions and initiate new ideas to supervisor proactively" at Level 5 Frontlines worker; (d) the main benefits of safety leadership scheme includes "minimize the work-related accidents on site", "a powerful influence on promoting the safety culture because initiated by the government", and "set clear expectation and can be measurable". Based on the above findings, it is recommended that training, instructions, and remarks should be given for safety improvement at various levels.

A limitation of the study is the limited sample source and sample size. In this study, participants at Level 1 CEO, Level 2 Project Management Team, and Level 3 Supervisors/Foremen were mainly from large-sized enterprises. Further research work should be done to increase the sample size and to replicate the survey to small and medium-sized enterprises (SMEs). The present study examines the current status of safety awareness and behaviour at various levels of construction practitioners. Similar studies should be carried out in regular basis to monitor the enhancement of safety culture in the construction industry.

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Causes of Risk Misallocation in the Zambian Construction Industry

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Abstract

Risk misallocation has been a concern in the construction industry globally due to its resultant effects of quality shortfall, disputes, claims, cost and time overruns. Various studies have focused on the identification of misallocated risks and how a project team can rectify the problem. However, the current discourse does not address the causes of misallocation. This research is aimed at bridging that gap by establishing why risks are misallocated in the construction industry, with the Zambian building sector as a focus. The study used heterogeneous purposive sampling to select professionals in the Zambian construction industry for semi-structured interviews. The professionals selected had over ten years' experience in the building sector and had worked on building projects with various peculiarities. Various causes for misallocation were identified, and these were divided into three main categories, namely, work environment related, worker related and work related. Work environment factors include available contract forms; data, information and feedback, and contract conditions; worker factors include lack of perception and knowledge, inadequate skills and training and poor understanding of the consequences of risk; work related factors include the rationale for risk allocation and available response mechanisms. The identification of causes of risk misallocation helps the client to better understand how risk allocation can be enhanced in the construction industry; this is a positive step toward reducing misallocation and improving project performance in the construction industry. The research highlights the need for the construction industry to have diverse contracts, favourable and enabling contract conditions and workers with the necessary skills and understanding of the consequences of unmitigated risk among the contracting parties. Contractor and client as the contracting parties also need clear knowledge and perception of risks in addition to adopting a rationale for risk allocation that is not only based on responsibility but also ability to manage.

Keywords: Risk misallocation, buildings, causal issues, Zambia

1. Introduction

A construction project of any magnitude or nature is normally faced with a variety of risks. These risks could be market related, environmental, economic, financial, social, legal, technological, political, technical or physical (Sharma & Bhatnagar, 2006). The generic understanding of risk is that it is an event or occurrence that negatively impacts project performance (Flanagan & Norman, 1993; Smith, Merna, & Jobling, 2006). However, risk can also be construed as an event or occurrence that can impact project performance positively or negatively (Hilson, 2002; PMI, 2004). Caño and Cruz (2002) define *risk* as "an uncertain event that, if it occurs, has a positive (opportunities) or negative (threats) effect on a project objective" (p. 473). The way in which risk is managed can result in either threats or opportunities. It is during the risk management process that liability for risk, commonly known as *risk allocation*, is assigned. This is normally done in the risk response stage. A risk response measure could be an alternative procurement method, a construction method or material, monitoring, the use of insurance or bonds, contingency (time or money), subcontracting or even collaboration (Bakr, Khaled, & Ayda, 2012; Loosemore and McCarthy, 2008; Serpella, Ferrada, & Rubio, 2014; Smith, Merna, & Jobling, 2006; Uff, 2010). In architectural and engineering projects the allocation of risk is done through the standard form of contracts. Contracts allocate risks by providing for future contingencies with varying degrees of specificity (Triantis, 2000). Nevertheless, it is not uncommon for the standard forms to have modifications (Mooney & Mooney, 2013) resulting in either unbalanced risk allocation or more equitable allocation, so when the occurrence of an unforeseeable event would cause a promisor to bear an unexpectedly large loss in performing their contractual obligation, the parties may perhaps renegotiate and modify the promisor's contract (Triantis, 2000).

Various risks have been observed to negatively impact project delivery in the Zambian construction industry, leading to quality shortfalls, as well as cost and time overruns (See Kaliba, Muya, & Sichombo, 2013). In addition, claims in the industry are rampant, with such causes as poor risk sharing and incomplete and incomprehensive contract documentation (Sibanyama, Muya, & Kaliba, 2012). Mukumbwa and Muya (2013) find in their study of unethical practices in the Zambian construction Industry (ZCI) one-sided contracts, where risk is transferred to the contractor, and insertion of unfair clauses which are disadvantageous to the contractor.

This research is aimed at identifying the prevalent risks and the practices that lead to risk misallocation. This has been done cognizant of prior studies which have identified misallocated risks with a view to allocating risks appropriately between the client and contractor. It is important that the causes of misallocation be established if this problem is to be dealt with at the source in the future.

2. Risk Allocation in the Construction industry

Risk allocation is the assigning of management responsibility and accountability for risk(s) (Alsalman and Sillars, 2013). Risk allocation practice in the construction industry has been described as poor, unbalanced, balanced, and from misallocated to inappropriate (Alsalman &

Sillars, 2013; Baloi & Price, 2003; Khazaeni et al., 2012). For risk allocation to be carried out, risk identification, risk analysis and response should be undertaken. Poor risk allocation refers to any instance of misallocation, including incomprehensive allocation of risks (Meng, 2012; Mead, 2007); unbalanced risk allocation refers to allocation of most of the risks to one party without justification (Alsaman & Sillars, 2013; Bakr, Khaled, & Ayda, 2012; Lam et al., 2007); balanced risk allocation refers to liability associated with risk events, and thus possible loss or gain from the project, properly identified and distributed (Khazaeni, el al 2012); inappropriate risk allocation refers to contractual shifting of risk to the contracting party with the least amount of bargaining power (Hanna et al., 2013).

This research defines risk misallocation as the allocation of risks wrongly or inappropriately (Hanna, Thomas, & Swanson, 2013); that is, it refers to any wrong method of allocation and/or inappropriate response method and/or allocation to the wrong party between client and contractor and their representatives and/or allocation of inappropriate resources or lack of allocation. Alsalman and Sillars (2013), using a questionnaire survey, established that when risks are not allocated accordingly they result in disputes, tensions, claims, quality shortfalls and time and cost overruns.

3. Methodology

This study used a qualitative approach to appraise misallocation in the Zambian building sector using a heterogeneous purposive method to select various professionals (engineers, quantity surveyors, architects and procurement officers) in the Zambian construction industry for semi-structured interviews. Semi-structured interviews have been used in related studies (e.g., Goh and Abul-Rahman, 2013; Lehtiranta and Juunonen, 2014). A semi-structured interview is one which has a written set of open-ended or closed questions for use by the interviewer in a person-to-person interaction (Kumar, 2011). The professionals selected had at least ten years of experience in the building sector and had worked on a variety of building projects. The sample was selected from professionals in both public and private sectors; contractors were selected from the building category in grades 1–3. Grade 1–3 contractors are registered under the National Council for Construction (NCC): grade 1 represents the highest contractor grade, those contractors with unlimited capacity; grade 2 is for contractors with a capacity of carrying out projects of up to K25M (US$2M; exchange rate: US1 = K12.5); grade 3 contractors carry out projects of up to K10M (US$0.8M). The grades go up to 6. Grades 1–3 were chosen because 90% of the work in the building sector is done by these contractors, and they are obligated to subcontract 20% of the value of the works to grades 4–6 for public works when necessary. However, maximum contract values of Grade 4 (K5M [US$400,000]), Grade 5 (K3.5M [US$280,000]) and Grade 6 (K1M [US$80,000]) should not be exceeded. The respondents were as follows: 2 quantity surveyors, 2 architects, 2 civil engineers, 2 clients, 2 project managers, 1 contractor grade 1, 1 contractor grade 2, 1 contractor grade 3 and 2 procurement officers, giving a total of 15 respondents (see Table 1 for details).

The interviews to gain insight into issues leading to risk misallocation ranged from about 45 minutes to 70 minutes. Before the interview, permission was sought to audio record, and where the permission was not given, permission was obtained to take notes. Interviews were chosen because they are the best tools for collecting in-depth information (Greener, 2008; Patton, 2002). Semi-structured interviews were preferred because they normally provide uniform information (Gray, 2009). Apart from the ability to collect in-depth information, interviews aid in the generation of historical data (Cresswell, 2007) and provide an opportunity to probe. Other advantages to interviews include these: information can be supplemented, questions can be explained and they can be used in any type of population (Kumar, 2011). Conversely, interviews have the demerit of being time consuming and expensive (Bhattacherjee, 2012; Cresswell, 2007; Gray, 2009; Kumar, 2011). The seven-step procedure outlined by Cresswell (2007) was used as follows: (1) locating an individual, (2) gaining access and making rapport, (3) purposefully sampling, (4) collecting information, (5) recording information (audio recording and/or taking notes), (6) resolving field issues, and (7) storing data. Location of individuals and gaining access was mainly done through their professional bodies. Prior contact was made either by e-mail or phone call to ascertain whether an individual had at least 10 years' experience in building projects. Table 1 shows respondents' years of experience, sector of engagement and nature of building projects worked on. The average in years for the respondents was 17 years. It is quite clear that the years of experience are vast and the nature of building projects provides a good mix for the study.

Table 1: Respondents' characteristics

I.D	***Sector***	***Experience in Years***	***Role in construction***	***Scope of building projects in years of experience***
1	*Public*	*15*	*QS*	*Offices, houses, schools*
2	*Public*	*12*	*Civil Eng.*	*Offices , hospitals, schools*
3	*Public*	*10*	*Procurement officers*	*Offices, houses*
4	*Public*	*20*	*QS*	*Housing units, offices, health facilities, hospitals*
5	*Public*	*19*	*Architect*	*Schools, offices, border infrastructure, houses*
6	*Private*	*10*	*Contractor*	*Houses, student hostels, high rise buildings*
7	*Private*	*32*	*QS/PM*	*Offices, hospitals, residential, banks, filling stations, stadia, factories*
8	*Public*	*21*	*Client org*	*Primary schools, secondary schools, colleges, houses*
9	*Public*	*23*	*PM*	*Prisons, military installations, houses, rural health centers, flight terminal, border facilities, offices*
10	*Private*	*30*	*Eng. Consultant*	*Showrooms, schools, filling station, hospitals hotels, office buildings*
11	*private*	*29*	*Contractor*	*Housing, offices, banks, schools, hostels*
12	*Private*	*10*	*Contractor*	*High schools, maternity wards, student hostels, offices*
13	*Private*	*10*	*Client Org*	*markets, fire stations, bus shelters, houses,*
14	*Private*	*15*	*Procurement Officer*	*Office blocks, houses, farm layouts and different buildings, lodges, banks*
15	*Privat e*	*10*	*Architect*	*Houses, offices, shops, farm buildings, banks*

The analysis was done mainly through content and interpretive analysis. Interpretive analysis aims to capture hidden meaning and ambiguity (Gray, 2009), looking at how messages are encoded, latent or hidden. Content analysis is a research tool used to determine the presence of certain words or concepts within text or sets of texts (Robson, 2011). In some instances, there was a link in the analysis between the current practice and existing theory in risk allocation, namely, transaction cost theory, expectancy theory, principal-agent theory and structuration.

4. Discussion

4.1 Prevalent Risks to Building Projects

Various risks impact building projects, and the following were indicated by respondents as prevalent: late payment (80%); lack of inspection, supervision and monitoring by consultants (73%); poor supervision by contractors (73%); contractor's cash flow problems (73%); lack of adherence to contractual provisions by client (67%); slow decision making by client (60%); bureaucratic processes (60%); frequent changes in material prices (60%); unstable exchange rate (60%); poor workmanship (52%); frequent change in scope (52%). These risks are diverse due to the nature of building projects. Late payment is mainly attributed to poor financial standing of the client, poor budget planning or poor bureaucratic processes. This could be contributing to contractors' poor cash flow.

4.2 Nature of Risk Misallocation in the Building Sector

All respondents, as shown in Table 2, asserted that the allocation of risk is not balanced because contractors are compelled to carry more risks than the client. Additionally, in certain instances, risks which are better shared between the client and the contractor, such as escalation in the cost of materials and unstable exchange rates, are shifted to the contractor. The underlying reason for this practice, as explained by the consultants, was to minimize the cost to the client. It was also clear that certain methods of allocation preferred by the client contributed to misallocation, such as the practice of obtaining bonds from banks only and the allowable level of subcontracting. This was indicated by 60% of the respondents. Some risks were not allocated despite the fact that these are present in the original standard forms of contract which were modified using waiver clauses, leading to some clauses becoming non-applicable. The respondents (60%) suggested that sometimes either the client or the contractor is wrongly allocated a risk resulting from modification of a standard contractual clause, such as the omission of fluctuation and escalation clauses. Lastly, it was also common to allocate resources wrongly due to the underestimation of the scope or nature of the work. This form of misallocation would be mainly in terms of inappropriate finance allocation, as illustrated by 100% of the respondents; insufficient personnel to supervise and monitor the works, as pointed out by 80% of the respondents and insufficient or wrong plant and equipment revealed by 60% of the respondents. This is usually occasioned by incomplete design and a lack of investigation of the site conditions.

Table 2: Nature of risk misallocation in the construction industry

Nature of misallocation	*Frequency*
Unbalanced risk allocation	*15*
Wrong method of allocation	*9*
Risk allocation to wrong party	*9*
Lack of allocation in signed documents	*3*
Inadequate or wrong resources used in allocation (personnel)	*12*
Inadequate or wrong resources used in allocation (plant or equipment)	*6*
Inadequate resources used in allocation (finance)	*15*

4.3 Causes of Misallocation: Work Environment Related

The environment relates to the surrounding conditions in which an employee or organisation operates. It can be composed of physical conditions, such as office temperature, or equipment such as personal computers. However, for this study the environment was used to refer to work processes or procedures as they relate to risk in a project environment. Process and procedures followed on projects that were particularly related to risk allocation were considered. The following were identified as factors contributing to misallocation.

4.3.1 Contract Forms Used

The main contracts in use in the Zambian construction industry are the Zambian Public Procurement Agency (ZPPA) contracts (2013), which include open national bidding, international bidding (FIDIC red book, harmonised 2005 version) and small works contracts, and the Joint Liaison Contract (JLC), commonly known as the ZIA (Zambia Institute of Architects) contract. All the respondents claim that these are almost always modified to accommodate the requirements of the clients or financiers of projects. Occasionally, this leads to allocating most of the risks to contractors. Of the respondents, 60% also indicated that current contracts do not reflect what is needed because they are based on traditional procurement, and in recent times professionals in the industry have had contracts that are design-and-build in nature and feel the current contracts do not seem to address the risks that come with such arrangements. It is important to point out that contracts in use based on traditional procurement do not reflect the risk liability in an integrated system of procurement. The respondents (60%) indicated that there is a need to have a flexible contract or new contract showing the actual risk liability in such an arrangement.

4.3.2 Data, Information and Feedback

Data and information were cited as some of the initial causes of risk misallocation. Designers (architects and engineers) and cost estimators (quantity surveyors) interviewed (60% of respondents), especially those in the public sector, suggest that most of the time they design or estimate projects without going to the site or conducting necessary investigations; this results in inaccurate assumptions of site conditions. Contractors indicated that most of the data they base their tender price on lack detail, especially drawings which had either missing or insufficient detail. Contractors claim they would sometimes tender for projects, especially for public sector projects, without going to the site, making it difficult to quote properly and allocate resources accordingly. There seems to be lack of information and project data for decisions to be made on risk where site conditions are concerned.

Feedback on risks between the contractor and the client once projects have commenced was described as generally poor by 80% of the respondents. When steps were taken to get feedback, the feedback was not given in a timely manner. However, among consultants there seemed to be various methods of feedback on issues to do with risk, such as reports and meetings. It was also noted that contractors who have been in operation for 3 years or more appeared to have the knowledge to query on certain issues which they felt would affect their performance, such as verification of variations and specification, and demand for detailed drawings. Contractors (100%) indicated that the lack of design details and late feedback lead to risk misallocation on their part, especially in the allocation of resources and pricing. Consequently, consultants and procurement officers (73%) from the private and public sectors pointed out that when there was no clarity in a drawing the contractor tends to over-price the work to cover risk. This is expected even more when escalation and fluctuation clauses are omitted in a contract. The latter could be understood as an act by the client or employer to keep transaction cost to a minimum at the peril of the contractor. Nevertheless, in the final analysis, costs are hardly reduced, as alluded to by the consultants, because contractors give fairly high bids, reacting from an expectancy theory viewpoint. Fair bids and contract sums could therefore be attained through the preparation of clear and detailed contract documents.

4.3.3 Contract Conditions

Various contractual conditions which form part of the procedure for practice in the Zambian construction industry could be said to be inhibiting appropriate risk allocation and result at times in either misallocation of resources or formulation of one-sided contracts. The following are practices that seem to be contributing to misallocation.

Sub-contracting. Most contracts carried out in the Zambian construction industry have a level of subcontracting of 20% of the value of the work. For large projects contractors have a mandate to subcontract 20% of the work to medium- and small-scale contractors when necesary. The respondents, especially consultants, indicated that this level of subcontracting is too low, and that those awarded the 80% in most cases do not themselves have the capacity or need to subcontract much more than 20%, and failure to subcontract more than 20% invariably leads to late completion. On the other hand, such specialised works as electrical, plumbing and air-conditioning exceed the 20% threshold and result in works being carried out by the main contracted, who may not be specialised. Using inappropriate subcontracting levels may lead to wrong resource allocation, leading in turn to late project delivery.

Omission of escalation and fluctuation clauses: Contracts over a twelve-month period normally require the use of escalation and fluctuation clauses, mainly to protect the contractor from increased prices. However, in the Zambian construction industry these clauses are omitted or waived most of the time, even for contracts whose duration is over 12 months, resulting in the contractor carrying this risk when it should be covered or shared with the client. This was reported by 93% of the respondents. This, if illustrated from a principal agent point of view, could be said to be spawning opportunistic behaviour by the client (principal), who will be trying to lower costs. However, the contractors proactively mitigate this risk by putting a high mark-up on their bids (expectancy theory). This was alluded to by 73% of the respondents. Nevertheless, this demonstrates that the client has not fully analysed the consequence of this act, which may result in higher costs.

Preferred sources of bonds and guarantees: The Zambian construction industry has traditionally demanded the securing of bonds and guarantees from banks only. However, in the last year all respondents indicated that insurance firms have become acceptable as sources of bonds and guarantees. This is a positive move, ensuring that performance bonds and advance payment bonds are obtained on projects. However, despite this, most clients still insist on bonds or guarantees from banks. Banks need collateral in the form of fixed assets. This in turn reduces the sources of finance for contractors, which normally results in poor cash flow during project execution. This is so because obtaining guarantees or bonds initially from banks lessens the opportunity of this avenue being utilised in the future, as the collateral held by the bank will render a contractor less liquid. This could be minimised if bonds or guarantees are obtained from insurance houses, which usually require payment of premiums, rather than collateral in the form of fixed assets. The majority of the respondents (87%) were of the view that bonds and guarantees obtained from insurance houses afford contractors the opportunity to source additional finance if needed from the bank, unlike when they are initially obtained from the bank. This helps the contractor’s financial management and cash flow and could help cushion the risk of late payment by the client, thereby ensuring that resource misallocation in the form of finance is minimised.

Safety Provisions: One project manager and 1 architect, and 2 of 3 contractors, comprising only 33% of respondents, stated that there seems to be a wrong method of risk allocation associated with safety because the clause is not punitive towards non-compliance. Though the respondents may not be in the majority, they give insight into why accidents are a common feature on construction sites. Consequently, contractors do not comply in terms of providing a safe working environment and provision of proper safety gear for workers on site. The respondents were of the view that if the safety clause were punitive in nature it would reduce the risk of contractors not complying.

4.4 Causes of Misallocation: Worker Related

The *Oxford Learner’s Dictionary* defines a *worker* as “a person that performs a specific or necessary task or who completes tasks in a certain way.” For tasks to be completed successfully workers need to have the necessary skill and capacity to perform the task. For risk allocation or management to be done effectively the skills and capacity of those involved should be adequate (Mu, Chen, Chohr, & Peng, 2014).

4.4.1 Perception and Knowledge

Perception of risks is significant in the consideration of the allocation of any risk. One rarely allocates risk(s) that are perceived to be less important or thought to have a low possibility of occurrence. Most of the respondents (67%) asserted that sometimes risks are not allocated due to lack of perception. In some cases, the resources allocated are not appropriate due to lack of perception or knowledge of an event as being a risk. There was nevertheless unanimity among the respondents that risks that are poorly managed lead to project failure. Giddens (1978) notes in his seminal work that in the duality of structure only a knowledgeable agent can influence structure or perhaps the way risks are allocated. From a structuration theory point of view, lack of perception in the Zambian construction industry of certain risks is leading to misallocation. Agents cannot allocate or monitor what they do not perceive to be a risk.

4.4.2 Skill and Training

Effective carrying out of risk allocation requires that risks be identified, analysed and treated. The majority of respondents (67%) indicated that they have had some training in risk management: some aspects of risk allocation were covered during their tertiary education, during their professional membership registration process or during a workshop or a seminar; the other 33% appear to have had no training at all. When asked the methods they used for risk identification, the majority indicated experience on past projects (62%); others indicated local knowledge (27%) and 33% use checklists. Other methods captured for risk identification included document review, meetings, works task analysis and cash flow analysis. Risk analysis is not actively done in the Zambian construction industry. Experience was indicated by 47% of the respondents as the method utilised for risk analysis, though it is rarely done; others indicated that they do not use any method for risk analysis (53%). For risk response, all the respondents indicated that this is done in the contract documents used. However, given that most contracts are modified and some clauses omitted or waived, risk response and analysis should be undertaken when conducting contract modifications.

4.4.3 Poor Understanding of Consequences of Risk

The majority of respondents (80%) were of the view that most clients as they modify contractual clauses or fail to honour contractual obligations do not fully understand that they allow other risks to occur. Figure 1 shows the risks that were mentioned by various respondents as being unanticipated by clients.

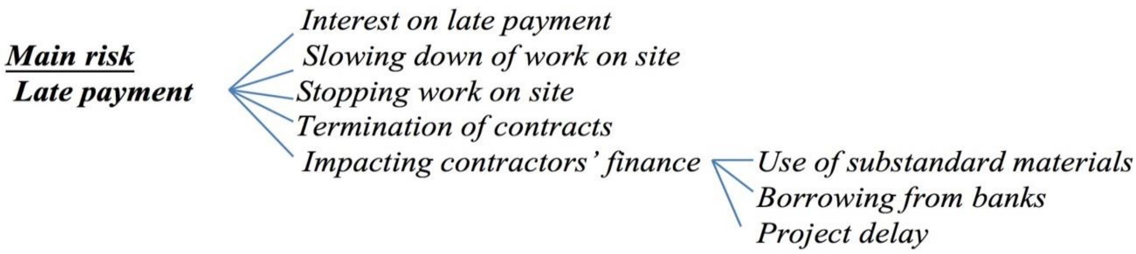

Figure 1. Risks consequential to late payment (respondents' views)

That is, late payment either by public or private clients results in other risks. As many respondents noticed, clients normally foresee paying interest on late payments but not the other risks.

4.5 Causes of Misallocation: Work Related

4.5.1 Rationale for Allocation

The *Oxford Learner's Dictionary* defines *work* as "a task or tasks to be undertaken." In the construction sector various tasks are undertaken by various professionals. Risk allocation on contracts used in the Zambian construction industry is understood to be based on responsibility or role by 67% of the respondents. Other rationales used to allocate risk identified by respondents (20% each) include risk avoidance and management ability. Basing risk allocation on responsibility or role is good for establishing liability, basing on a principal agent reasoning, but it may neglect or lead to misallocation of external risks which are not a direct responsibility of either party. In addition, it may result in risk being allocated to the party least able to manage risk. Moreover, the one whose role includes being responsible for risk is not necessarily the one best suited to manage the risk.

4.5.2 Available Response Mechanism

All types of construction projects have risks, building projects included; uncertainties sometimes lead to risks not being foreseeable. The majority of respondents, especially those in the public sector, are reactive when it comes to risks, and they respond to risk mainly to avoid audit queries and budget overruns (indicated by 60% of the professionals). This leads to misallocation by unfairly allocating risks to contractors. Contractors (100%) in their defence rarely query such allocations for fear of losing work opportunities.

5. Conclusion

Different construction industries in different jurisdictions have peculiar risks impacting on their performance and their own challenges in achieving appropriate risk allocation. Late payment is the most prevalent risk in the Zambian construction industry. Various risk misallocation practices have been found to exist in the Zambian construction industry, such as unbalanced or one-sided allocation, wrong or inappropriate methods of allocation in terms of response strategy used, and use of wrong or inappropriate resources (plant and equipment). Causes of this misallocation have been found to be environmental factors (contract used; data, information and feedback; contract conditions), worker related factors (perception and knowledge, skill and training and poor understanding of the consequences of risk) and work related factors (rationale for allocation and response mechanism). The clients in their preparation of contract documents and conduct of contract administration have been seen to take measures that seemingly reduce costs without considering how the reaction from contractors would impact cost. From an expectancy theory perspective, contractors tend to over-price bids as a response to client omission of clauses and neglect of adherence to contract conditions, such as costs awarded with an extension of time.

It could therefore be concluded that risk misallocation is contributing to poor project delivery in the building sector. The research highlights the need to have diverse contracts, timely exchange of information and data between contracting parties, favourable and enabling contract conditions, necessary skill and understanding of the consequences of unmitigated risk among the contracting parties, clear knowledge and perception of risks and the adoption of a rationale for risk allocation that is based not only on responsibility but also on ability to manage. In addition, flexibility by clients on sources of guarantees and bonds such as insurance companies could help the contractors' cash flow, thereby reducing the risk of late payment. Furthermore, varying the percentages for subcontracting according to project requirements could lead to favourable project delivery. The future focus of this research is to validate these findings through a questionnaire survey and document analysis of contract documents used in the Zambian construction industry.

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Causation Model for Psychological Injuries in the Construction Industry

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Abstract

A plethora of studies is found, which investigates physical injuries and health problems in construction. Similarly, numerous models have been developed to date to explain their causes. However, an equally important work health and safety issue, the psychological wellbeing of construction workers, is an under explored area. This research empirically analysed 376 cases of psychological injuries occurred to construction workers and developed a causation model. The study found seven causes that are responsible for psychological injuries amongst construction workers, viz.: (1) workplace harassment and bullying, (2) work pressure, (3) work-life conflict, (4) discrimination, (5) poor physical work environment, (6) job uncertainty and (7) poor workplace relationships. Among these, long sustained workplace harassment and bullying, often accompanied by violence, produces critical psychological injuries that require time-off-work for longer than a year. Similarly, constant work pressure leads to severe psychological injuries that require time-off-work for 100 to 365 days. The study highlights the urgent need to curb workplace harassment and bullying in order to make the construction industry free from critical psychological injuries.

Keywords: Work health and safety, psychological injury, construction operatives, causation model.

1. Introduction

Construction accidents have been explored extensively to date, resulting in several accident causation models. These various models focus on physical injuries and health issues because these are visible to the outer world and loud when occur. Most of the existing safety management strategies and systems too are heavily focused on curbing physical injuries and health problems. An equally important work health and safety (WHS) issue is the psychological wellbeing of construction workers. Because psychological injuries suffered by workers are invisible and silent, unlike physical injuries, they go unnoticed for extended periods, causing serious damages to workers. Hohnen and Hasle (2011) asserted that most employers fail to see the psychosocial injuries endured by workers and current WHS management practices too are heavily focused on technical aspects and neglect psychosocial hazards.

Some previous studies are noted within the broader topic of psychological health of construction workers. Golderhar et al. (1998) examined the impact of sexual harassment, gender discrimination, job uncertainty and over compensation at work on female construction workers' physiological well-being. Golderhar et al. (2003) modelled the relationships between job stressors and accident outcomes in construction projects. Likewise, Siu et al. (2004) investigated relations among safety climate, psychological strains and safety performance in construction projects. Larsson et al. (2008) studied the significance of good psychological climate in construction projects for improved safety outcomes. Leung et al. (2010) identified workplace factors affecting job stress of construction workers and further explored the impact of it on injury incidents. Melia̓ and Becerril (2007) explored how factors such as leadership, role conflict and mobbing behaviours influence workers' psychological health. Most of these studies still placed the focus on accident outcomes and treated psychological symptoms as mediators of physical injuries and health problems. The other studies were narrow in scope, suggesting further explorations are needed to understand and model the realm of psychological injuries of construction workers. To this end, this research aimed at identifying the factors that affect the psychological health of construction workers and mapping them in a causation model.

2. Literature review

Psychological health is defined as a state of mental well-being that influences one's ability to realise his/her potentials and work productively to contribute to the advancement of self and society while successfully managing the stressors of work and life (CSA 2013). Poor psychological health lead to several undesirable behaviour patterns and symptoms in employees, viz.: difficulty to focus on work and to make rational decisions; finding it hard to meet reasonable goals and deadlines; being absent from or late to work frequently; excessive tiredness and fatigue; getting overwhelmed or irritated easily with people or work tasks; displaying negative thoughts and loss of self-confidence; avoiding workplace gatherings such as staff meetings, socialisations, etc.; appearing atypically worried, apprehensive, emotional or tearful; and resorting to alcohol or drugs to cope (Beyondblue 2014).

Unfavourable conditions and/or stressors encountered at workplaces can trigger poor psychological health in employees. Eight such themes were elicited in a critical review of literatures, as discussed below. The literature review provided valuable insights and a solid foundation for the empirical study.

2.1 Work pressure

The inherent nature of construction could exert pressure on site management team and workers as they try to accomplish several tasks concurrently within a limited time and space. Choudhry and Fang (2008) reported that construction workers were constantly instructed by their supervisors to perform the task quickly, which often led to compromising safety for productivity and thereby higher injury rates. This situation causes worker to be under constant job stress. Leung et al. (2010) added that work overload also increases job stress within workers.

2.2 Workplace relationships

Poor support or relationships at workplaces can put a psychological strain on workers (Walen and Lachman 2000). Having a sense of team spirit and developing good relationships with workmates are of significant socio-psychological influencers for workers (Kazaz and Ulubeyli 2007). This creates a harmonious and positive workplace where workers tend to be morally supportive to each other. However, social relationships among co-workers can be a challenging issue for migrant workers. Language barrier is an impediment. Fang and Goldner (2011) argued that local language competency is a determining factor for migrant workers' successful transition into work culture. Moreover, it is directly linked to their economic success, which also influences the psychological well-being.

2.3 Poor physical work environment

Arboleda and Abraham (2004) postulated that being constantly exposed to extreme outdoor temperatures, poor air quality, excessive noise, dirty drinking water, odour, chemicals and hazardous working conditions can induce stress in workers.

2.4 Work-life conflict

Tennant (2001) observed that most adults attain satisfaction in life from work and family; however, these could also be sources of stress if not balanced effectively. Van Amelsvoort et al. (2004) postulated that work-family conflicts often result in inadequate time and energy to fulfil both family and work duties; one of them is likely to be compromised. Bust and Gibb (2006), for example, found that shift work among construction workers created family problems and stress. Moreover, workers with family issues had their work performance affected, which in turn showed repercussions on their economic situations. These factors collectively affect their psychological state (Glasscock et al. 2006).

Overtime work is commonly practised by organisations when a project is behind schedule or faces labour shortages. Overtime can be in the form of extending the daily work hours or rostering weekend work. In construction projects, workers generally cannot opt out overtime work. Long work shifts exceeding 13 hours or continuously working throughout weekends could lead to both physical and mental exhaustion, particularly in difficult conditions like extreme heat or cold (SoialistWorker 2011).

2.5 Workplace harassment and bullying

Mikkelsen & Einarsen (2002) found that exposure to harassment and bullying at work was associated with an increased number of psychological and psychometric complaints. Likewise, Law et al. (2011) found in Australia that 24% of compensation claims in 2007 and 2008 were linked to workplace harassment and bullying. Moreover, gender-based and sexual harassments were identified by Goldenhar et al. (2003) as strong stressors that cause poor psychological wellbeing for women in the construction industry. Severe forms of harassment and bullying are regarded as violence, which are extreme social stressors (Zapf et al. 1996). Leymann (1996) enlisted behaviours that constitute violence at work, which include: social isolation, assigning a person too little or too simple tasks, slander, intimidating or criticising, physical violence and threat of violence, and rumours about one.

2.6 Discrimination

Literature suggests that migrant workers may face discriminatory treatments by employers, local workers and/or unions. Discrimination by employers include unequal wages for the same jobs, offering jobs un-matching their qualifications/skills and limited work hours. Wong et al. (2007) claimed that migrant workers are perceived to be increasing competition in the market, thereby threaten job opportunities for local workers. As such, migrant workers face hostility from locals and at times are linked to increased crime rates in the city. Harcourt et al. (2008) argued that discrimination against migrant workers is not limited to employers or local workforce and pointed out that unions that lobby for restrictions on immigration to satisfy the majority group are hesitant to help ethno-cultural groups to acquire decent work conditions. Depending on the country of origin and economic backgrounds, migrant workers would initially tolerate discrimination. However, over time they experience frustration, feelings of shame, bitterness, strain and loss of sleep (Simich et al. 2006).

2.7 Job uncertainty

Dekker and Schaufeli (1995) found that job uncertainty faced by employees of a transport organisation in Australia was strongly associated with psychological distress. They further argued that the negative psychological effect of job uncertainty extends beyond the potentially redundant employees and affects their families too. Among the organisational practices that pose a sense of job uncertainty are: casual/contract employment, redundancy, gender/ethnic/nationality preferences, etc. Job uncertainty for construction workers is placed in a delicate position. The continuity of construction jobs is heavily dependent on the availability of new projects for the employer. Many external factors influence this; i.e., changes to government policies on infrastructure development and other economic issues can impact on construction demand, which may make job insecurity a constant issue in construction.

3. Research method

Figure 1 illustrates the methods deployed in this empirical research, which utilised a large database of construction accidents for developing the causation model. Accident data for the research were obtained from Safe Work South Australia, which is a state government agency responsible for work health and safety. They maintain a database of workplace accidents across all industries in South Australia. The database encompassed 29,205 construction accidents, reported during 2002-13. Filtering the database, a subset of 444 records was extracted, which described incidents related to psychological injuries to construction workers.

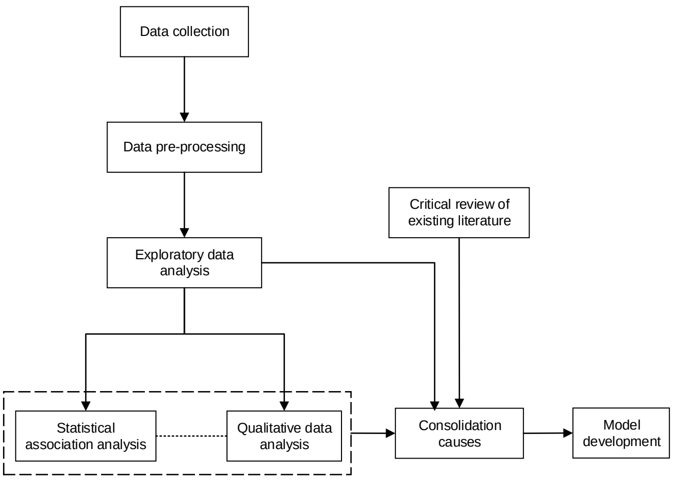

Figure 1: Research process and method

Pre-processing was undertaken to prepare the filtered data for statistical analysis. A typical case was characterised by variables such as: mechanism of incident, occupation, age, gender, language, nationality origin, experience, timing of incident, date of incident, employer size, description of incident, lost days and worker’s compensation paid. First, records that are not related to construction, but had been incorrectly recorded were removed (21 cases). Further checking was conducted to identify cases that are not significant for analysis. Forty-seven cases with both zero lost days and zero compensation were identified and removed, resulting in 376 usable cases for further analysis. Then, entries and descriptions across records were made consistent. Finally, nominal scales were introduced for variables that had numerical entries to facilitate non-parametric statistical analyses.

After the data pre-processing, an exploratory analysis using descriptive statistics was performed to gain a broader understanding of the psychological injuries in the South Australian construction industry. Subsequently, associations between the independent variables and the severity of psychological injuries were investigated using chi-square tests. While chi-square statistics are helpful for revealing associations they cannot be interpreted as causations. Thus, incident descriptions were qualitatively analysed to corroborate how the associations exhibit causation. Finally, findings from the quantitative and qualitative analyses and the literature review were consolidated, enabling the development of a new causation model for psychological injuries in the construction industry.

4. Quantitative data analysis and findings

The data set was redefined by 10 independent variables and one dependent variable (severity of psychological injury) in the pre-processing stage. In the original database, some of these variables were defined by different measurement scales, such as: occupation of victim had 67 job titles; age was in years; language background had 7 entries; nationality origin consisted of 9 countries; time of incident was 30-minute class intervals; and month of incident had 12 entries. Table 1 shows how these variables were re-categorised using nominal scales. Some of the categories, such as gender, mechanism of injury and employer size, were directly taken from the original dataset.

Table 1: Variable measurements

Variable	Measurement (nominal)
Independent variables:	
1. Mechanism of injury	Assault; exposure to a traumatic event; exposure to workplace or occupational violence; work pressure; workplace harassment and/or bullying; suicide or attempted suicide; other mental stress factor
2. Season of injury	Summer (Dec, Jan & Feb.); autumn (Mar, Apr & May); winter (Jun, Jul & Aug); spring (Sep, Oct & Nov)
3. Work shift of injury	Morning shift; afternoon shift; evening shift; night shift
4. Age range of victim	Under 20; 20 to 29; 30 to 39; 40 to 49; 50 to 59; over 60
5. Gender of victim	Male; female
6. Occupation category of victim	Office staff; site staff; trades personnel; machinery operator; apprentice; general worker
7. Experience of victim	Experienced worker; new worker
8. Native language of victim	English; non-English
9. Nationality origin of victim	Australian; non-Australian
10. Employer size	Small (1 to 20 employees); medium (21 to 200 employees); large (more than 200 employees)
Dependent variable:	
11. Severity of psychological injury	Minor; moderate; major; severe; critical

The dependent variable, severity of psychological injury, was derived based on the number of lost days reported for the cases. The utilisation of lost days to categorise injuries in to different severity levels has commonly been used by previous researchers who investigated physical injuries in construction; for example, Dumrak et al. (2013) and Arquillos et al. (2012). Nonetheless, varied severity levels and groupings of lost days were implemented by different researchers. This research adopted five levels of severity such as: minor, moderate, major, sever and critical, and the definitions for these categories are given below, which were derived from the risk matrix recommended by the National Patient Safety Agency (NPSA) (2008):

- **Minor** – psychological injuries requiring time off work (lost days) for shorter than 3 days.
- **Moderate** – psychological injuries requiring time off work (lost days) for 4 to 14 days.
- **Major** – psychological injuries requiring time off work (lost days) for 15 to 99 days.
- **Severe** – psychological injuries requiring time off work (lost days) for 100 to 365 days.
- **Critical** – psychological injuries requiring time off work (lost days) for longer than 365 days.

In interpreting the results, findings of both exploratory and chi-square analyses were looked at in a combined manner. The below sections expound the findings. In general, an upward trend in psychological injuries to construction workers in the South Australia is discernible. Whilst the severity level of psychological injuries are more on the minor category, the combination of major, severe and critical injuries constitutes one-third of all incidents. Given the psychological injuries are on constant increase, the ratio is likely to result in negative social outcomes and sufferings. It is therefore crucial that lessons are learnt from past incidents and measures are put in place to curtail them in the future. Table 2 elucidates chi-square analysis results. Interpretations of these results are provided below under appropriate subheadings.

Table 2: psychological injury severity pattern

Factor		Category (% of total accident)	% of accident within severity level				
			Minor	Moderate	Major	Severe	Critical
work-related factors	**Mechanism of psychological injury (x2 = 50.909, df =24, p =0.001)**	Being assaulted by a person or persons (12%)	80	2.2	0	13.3	4.4
		Exposure to a traumatic event (12.5%)	83	4.3	6.4	0	6.4
		Exposure to workplace or occupational violence (8%)	70	3.3	6.7	10	10
		Work pressure (33.2%)	54.4	2.4	23.2	17.6	2.4
		Work related harassment and/or workplace bullying (27.9%)	51.4	2.9	16.2	16.2	13.3
		Suicide or attempted suicide (0.8%)	100	0	0	0	0
		Other mental stress factors (5.6%)	76.2	4.8	4.8	9.5	4.8
	Occupation (x2 = 28.047, df =20, p =0.108)	Apprentice (6.6%)	72	4	4	8	12
		General worker (7.7%)	62.1	0	20.7	6.9	10.3
		Machinery operator (17.3%)	60	6.2	16.9	6.2	10.8
		Office staff (19.4%)	54.8	1.4	15.1	24.7	4.1
		Site staff (11.7%)	54.5	4.5	15.9	15.9	9.1
		Trade personnel (37.2%)	70	2.1	11.4	12.1	4.3
	Work shift (x2 = 13.257, df =12, p =0.351)	Morning shift (32.4%)	66.4	3.3	16.4	8.2	5.7
		Afternoon shift (21.5%)	63	3.7	7.4	17.3	8.6
		Evening shift (2.7%)	40	10	30	10	10
		Night shift (43.4%)	62	1.8	14.1	15.3	6.7
	Employer size (x2 = 29.209, df =12, p =0.004)	Large (34%)	56.3	5.5	24.2	9.4	4.7
		Medium (36.7%)	62.3	0.7	10.1	18.1	8.7
		Small (29%)	71.6	2.8	6.4	11.9	7.3
		Unknown (0.3%)	100	0	0	0	0
	Season (x2 = 27.245, df =12, p =0.007)	Autumn (24.5%)	66.3	0.0	15.2	9.8	8.7
		Spring (25.3%)	60.0	5.3	10.5	22.1	2.1
		Summer (22.9%)	73.3	2.3	8.1	10.5	5.8
		Winter (27.4%)	54.3	3.9	20.4	10.7	10.7
Worker-related factors	**Gender (x2 = 8.890, df =4, p =0.064)**	Female (19.1%)	50.0	2.8	18.1	22.2	6.9
		Male (80.9%)	66.1	3.0	12.8	11.2	6.9
	Age (x2 = 15.266, df =20, p =0.761)	Under 20 (1.9%)	71.4	0	28.6	0	0
		20 to 29 (14.9%)	69.6	1.8	10.7	12.5	5.4
		30 to 39 (26.1%)	61.2	3.1	15.3	12.2	8.2
		40 to 49 (27.4%)	64.1	3.9	10.7	11.7	9.6
		50 to 59 (25.8%)	58.8	2.1	17.5	18.5	3.1
		Over 60 (4%)	66.7	6.7	6.7	6.7	13.2
	Experience (x2 = 9.949, df =4, p =0.041)	Experienced (84.3%)	61.2	3.2	15.8	13.9	6
		New Worker (15.7%)	72.9	1.7	3.4	10.2	11.9
	Nationality origin (x2 = 18.553, df =8, p =0.017)	Australian (75.8%)	67.4	2.8	11.2	12.3	6.3
		Non-Australian (13.6%)	58.8	3.9	13.7	15.7	7.8
		Unknown (10.6%)	37.5	2.5	32.5	17.5	10.0
	Native language (x2 = 7.955, df =8, p =0.438)	English (96.3%)	63.3	3.0	13.3	13.5	6.9
		Non-English (2.1%)	62.5	0.0	12.5	12.5	12.5
		Unknown (1.6%)	50.0	0.0	50.0	0.0	0.0

4.1 Mechanism of incident

Data analysis revealed that work pressure and workplace harassment and bullying are the major causes of psychological injuries among construction workers with almost one-third of incidents are attributable to each. Moreover, these mechanisms are represented heavily in the major, sever and critical categories of injury severity. That is, work pressure recorded a total of 43.20% incidents in these categories whilst workplace harassment and bullying represented a total of 45.7%. Chi-square test results (x^2 = 50.909, df =24, p =0.001) reveal that there is a statistically significant association between injury severity levels and incident mechanisms.

4.2 Occupation

In terms of occupation, trades personnel were heavily represented in psychological incidents, followed by office-based employees of construction organisations and then machinery operators. Even though no statistically significant association between the occupations and the psychological injury severity levels was observed (x^2 = 28.047, df =20, p = 0.108), a quarter of office-based employees in construction suffered severe injuries, which resulted in time-off-work between 100 days and a year.

4.3 Work shift

No statistically significant association was observed between work shifts and psychological injury severities (x^2 = 13.257, df =12, p = 0.351). This finding contradicts with literature on severities in physical injuries, which confirms that a large proportion of fatalities occur in afternoon shifts (known as 'after lunch effect'), and more injuries occur in morning shifts. However, night shift workers represent psychological injury statistics heavily, across severity categories of major, sever or critical.

4.4 Worker's gender

Females accounts for only 13% of the South Australian construction workforce (Australian Bureau of Statistics 2013); but, they are represented doubled the rate for male workers in severe psychological injuries, as revealed in this study. In other categories of severities, females and males seem to represent almost similarly, leading to weak chi-square statistics (x^2 = 8.890, df = 4, p = 0.064) to conclude that there is no significant association between gender and psychological injury severity.

4.5 Worker's age

Past studies on physical injuries have concluded that the severity of physical injury increases with the age of workers (Arquillos et al. 2012). However, this study has found that there is no significant association between the age and the severity of psychological injury (x^2 =15.266, df =20, p =0.761). Age groups such as 30 - 39, 40 - 49 and 50 - 59 are nearly equally represented in the overall records.

4.6 Worker's experience

This study indicated a weak association between experience and psychological injury severity (x^2 =9.949, df =4, p =0.041). In contrary to psychical injuries reported in literature, new workers represented double the rate of experienced workers in the severity category of 'critical' psychological injuries that lead to time-off-work for longer than a year.

4.7 Worker's nationality origin and native language

Australian-born workers represented more in psychological injury statistics than overseas-born workers and an association is noted between the nationality origin and the injury severity (x^2 =18.553, df =8, p =0.017). However, language background of the worker did not show any association. Australian workforce comprises 26% persons born overseas (Australian Bureau of Statistics 2010), but their representation in psychological injury statistics (13.6%) is lesser. Nevertheless, they are disproportionately represented (37.2%) in injury categories of major, severe and critical.

4.8 Employer size

Only minor differences in the number of psychological incidents was observed across employer sizes though a significant association between the employer size and injury severity levels was apparent (x^2 =29.209, df =12, p=0.004). Small organisations represent more in minor incidents whilst nearly 25% of incidents occurred in medium-sized organisations resulted in severe or critical injury outcomes. A similar proportion of incidents in large organisations caused major psychological injuries. No significant differences in the percentage of critical incidents arose in small and medium organisations.

4.9 Season

The climatic season of winter recorded slightly a higher number of incidents (27.4%) of psychological injuries than spring (25.3%) and autumn (24.5%). Similarly, winter accounted for the largest proportion of major, sever and critical incidents than the other seasons, with a total of 41.8% of all the incidents occurred in that season. Chi-square test results also prove that there is a strong association between the season and injury severity (x^2 =27.245, df =12, p =.0007).

5. Qualitative data analysis and findings

The quantitative analysis displayed the aforementioned patterns within the incident cases. However, they did not explain the underlying issues that yield them. Hence, the qualitative analysis probed into the incident descriptions reported by victims and the following trends were discovered.

- One of the major causes of work pressure was excessive workload along with working long hours, sometimes continuously working without breaks, and trying to achieve unrealistic goals set by the management. Most of the workers were unable to cope with such excessive workloads, found the job to be very stressful and ended up having anxiety and depression. As reported by one of the victims "I was standing in the yard, shaking in tears, unable to achieve..... build up of pressure due to worrying about getting the job done on time........ unbearable work load".
- Under workplace harassment, bullying was reported to be the major issue followed by verbal abuse and sexual harassment. Interestingly these were mainly committed by co-workers rather than the management or employer. In most cases victims reported an ongoing harassment for a long time; for example, a worker indicated "I was going about my normal duties and could no longer handle the harassment and bullying that I was suffering. I find harassment about on that I had nothing to do with". Few cases of threatening behaviours either by a co-worker or employer were also reported. For example, a worker reported "I was victimised by the directors of the company and made to feel threatened and bullied. I feared for my life and felt

very unsafe at work. I had to call the police" and another worker alleged "I received threatening phone calls at night. Caller said he would kill or damage me and my family".

- Few workers reported stress and anxiety due to repetitive tasks over a long period of time. Others reported work environment to be the major cause of work pressure. They have experienced intolerable conditions and unsafe work practices that led to work stress.
- Confrontations with the employer or management were reported as causes of work stress. Arguments, aggressive and violent actions at meetings, false accusations, allegations of misconduct were the major reasons behind these confrontations.
- Job uncertainty, non-payment, underpayment or delayed payments of wages were also found to have caused depression. In few cases, unfair dismissals have caused stress.
- Work situation (isolation) and workload were cited as main reasons for anxiety and depression that led to very long absenteeism.

The qualitative analysis was extended to scrutinise the level of injury severity against incident descriptions and discovered the below patterns in the incident cases.

- Critical incidents were predominantly caused by multiple sources of harassment over a period; for example, "work and work environment causing anxiety, panic attacks and depression due to harassment, bullying and victimization"; and "workplace bullying, verbal and behavioural threats, sexual harassment, undermining authority, defamation".
- Unlike the above, severe incidents were equally caused by harassment and work pressure. Seventy-five percent of major incidents were caused by work pressure while only 25% were due to harassment; for example, a worker reported "work related stress and anxiety due to staff shortages and performing work of two", and another worker's account "work pressure, working long hours, work overload, and overseeing too many projects".

6. Discussion

The empirical analysis investigated the influence of personal factors (age, gender, experience, nationality and language background), work factors (occupation, work shift, work conditions, and employer) and environmental factors (season) on the psychological injury outcomes in the construction industry. It has been found that work factors have predominant influence in psychological injuries than other factors. Hence, the seven themes discovered in the literature research are confirmed to be relevant to the construction industry. However, the degree of influence varies in the construction industry setting in the descending order of: (1) workplace harassment and bullying, (2) work pressure, (3) work-life conflict, (4) discrimination, (5) poor physical work environment, (6) job uncertainty, and (7) poor workplace relationships. Similarly, the above order is also a reflection of the severity of these incidents, where harassment and bullying resulting mainly in critical to severe outcomes while work pressure and work-life conflict lead to severe to major outcomes. Other causes are not generally associated with higher order severities. It is interesting to observe that all critical incidents, except four cases, were caused by harassment and bullying. Thus, the study clearly highlights the need for curbing harassments and bullying to make construction workplaces free from critical psychological incidents.

7. Formulation of a causation model for psychological injuries

The findings of the two distinct research methods were consolidated and corroborated towards formulating a causation model for psychological injuries in the construction industry. Figure 2 demonstrates the model by mapping out the factors and their influence paths. The far left end of the diagram encompasses seven umbrella stressors with their originating sources. Being a victim of one or a combination of these stressors causes emotional distress with feelings such as tension, anxiety, insecurity, frustration and/or trauma in workers. Enduring these distress symptoms for an extended period can lead to excessive mental stress. When the excessive stress is not controlled, it can result in psychological depression, which often impacts on the physical health, behavioural and social patterns/habits, work performance and family relationships. These negative consequences in turn reinforce the emotional distress and mental stress.

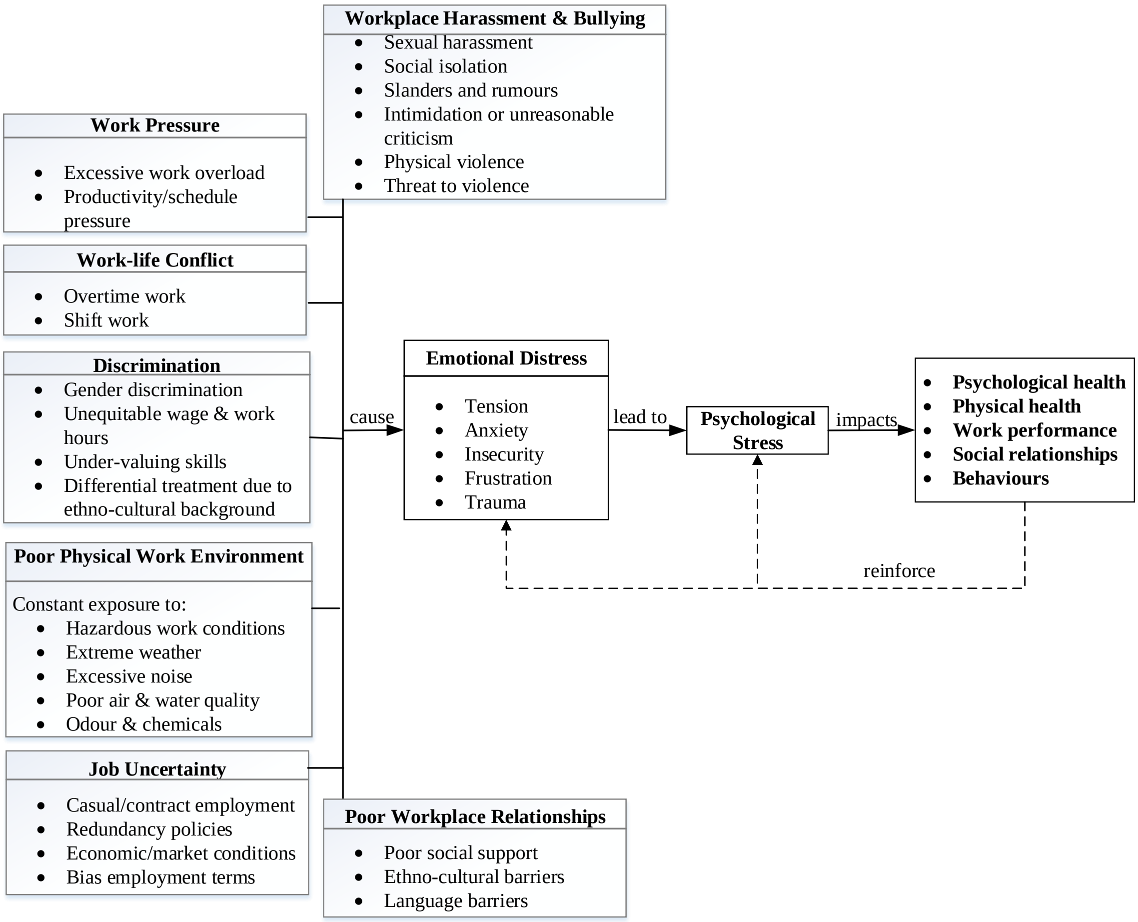

Figure 2: Causation model for psychological injuries

8. Conclusion

While numerous models have been developed by researcher to explain the causation of workplace accidents and health damages that occur to construction workers, silently suffered psychological injuries have not gained attention. This study proposes a causation model, which maps out seven factors along a stress influence path. The factors include: workplace harassment and bullying, work pressure, work-life conflict, discrimination, poor physical work environment, job uncertainty, and poor workplace relationships. The degree of distress exerted by workplace harassment and bullying, and work pressure is found to be more significant in the construction industry context than that of caused by other stressors. Workplace harassment and bullying have the potential to cause psychological damages that can lead to lost days in excess of a year and excessive work pressure could result in lost days due to psychological injuries longer than 100 days. Hence, these factors warrant special attention and scrutiny from organisational management as well as WHS authorities in order to maintain a construction industry that is free from serious or critical psychological incidents.

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SECTION

5

Sustainable construction

Global Real Estate Sustainability Benchmark (GRESB Survey): Improving Sustainability Performance in the Commercial Real Estate Sector in the Nordics

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Abstract

Considering the globe and the built environment, commercial real estate sector is one of the largest consumers of natural resources and greatest polluter with reference to GHG emissions and solid waste production. Among initiatives to reduce environmental impact of commercial real estate industry, Global Real Estate Sustainability Benchmark or as since December 2015 GRESB Real Estate Assessment (GRESB Survey) focuses on collecting information regarding sustainability performance of property companies and funds.

The purpose of this paper is to analyse GRESB Survey as a tool to improve the sustainability performance of commercial real estate industry. Drivers to participate, benefits, best practices and challenges with GRESB Survey among Nordic real estate companies and funds were analysed in the recent research conducted by the author.

This research on GRESB Survey and commercial real estate sustainability is a practical investigative research conducted during October 2014 – April 2015. Research data was collected by interviews and web surveys. Interviews and web survey addressed four different target groups; real estate investment companies and funds, real estate user owners, GRESB investor members and institutional investors aligned with principles of responsible investment.

Benchmark data with peer organizations provided by GRESB Survey directs participants' sustainability efforts, helps in allocation of resources, brings sustainability on the top management agenda and connects companies with investors on sustainability issues. GRESB Survey participation requires dedication, time, resources and willingness to meet challenges. GRESB Survey develops in agile way and it is expected to "raise the bar" over the years and become more analytical and detailed. Together with development of GRESB Survey itself and growing number of users, also other actors within real estate industry are developing new services and aligning existing services to better support real estate companies and funds with sustainability performance improvement through the GRESB Survey.

Keywords: Sustainability, ESG, GRESB Survey, GRESB Assessment, sustainability services

1. Introduction

Sustainable development is about integrating the needs of society while maintaining earth's ecological capacity and not endangering the possibility of future generations to meet their needs. Three dimensions of sustainable development; economical, environmental and social dimension, are interdependent and mutually reinforcing.[1] Built environment and buildings are responsible annually on global level for more than 40% of energy consumption, 30% of energy-related greenhouse gases (GHG) emissions and considering the whole building sector 30% of resource consumption, 12% of fresh-water use and 40% of total solid waste generation. On average building sector employs more than 10 % of global workforce. Construction and real estate sector play a significant role in the response to climate change and have substantial potential for sustainable reduction of emissions with minimum investments or even with net savings.[2] Considering the globe and the built environment, commercial real estate sector is one of the largest consumers of natural resources and greatest polluter with reference to GHG emissions and solid waste production.[3]

Along growing global awareness of the environmental impact of buildings and commercial real estate, sustainability has gained more important role in the real estate sector with environmental sustainability focus. However, the adaptation of sustainable principles has been hindered by the lack of evidence of concrete financial benefits and common agreements how to share the cost burden and benefits between investors, owners, fund managers and tenants regarding investments improving sustainability in real estate sector.[4]

Among initiatives to reduce environmental impact of commercial real estate industry, GRESB Survey focuses on collecting information regarding sustainability performance of property companies and funds. Benchmark information serves institutional investors and participants themselves to monitor, benchmark and improve sustainability performance further. GRESB Survey is aligned with international sustainability reporting schemes as Global Reporting Initiative G4 (GRI G4), UN Principles for responsible investment (PRI), Dow Jones Sustainability Index (DJSI) and Carbon Disclosure Project (CDP). GRESB Survey is not limited on environmental aspects only while it covers broader sustainability issues in terms of ESG criteria, such as sustainability management, assessment of sustainability risks, sustainability improvement programs and stakeholder engagement.[5]

GRESB Survey participation requires dedication, time, resources and willingness to meet challenges. GRESB Survey develops in agile way and it is expected to "raise the bar" over the years and become more analytical and detailed. Together with development of GRESB Survey

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[1] SFS - ISO 26000 (2009) p.9.

[2] UNEP (n.d.) online.

[3] Bauer et al. (2010) p.17.

[4] Schleich et al. (2009) p.203.

[5] GRESB (2015) p.2.

itself and growing number of users, also other actors within real estate industry are developing new services and aligning existing services to better support real estate companies and funds with sustainability performance improvement through the GRESB Survey. The purpose of this paper is to analyse GRESB Survey as a tool to improve the sustainability performance of commercial real estate industry and to discuss the range of services Ramboll can provide to real estate companies and funds to support both GRESB Survey participation and consequent development processes to improve sustainability performance further.

Two following chapters describe GRESB Survey and applied research methodology. The chapter four focuses on benefits and challenges related to GRESB Survey as well as on identified best practices and GRESB Survey's potential to improve sustainability performance of real estate investment funds and companies. Furthermore available tools and external services supporting GRESB Survey participation are discussed. Last chapters focus on business opportunities around GRESB Survey and its significance to different actors among commercial real estate industry.

2. About GRESB Survey

GRESB –survey was started in 2009 through a survey project of Maastricht University aiming to develop "Environmental real estate index". In five years GRESB Survey has developed into a global standard to assess the sustainability of real estate portfolios.

GRESB Survey contains 42 basic questions and 14 questions covering new construction and major renovation activities. The survey collects information on performance data as energy, GHG emissions, water and waste. In addition GRESB Survey covers also sustainability risk assessment, performance improvement programs and engagement with employees, tenants, suppliers and community. Reported sustainability aspects are divided into following sections:

- Management e.g. strategy, objectives, resources, decision-making.
- Policy and disclosure e.g. guidelines, policies, reporting and third party reviews.
- Risks and opportunities e.g. governance and sustainability.
- Monitoring and environmental management systems and certifications.
- Performance indicators e.g. energy, GHG and water data, waste management.
- Building certifications e.g. green building certificates and energy ratings.
- Stakeholder engagement e.g. employees, tenants, suppliers and local communities.
- New construction and major renovations:
    - Sustainability requirements of projects and sites
    - Community engagement and socio-economic impact
    - Materials and certifications
    - Energy efficiency
    - Requirements for occupant wellbeing, energy and water efficiency
    - Supply chain requirements
    - Health and safety on-site

GRESB allocates an overall GRESB score to each participating real estate company or fund. Due to complexity of the sustainability and real estate sector as well as variations between countries and regulatory environments, companies and funds are analysed through peer group benchmark instead of absolute sustainability performance. Peer group comparison takes into account country, regional, sector and investment type of variations.

Participation to GRESB Survey is free of charge. GRESB on-line survey reporting period is between 1st of April and 1st of July. Survey submissions are validated during the months of July and August. GRESB Survey results are published in September. Participants receive their GRESB Scorecard with headline results as overall score, strengths and weaknesses and the score on reported sustainability aspects. For extra charge, survey participants can purchase complete and more detailed benchmark report covering single answers of the GRESB Survey. Key figures describing the scope of GRESB Survey are illustrated in the table below.

Table 1: GRESB Survey highlights 2014-2015.

	2014	*2015*
GRESB participants	*637*	*707*
GRESB investor members	*46*	*51*
Company and fund manager members	*56*	*87*
Associate members	*21*	*28*
Partners	*12*	*13*
Institutional capital	*$5.5 trillion*	*$6.1 trillion*
Property value	*$2.1 trillion*	*$2.3 trillion*
Assets covered	*56000*	*61000*
New construction and major renovation assets	*3329*	*4127*

3. Research methodology

This research on GRESB Survey 2014 and commercial real estate sustainability is an investigative field study. Collection of research data was conducted between October 2014 and March 2015. Data was collected by interviews and with web-surveys. Nine interviews were conducted in November 2014 with a sustainable investment consultant and five real estate companies and funds in Finland and in Sweden.

Web-surveys were conducted with Webropol on-line survey and analysis software. Altogether four web-surveys were conducted for different commercial real estate actors. Web-surveys for real estate companies, funds and user-owners were conducted between December 2014 and March 2015. Target group was divided in two groups; companies already participating into GRESB Survey (GRESB - pioneers) and companies potentially interested in participation into GRESB Survey (GRESB - potentials). Web-surveys for investors were conducted between January and March 2015. Also investor target group was divided into two; GRESB investor members (GRESB – investors) and investors not being members of GRESB (Non-GRESB-investors).

Web-surveys included both multiple choice and open-ended questions. Survey was sent as an email link to targeted respondents and survey was also promoted in social media, LinkedIn. The survey had total 41 respondents (including the interviews) and the distribution of respondents is illustrated in following table. Sample size is approximate due the promotion of the survey in social media, but illustrates the number of emails sent to target groups with the survey link. Web survey participation was voluntary and respondents could skip any question and discontinue at any point. All responses are anonymous and kept confidential.

Table 2: GRESB Survey –research sample sizes and response rate.

Target group	*Responses*	*Sample size*	*Response rate*
GRESB – pioneers	*14*	*15*	*93 %*
GRESB – potentials	*17*	*70*	*24 %*
GRESB – investors	*7*	*33*	*21 %*
Non–GRESB-investors	*3*	*50*	*6%*
TOTAL	*41*	*168*	*24 %*

At the time of the research a total of 15 real estate investment companies and funds were identified as GRESB Survey participants in the Nordics. Later it was revealed that altogether 21 real estate companies and funds in the Nordics participated into GRESB Survey in 2014 and the number of participants grew into 41 participants in GRESB Survey 2015.[6]

The aim of the research was to understand:

- Benefits of GRESB Survey?
- Best practices and challenges with GRESB Survey?
- If GRESB Survey does help companies and investors to improve the overall sustainability performance? And how eventually?
- On what matters are external partners used in sustainability reporting process and GRESB Survey participation?
- What kind of tools, programs and software is used to facilitate data collection in connection to sustainability performance indicators?

[6] 2015 GRESB Report – Europe Snapshot, p.1.

4. Impressions about GRESB Survey

Real estate companies and funds, especially listed ones, are faced by the burden of ”multiple sustainability reporting”. Some of the sustainability reporting frameworks such as GRI, CDP, DJSI and EPRA are well established and ”institutionalized” among commercial real estate companies and funds in their efforts to communicate to their owners, investors, creditors and other stakeholders about their sustainability efforts and commitment. What are the perceptions towards GRESB Survey, an additional sustainability reporting framework among many others?

Real estate companies and funds participating into GRESB Survey consider it the most important sustainability reporting scheme backed by GRI sustainability reporting. GRESB Survey is seen to have focus on industry-related, material aspects and as a valuable tool for improving the sustainability performance of real estate companies, funds and commercial real estate portfolios. Benchmark data with peer organizations directs sustainability efforts, helps in allocation of resources, brings sustainability on the top management agenda and connects companies with investors on sustainability issues. It should not be seen as “judgement” of existing practices, but as a starting point of a continuous improvement process.

4.1 Benefits of GRESB Survey

While asking the importance of different sustainability reporting and assessment schemes, there is no doubt of how strong position GRESB Survey has when compared with sustainability reporting frameworks as illustrated in Figure 1. GRESB pioneers as reporting companies consider also the importance of other schemes as GRI reporting and EPRA Sustainability BPR. Sustainability reporting according GRI guidelines is considered by one interviewee as something that “Once you start, you can’t give it up...” It is very improbable that GRESB – survey would replace GRI sustainability reporting as GRI serves all stakeholder groups and is an “open access system” once published on-line.

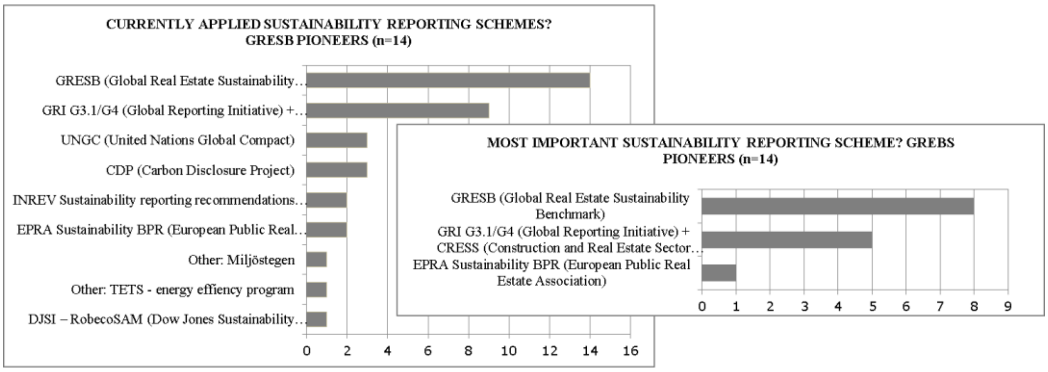

Figure 1: Sustainability assessment schemes used by GRESB pioneers.

According to GRESB – potentials open-ended responses, sustainability reporting pushes companies to set indicators in the first hand. Monitoring and reporting on environmental e.g. energy indicators leads to setting more precise targets for improvement and follow-up of the performance. Setting up reasonable targets enables reaching them with natural consequence of positive results that motivates companies to set more challenging targets, widening the scope of environmental targets or investing in sustainability efforts.

Figure 2 illustrates benefits GRESB Survey provides both for GRESB – investors and GRESB – pioneers. Among benefits provided by GRESB Survey, the GRESB – investors emphasized increased transparency towards investors themselves as the key benefit provided by GRESB Survey. According to open-ended answers GRESB Survey gives investors pieces of information they have not thought about before and this information can be used as a catalyst for new sustainability initiatives. One respondent highlights the idea of implementing a "robust" Green Lease as new standard for all office and retail asset. When not all companies and funds within the investment portfolio are participating into GRESB Survey, investors tend to engage with them with issues and ideas from GRESB Survey, resulting in improvement the overall sustainability performance of the portfolio.

Communication and branding benefits as well as improved credibility of sustainability disclosure rank high among benefits of GRESB – pioneers. Furthermore the survey gives new ideas from peer group and from the survey itself. GRESB Survey directs sustainability efforts by evidencing aspects that may not be considered earlier and showing where the industry is heading to regarding sustainability. Several interviewees see GRESB Survey as a development tool for sustainability, showing what is material and important in the real estate industry. GRESB Survey encourages self-evaluation which leads to self-reflection and works as natural, in-born catalyst for sustainability improvements.

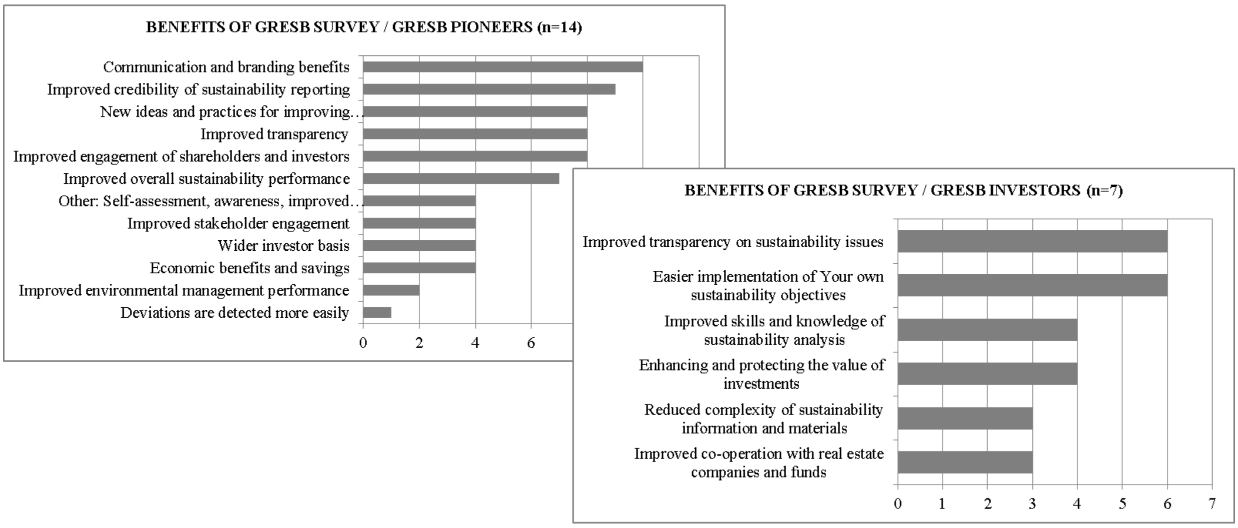

Figure2: Benefits provided by GRESB Survey.

One interviewee emphasizes the global focus and approach to sustainability innovations of GRESB Survey as feeding the real estate industry over the time with new ideas as innovations become everyday work and are found as a part of the GRESB Survey questions.

After completing GRESB Survey, as revealed by open-ended responses participants got to know what they have to actually work with e.g. focus more on water consumption of to develop external communication about sustainability on their website. GRESB Survey reveals strengths and weaknesses of companies and helps to prioritize and allocate resources correctly in actual and relevant sustainability aspects.

Improved transparency and connectivity with investors is naturally important for GRESB – pioneers. Furthermore GRESB Survey is described in open-ended responses of GRESB - pioneers also as a tool for putting sustainability on the agenda of top management in concrete and appetizing way. First it pushes for more structured management of sustainability aspects and making sustainability more concrete and simpler to deal with. Second as a consequence, GRESB Survey facilitates target setting, measurement and communication about sustainability efforts with management, investors and own personnel. As one interviewee describes: "GRESB Survey visualizes connection between sustainability work and progress to all employees. It gives a new meaning to sustainability work."

4.2 Challenges and best practices with GRESB Survey participation

Challenges experienced with GRESB Survey participation are dependent on knowledge and experience of sustainability reporting and sustainability data collection practices of participating organizations. Many of private real estate investment companies and funds are small and medium sized companies (SME), often with less than 30 employees. Private SMEs have also different governance and reporting obligations as listed, public real estate investment companies and funds.

Data collection and processing existing data into GRESB Survey –format, where the aim is to collect data by property types and separate consumption and waste data between landlord and tenants. When portfolio includes many multi-purpose properties, division of energy consumption data between different property types leads to excessive manual calculation and aggregation of performance indicators. Generally the amount of data; performance indicators, process descriptions and evidencing documents may be challenging for SMEs and portfolios with large number of properties.

Survey is perceived as rigid and data to be submitted must be very precise. As GRESB Survey has global reach and it develops over the time, some questions remain generic, difficult to understand and without common clarification.

Respondents were asked to share best practices applied in connection of GRESB Survey participation. First timers should consider GRESB Survey as a starting point in a process of continuous improvement, not as judgement of existing policies and performance. When there is no clarification for a problem participant is dealing with, it is important to make own conclusions and assumptions, explain them thoroughly and be consistent with methodology over the time. Time and resources can be saved by getting familiarized with GRESB Survey guidance, committing top management and other people and functions needed in reporting process properly and well in advance. Sharing and publishing information about sustainability commitment, efforts and activities facilitates GRESB Survey submission. One respondent describes: “Don’t overdo. Use what you have and build on that.”

4.3 Does GRESB Survey help to improve sustainability performance?

One central question of this survey is, whether GRESB Survey actually helps companies to improve sustainability performance. To start the analysis it is feasible first to understand what kind of benefits improved sustainability performance may offer to real estate companies and funds according all respondent groups. Improved sustainability is first associated with reduced operating costs and environmental impact of properties. Secondly it is associated with health, comfort and higher quality of buildings, which consequently may result in improved tenant satisfaction and commitment. Furthermore branding, marketing and sales related benefits are emphasized together with meeting investors’ and shareholders’ sustainability criteria (Figure 3).

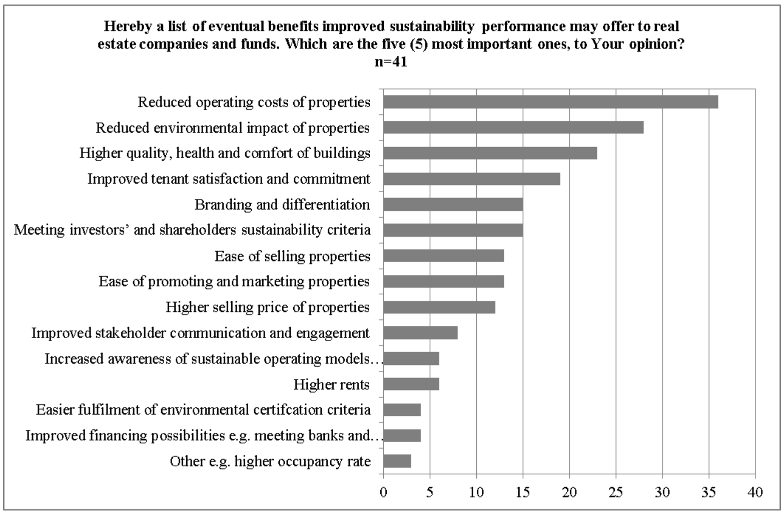

Figure 3: Benefits of improved sustainability performance.

Both GRESB – pioneers and GRESB – investors were asked whether GRESB Survey helps to improve overall sustainability performance, on company or on the real estate investment portfolio level. All except one of GRESB – investors witnesses GRESB Survey role in this improvement process Within GRESB – pioneers majority sees GRESB Survey as a tool for improving overall sustainability performance, but the difference is not so clear (Figure 4).

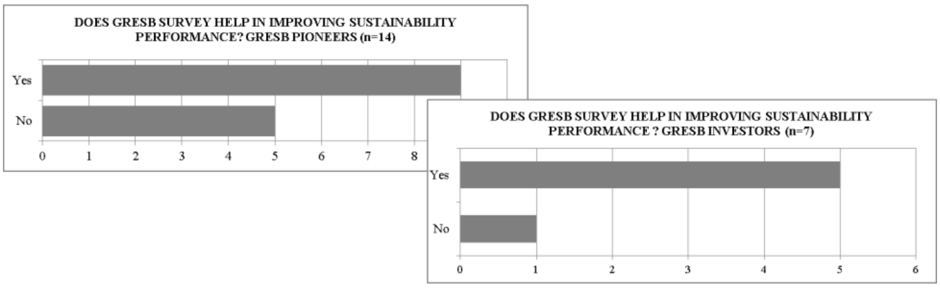

Figure4: Does GRESB Survey help in improving sustainability performance?

Still interviews and open ended comments emphasize clearly the practicality, benchmarking function and real estate industry focus of GRESB Survey in improving sustainability performance of companies and funds.

4.4 GRESB Survey and external partners, tools, programs and software

External partners are used in connection to sustainability reporting and GRESB Survey by two thirds of respondents in both GRESB pioneers and GRESB potential group. One group of external partners are marketing and communication agencies providing services for design, repro, printing and composing texts. Consumption data collection, calculation of emissions and environmental performance indicators as well validation of data to be reported is other group of tasks that are commonly outsourced to external partners. As already mentioned GRESB Survey indicators require asset level data, division between landlord and tenant as well as aggregation of data by property types, which may make the GRESB Survey more challenging in comparison to GRI sustainability reporting.

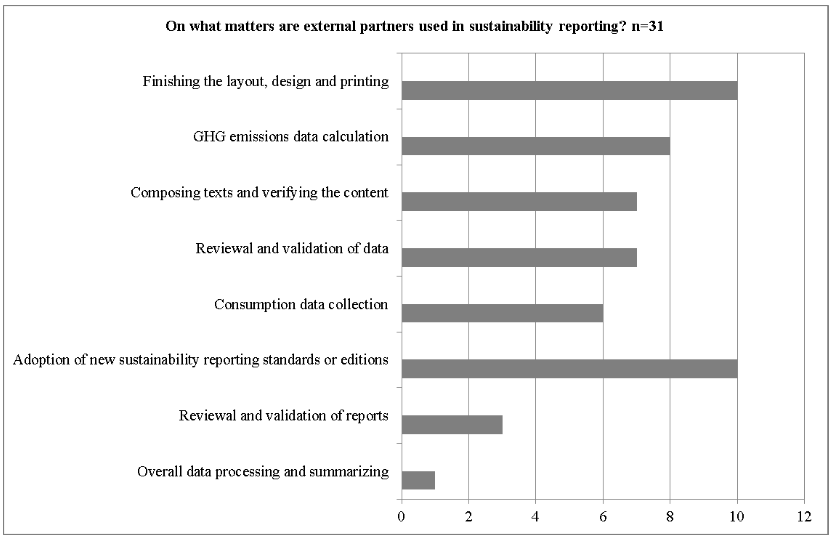

Figure5: Does GRESB Survey help in improving sustainability performance?

According to the open-ended responses, almost half of the respondents both in GRESB – pioneers and GRESB – potential groups use a variety of tools, programs and software to facilitate sustainability reporting and actual sustainability performance at the end. Data management systems are getting more sophisticated and more commonly used by real estate companies. Furthermore data management systems are also adapted to meet the criteria and requirements of different sustainability reporting frameworks. Good example of this is Nuuka Solutions's DMS elaborating data into GRESB Survey format, developed together with Genesta Property Nordic AB. This is a good example how sustainable innovations and practices are spread and shared for the benefit of whole industry and society.

Respondents use both internally and externally developed software and tools for data collection, monitoring and reporting. In some cases existing applications as electronic maintenance manual is customized and developed further to provide information for sustainability monitoring and reporting. In some cases the overall responsibility on data collection, monitoring and reporting is given to service providers. Most commonly used external tools are: Vitec Energy / WebEss, Credit 360°, Nuuka DMS and RESPECT Europe Svante. Widening the focus from energy, water, waste and GHG data collection and monitoring into overall sustainability data collection, some respondents view this comprehensively summing up different stakeholder, employee and customer satisfaction surveys with data management as well as financial reporting and consolidation tools.

5. Discussion

External partners as consultants should be recognizing the growing importance of GRESB Survey in improving the sustainability performance of real estate investment companies and funds. Sustainability communication and reporting is not requested only from listed, public real estate investment companies and funds, smaller organizations should follow and adopt new practices to meet growing demand for sustainability data by tenants, investors, financers and employees. Ramboll has recognized this opportunity and actively aligns existing services and develops new services to facilitate GRESB Survey participation to any size of real estate investment companies and funds. It is not only organizations participating into GRESB Survey, but also institutional investors and financing institutions which can be helped by Ramboll to develop further their sustainability assessment process of commercial real estate portfolios within the GRESB Survey framework.

Ramboll has gained a wide knowledge and experience around GRESB Survey and works actively with real estate companies and funds by providing various services to facilitate GRESB Survey participation of first timers and more experienced participants. Ramboll GRESB Survey services cover the whole GRESB Survey process from assessing the actual state of sustainability management, monitoring and reporting capabilities into analysing GRESB Benchmark Report with identification of respective short-, medium- and long-term development issues. Most successful project resulting in GRESB Green Star award and comprehensive development of sustainability performance has been carried out as in-house consulting.

6. Conclusions

GRESB Survey is considered very important sustainability ranking scheme by respondents, backed up by GRI reporting. GRESB Survey offers new ideas and insight both for the improvement of sustainability performance of real estate investment companies and funds as well for sustainability assessment process of institutional investors. GRESB Survey is material and practical framework which improves sustainability performance of real estate investment companies and funds and investor members’ commercial real estate portfolios.

Benchmark data with peer organizations directs sustainability efforts, helps in allocation of resources, brings sustainability on the top management agenda and connects companies with investors on sustainability issues.

GRESB – survey participation requires dedication, time, resources and willingness to meet challenges. Pioneering real estate consultants as Ramboll are aware of the growing role of sustainability in improving overall profitability of real estate investment companies and funds and securing long-term value of properties. GRESB Survey has proven to be a material, concrete tool in improving sustainability performance of commercial real estate industry by pushing participants to improve sustainability management and communication processes.

External partners as consultants have been recognizing the growing importance of GRESB Survey in improving the sustainability performance of real estate investment companies and funds. Wide range of skills and capabilities are developed to support listed, public real estate investment companies and funds, as well as private real estate investment companies and funds in their sustainability work to meet requirements of institutional investors covering commercial real estate investment universe. GRESB Survey will develop and "raise the bar" until sustainability will be managed with same regime and accuracy as company financials.

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A Study on the Expansion of Database for Establishing Low Energy Building Materials Information Portal

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Abstract

The purpose of this study is to provide reliable service of materials information portal through the establishment of public big data by collecting and integrating scattered low energy building materials and equipment data. In the establishment of low energy building materials database in the country, there was almost no case of integrating scattered data based on the standardized data classification system and code. Therefore, data attribute items were extracted based on information highly used in the building market in this study in order to establish building materials database, and data standardization was carried out through the definition of attribute of such entities.

Keywords: Materials information portal, building materials database, entity definition, data standardization

1. Introduction

Price comparison web sites in Korea mainly target consumer goods used in everyday life such as clothing and home appliances, but a website providing real estate information has appeared recently so that the object of service is becoming more diversified. The service provided by those web sites is mostly price comparison, product and consumer review information, allowing users to obtain information regarding a desired product and product manufacturers to have price competitiveness. When consumers purchase a product, the product, product quality and diversity are emphasized for decision making, and they can receive information regarding the product promptly through a price comparison web site and purchase the same product at a low price. Due to such advantage, 51% of consumers who purchased a product actually purchased a product after price comparison through a price comparison web site, and 45.4% among them considered product reviews when deciding whether or not to purchase the product (Ma, Mi-Yeong (2008)). The Public Procurement Service, the central procurement agency of Korean government, opened Korea On-line E-procurement system in 2002 and currently 47,000 public agencies and 270,000 procurement companies use this system in all procurement stages including the registration of company, bidding, contract, inspection and payment (Public Procurement Service (2015-1)). Korea On-line E-procurement system plays a role of single window for public e-procurement by integrating bidding information of all public agencies, but since publicness of purchase should be considered in addition to economic rationality, so this system has the relevant limitation unlike private procurement. The purpose of this study is to establish low-energy building materials information database in order to provide low-energy building materials information portal service by applying the concept of price comparison web site explained above into building materials & equipment field.

The low energy building materials information portal (hereinafter referred to as 'materials information portal') in this study is established at national level with quasi-governmental agencies including Korea Energy Agency and Korea Appraisal Board, and as the concept of general-purpose service targeting whole nation, this portal integrates scattered database and provide reliable contents related to government systems and policies in order to allow portal service users to select a desired product rationally. Also, this portal leads healthy competitions between companies through the product price and quality comparison so that reasonable prices can be established in the market. Besides building materials and equipment data, for service provision, data related to laws, excellent cases of low energy buildings and economic evaluation should be added and supplemented to complete the integrated information database, and building materials database among the integrated information database includes core information for the whole construction tasks including design, construction, purchase and estimate. Therefore, efficient data collection, classification and continuous update regarding building materials are required, so the purpose of this study is to examine the establishment and expansion of materials database for establishing materials information portal.

2. Status of materials database establishment in Korea

2.1 Korea Prices information

Korea Price Information, Corp. is a price investigation and cost accounting service agency registered on the Ministry of Strategy and Finance and it has establish database by integrating price and survey information and provides information through Korean prices information sheet through on- and off-line. The price information shown in the prices information sheet can be used in studies and practical fields regarding the calculation of equipment cost and initial investment amount, and basic information such as the model name and specifications is uploaded by companies and the detailed information including product catalogue can be checked through the link of company's website. Information based on the unit price of product is provided except for construction or installation cost.

2.2 Efficiency management machinery, equipment or materials and high-efficiency energy machinery, equipment or materials

Korea Energy Agency operates the energy consumption efficiency rating indication system and high-efficiency energy using appliance certification system, and the energy consumption efficiency rating indication system is the obligatory report system to lead manufacturing companies that produce applicable products for energy consumption efficiency rating indication system to produce and sell energy-saving products (efficiency management machinery, equipment or materials) from the production step in order to allow consumers to check and purchase highly efficient energy-saving products easily. In this system, products are indicated separately into 5 grades according to energy consumption efficiency or energy usage, and the minimum energy efficiency applies to Minimum Energy Performance Standard (MEPS). Target items are 28 items including electric cooling apparatus and an energy consumption efficiency rating label cannot be attached to any product not announced in the Ministry of Trade, Industry and Energy's efficiency management machinery, equipment or materials operating procedure.

High-efficiency energy using appliance certification system is voluntary system to certificate a product of which energy efficiency and quality test results satisfies a certain standard announced by the government as high-efficiency energy machinery, equipment or materials. This certification system is to revitalize distribution of high-efficiency energy products and certificate is issued by Korea Energy Agency upon a voluntary request of manufacturing company. The target items are 47 items and any product not included in the application range announced in the Ministry of Trade, Industry and Energy's regulation on the distribution and promotion of high-efficiency energy machinery, equipment or materials is not subject to high-efficiency certification. The materials information database in this study is established with only items related to the building energy usage for two systems above. The characteristics of information included in the prices information sheet in Korea, efficiency management machinery, equipment or materials, and high-efficiency energy machinery, equipment or materials are as shown in Table 1 below and systematic construction of the materials information database is showed in Figure 1.

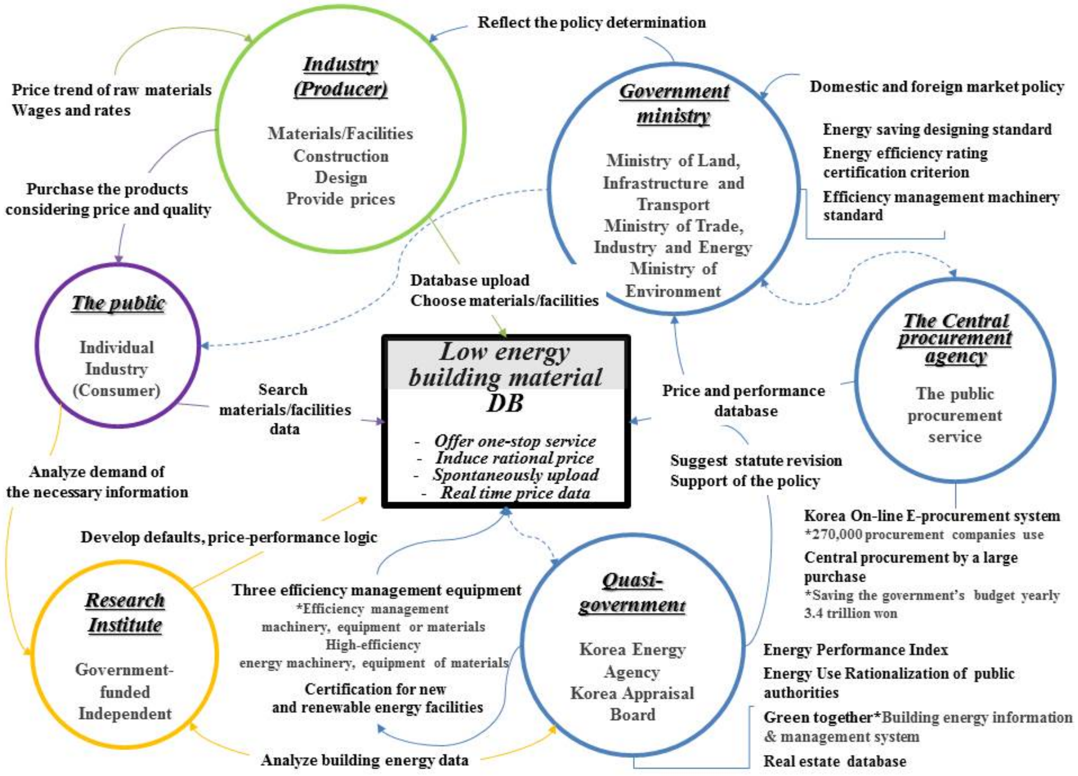


Figure 1: Systematic construction of the materials information database

Table 1: Properties of the materials database in Korea

Classification / source	*Characteristics of available information*	*Depth of information (eg: boiler)*
Public Procurement Service	*Building, machine & equipment, electricity, materials and construction cost* *(Based on price)*	*Boiler* *Model name, capacity, unit price*
Prices information sheet	*Price information such as building, facility, electricity, lighting and survey information, etc* *(Based on price)*	*Gas boiler* *Model name, company name, specification, unit price*
Efficiency management machinery, equipment or materials	*Applicable product for energy consumption efficiency rating indication system* *(Based on performance)*	*Gas boiler for home* *Model name, company name, heating thermal efficiency %, efficiency level*
High-efficiency energy machinery, equipment or materials	*Applicable product for high-efficiency test* *(Based on performance)*	*Gas boiler for industry building* *Model name, company name, rated capacity, efficiency % (total calorific value, net calorific value), air flow rate of air blower, CMM, etc*

2.3 Korea On-line E-procurement System of Public Procurement Service

Korea On-line E-procurement System (www.g2b.go.kr) established as one of 11th projects for e-government in 2002 is the comprehensive e-procurement system to enable digitization of transactions between the government, public agencies and companies from purchase decision to payment (Seo, Jin-Wan (2009)), and the size of the public procurement market is 110 trillion KRW as of 2014 (Public Procurement Service (2015-2)) and it plays a role of saving national finance and improving technology competitiveness of companies by making procurement companies to provide quality service at a proper price. However, complicated procedures and unnecessary regulations of public procurement market have brought difficulties to startup companies to enter the procurement market, and excessive authentication requirements regarding products have become a burden to companies (Public Procurement Service (2015-2)). Also, the government procurement has public aspects such as the management of supply market considering the supply aspects, influence on the economy and industry due to public agency's consumption, professional support of procurement activities (Kidd (2007)) besides economic rationality, so the same product can be searched from Internet shopping web site at a lower price than the procurement price and procurement products are posted on Korea On-line E-procurement system for 1 year to 1 and a half year, there is a possibility that the price information may not be updated for a number of months rather than real-time update of price information, and it is the difference of government procurement from the private procurement based on economic rationality.

The materials information portal has no purpose of promoting public system targeting the whole nation or publicness aspect of purchase so that purchase behavior will be carried out according to economic rationality considering quality and price, and when materials production companies post the characteristics, performance and price information of products according to the standardized formats for data upload, consumers will be able to access the product information posted by companies by searching a desired condition.

3. Low energy Building Materials database

3.1 Range of Low energy Building Materials database Establishment

Low energy building materials database is established targeting materials and equipment systems such as insulation materials, windows, air conditioning equipment and boilers that influence the energy consumption of buildings, and the production information such as efficiency management machinery, equipment or materials, high-efficiency energy machinery, equipment or materials managed by Korea Energy Agency are also included. The following table shows the target and range of materials database establishment.

Table 2: Range of materials database establishment

Classification / source	Classification of establishment items			Number of items
	Materials	*Equipment*	*Electrical instrument*	
Public Procurement Service	*Insulation material, window, glass, interior finishing materials, exterior finishing materials, blind and shade, etc*	*refrigerator, air conditioner, ventilator, heat exchanger, heat pump, boiler, duct, etc*	*lighting fixture, lamp*	*165*
Prices information sheet	*Insulation materials, glass, window materials, block, roof materials, etc*	*boiler, air conditioner, refrigerator, heater, cooling and heating equipment, etc*	*lighting fixture, lamp*	*150*
Efficiency management machinery, equipment or materials	*Windows*	*Electric cooler, electric cold and hot water dispenser, household gas boiler, electric cooler and heater, gas water heater, electric heating fan, multi electric heat pump system*	*Incandescent lamp, fluorescent lamp, lamp with built-in ballast stabilizer*	*11*
High-efficiency energy machinery, equipment or materials		*heat recovery type ventilating system, gas/oil boiler for industry and buildings, pump, centrifugal type・screw type chiller, direct fired and absorptive cold and hot water dispenser, ventilator, centrifugal type air blower, etc*	*metalhalide lamp, embedded and fixed LED light fixture, light fixture for electrodeless fluorescent lamp*	*25*

3.2 Code system of low energy building materials database

In order to consider operation and management of materials database in future and enable linkage and operation with domestic building materials database later, the product list system and classification code of Public Procurement Service were introduced. The classification code was same with Public Procurement Service's code until sub-class, and the code for sub sub-class was recomposed according to the range of data to be established in this study. The established database for low energy building materials and equipment related insulation material, window, glass, refrigerator, boiler and lighting fixture was classified into 5 levels and 165 cases were coded. Table 3 shows a part of building material items.

Table 3: Code system of materials database (part)

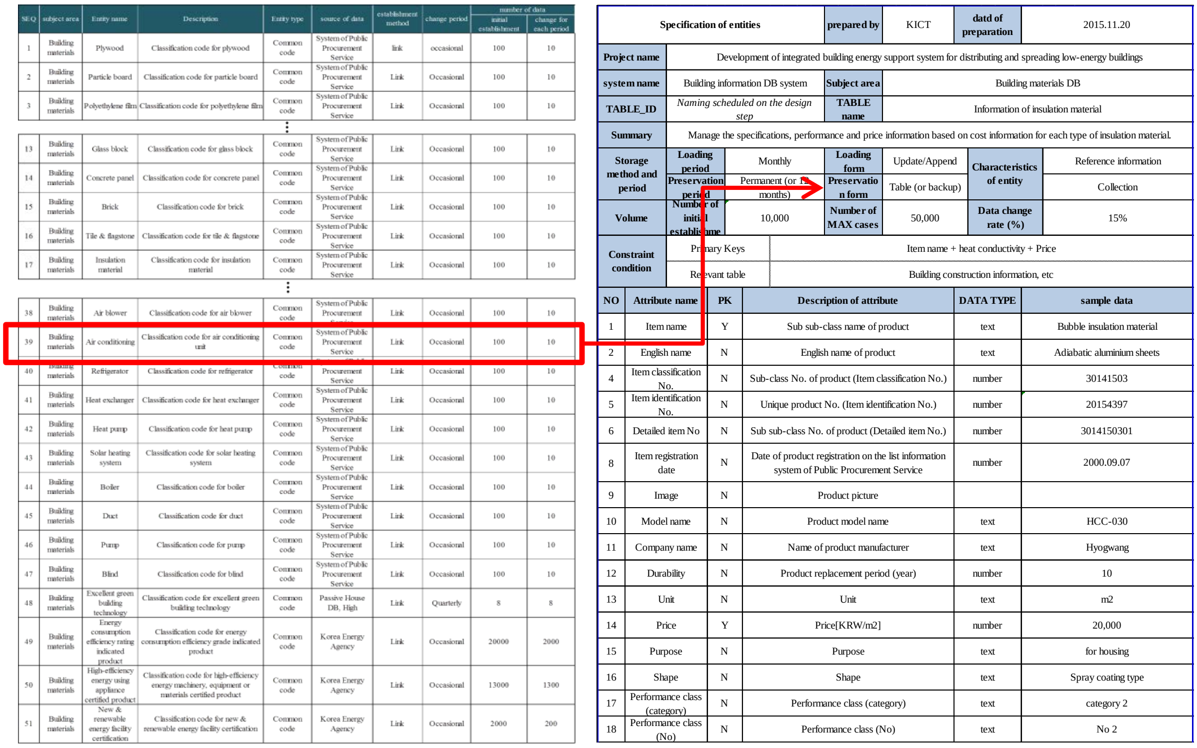
Major Class		Middle Class		Minor Class		Sub-class		Sub Sub-class		Code name
CODE	ID	CODE	ID	CODE	ID	CODE	ID	CODE	ID	CODE
30	Building materials	14	Insulation material	15	Heat insulation material	03	Bubble insulation material	01	Bubble insulation material	3014150301
						08	Fiber insulation material	01	Fiber insulation material	3014150801
						14	Foam polystyrene insulation material	01	Foam polystyrene insulation material	3014151401
						15	Extruded foam polystyrene insulation material	01	Extruded foam polystyrene insulation material	3014151501
				16	Special insulation material	01	Soundproof insulation material	01	Soundproof insulation material	3014160101
						04	Spray coating insulation material	01	Rock wool spray coating	3014160401
						04	Spray coating insulation material	02	Perlite	3014160402
						99	Fire resistive covering material	01	Fire resistive covering material	3014169901
		17	Window & glass	15	Door	01	Glass door	01	Glass door	3017150101
						04	Timber door	01	Timber door	3017150401
						05	Metallic door	01	Metallic door	3017150501
						88	Synthetic resin door	01	Synthetic resin door	3017158801
				16	Window	95	Synthetic resin window	01	Synthetic resin window	3017169501
						96	Timber window	01	Timber window	3017169601
						98	Metallic window	01	Metallic window	3017169801
				17	Glass & glass products	05	Laminated glass	01	Laminated glass	3017170501
						06	Tempered glass	01	Tempered glass	3017170601
						08	Plate glass	01	Colored glass	3017170801
								02	Clear glass	3017170802
								03	Flat glass	3017170803
								04	Embossed	3017170804

									glass	
								05	*Reflective glass*	*3017170805*
								06	*Heat reflective glass*	*3017170806*
								07	*Spandrel glass*	*3017170807*

3.3 Establishment of low energy building materials database

Data modeling work is necessary for database establishment, and for this, the list and specification of entities are prepared and database is established according to the list and specification of entities. At first, an entity is tangible (eg: person, automobile, etc) and intangible (eg: hobby, trip, etc) information and it is defined as several related attributes which could explain and characterize the relevant information. The list of entities contains information regarding source of data, change period and number of materials for each data item to be established, so it is prepared to determine data area and capacity, and the specification of entities is prepared to define attributes related to data to be established and establish the relevant attribute information. Figure 2 shows the list and specification of entities in materials database.

Attribute information of materials database can be classified into general item and detailed information item for each product. Data was established with information that could include the product performance and characteristics information by collecting basic information such as product model name, image, company name, price and specifications in general item and collecting advisory opinions from employees of materials production and sales companies for the detailed information. The materials information data for materials information portal should be established to draw materials information search function as well as service result in economics section such as energy consumption reduction effect and cost recovery period according to the application of materials selected by consumers to buildings, so attribute information which influenced the building energy consumption was also included in the detailed information in addition to detailed information items generally used in the market, and the relevant detailed information items were composed based on input items of ECO2, which is building energy performance evaluation program used in domestic building energy efficiency rating system for calculating the rating. In case of detailed information items, the attribute of insulation material was defined with heat conductivity (W/m^2K), density (kg/m^3) and combustibility (burning time, burn length), and in case of boiler, it was defined with thermal efficiency (%), rated heat quantity (kW) and heating area(m^2).



SEQ	subject area	Entity name	Description	Entity type	source of data	establishment method	change period	number of data: initial establishment	number of data: change for each period
1	Building materials	Plywood	Classification code for plywood	Common code	System of Public Procurement Service	link	occasional	100	10
2	Building materials	Particle board	Classification code for particle board	Common code	System of Public Procurement Service	Link	Occasional	100	10
3	Building materials	Polyethylene film	Classification code for polyethylene film	Common code	System of Public Procurement Service	Link	Occasional	100	10
⋮									
13	Building materials	Glass block	Classification code for glass block	Common code	System of Public Procurement Service	Link	Occasional	100	10
14	Building materials	Concrete panel	Classification code for concrete panel	Common code	System of Public Procurement Service	Link	Occasional	100	10
15	Building materials	Brick	Classification code for brick	Common code	System of Public Procurement Service	Link	Occasional	100	10
16	Building materials	Tile & flagstone	Classification code for tile & flagstone	Common code	System of Public Procurement Service	Link	Occasional	100	10
17	Building materials	Insulation material	Classification code for insulation material	Common code	System of Public Procurement Service	Link	Occasional	100	10
⋮									
38	Building materials	Air blower	Classification code for air blower	Common code	System of Public Procurement Service	Link	Occasional	100	10
39	Building materials	Air conditioning	Classification code for air conditioning unit	Common code	System of Public Procurement Service	Link	Occasional	100	10
40	Building materials	Refrigerator	Classification code for refrigerator	Common code	System of Public Procurement Service	Link	Occasional	100	10
41	Building materials	Heat exchanger	Classification code for heat exchanger	Common code	System of Public Procurement Service	Link	Occasional	100	10
42	Building materials	Heat pump	Classification code for heat pump	Common code	System of Public Procurement Service	Link	Occasional	100	10
43	Building materials	Solar heating system	Classification code for solar heating system	Common code	System of Public Procurement Service	Link	Occasional	100	10
44	Building materials	Boiler	Classification code for boiler	Common code	System of Public Procurement Service	Link	Occasional	100	10
45	Building materials	Duct	Classification code for duct	Common code	System of Public Procurement Service	Link	Occasional	100	10
46	Building materials	Pump	Classification code for pump	Common code	System of Public Procurement Service	Link	Occasional	100	10
47	Building materials	Blind	Classification code for blind	Common code	System of Public Procurement Service	Link	Occasional	100	10
48	Building materials	Excellent green building technology	Classification code for excellent green building technology	Common code	Passive House DB, High	Link	Quarterly	8	8
49	Building materials	Energy consumption efficiency rating indicated product	Classification code for energy consumption efficiency grade indicated product	Common code	Korea Energy Agency	Link	Occasional	20000	2000
50	Building materials	High-efficiency energy using appliance certified product	Classification code for high-efficiency energy machinery, equipment or materials certified product	Common code	Korea Energy Agency	Link	Occasional	13000	1300
51	Building materials	New & renewable energy facility certification	Classification code for new & renewable energy facility certification	Common code	Korea Energy Agency	Link	Occasional	2000	200

Specification of entities		prepared by	KICT	datd of preparation	2015.11.20
Project name	Development of integrated building energy support system for distributing and spreading low-energy buildings				
system name	Building information DB system	Subject area	Building materials DB		
TABLE_ID	*Naming scheduled on the design step*	TABLE name	Information of insulation material		
Summary	Manage the specifications, performance and price information based on cost information for each type of insulation material.				
Storage method and period	Loading period: Monthly	Loading form	Update/Append	Characteristics of entity	Reference information
	Preservation period: Permanent (or 12 months)	Preservation form	Table (or backup)		Collection
Volume	Number of initial establishment: 10,000	Number of MAX cases	50,000	Data change rate (%)	15%
Constraint condition	Primary Keys	Item name + heat conductivity + Price			
	Relevant table	Building construction information, etc			

NO	Attribute name	PK	Description of attribute	DATA TYPE	sample data
1	Item name	Y	Sub sub-class name of product	text	Bubble insulation material
2	English name	N	English name of product	text	Adiabatic aluminium sheets
4	Item classification No.	N	Sub-class No. of product (Item classification No.)	number	30141503
5	Item identification No.	N	Unique product No. (Item identification No.)	number	20154397
6	Detailed item No	N	Sub sub-class No. of product (Detailed item No.)	number	3014150301
8	Item registration date	N	Date of product registration on the list information system of Public Procurement Service	number	2000.09.07
9	Image	N	Product picture		
10	Model name	N	Product model name	text	HCC-030
11	Company name	N	Name of product manufacturer	text	Hyogwang
12	Durability	N	Product replacement period (year)	number	10
13	Unit	N	Unit	text	m2
14	Price	Y	Price[KRW/m2]	number	20,000
15	Purpose	N	Purpose	text	for housing
16	Shape	N	Shape	text	Spray coating type
17	Performance class (category)	N	Performance class (category)	text	category 2
18	Performance class (No)	N	Performance class (No)	text	No 2

Figure 2: List and specification of entities

4. Discussion

For the establishment of low energy building materials database in this study, information is established under the cooperation with quasi-governmental agencies including prices information sheet, Public Procurement Service and efficiency management machinery, equipment or materials, but from the time of providing the service after materials information portal is completed, materials production and sales companies will upload product information. At this time, the information uploaded by companies show the price and quality of products in actual market, so it is the newest information, but companies will be responsible for the reliability of uploaded information. The verification and confirmation of information uploaded by companies are excluded from the concept of this study, but these elements are important items with regarding the usage frequency and satisfaction level of portal service from the viewpoint of consumers.

5. Conclusions

The purpose of this study is to provide reliable service of materials information portal through the establishment of public big data by collecting and integrating scattered low energy building materials and equipment data.

In the establishment of low energy building materials database in the country, there was almost no case of integrating scattered data based on the standardized data classification system and code. Therefore, data attribute items were extracted based on information highly used in the building market in this study in order to establish building materials database, and data standardization was carried out through the definition of attribute of such entities. It is possible to maintain accurate communication and data easily and improve operation efficiency in the portal development through the standardization of attribute definition by applying consistent input method (text or number), use of word and unit for materials of the same category.

The materials information portal can provide one stop service to users based on materials database under establishment in this study and real-time price information through voluntary upload of price information for establishing reasonable prices between materials production companies and allowing companies to register their products on the portal in future, so important verification process of standard system for portal data will be carried out continuously for searching, sharing and managing information from the position of portal users and developers and a study to improve users' satisfaction level such as GR certification (Good recycled), certification information such as environmental mark, review of legal obligations and recommendations before using materials and equipment and addition of user's review function will be carried out.

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How Will Green Property Services Change the Game? A Futures Studies View

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Abstract

As the environmental impacts of buildings have become more and more eminent, so too has the demand and need for specialized green property services. Green property services refer to operative real estate management services, including both property and facility management, which promote environmental, or green, aspect of the services. This study sets out to identify the possible future development paths associated with the expected rise in the demand of green property services in the future facilities market. The research uniquely utilizes a futures studies method in the context of facilities management. The futures wheel is a qualitative method based on expert opinions, and resembles structural brainstorming. With the futures wheel, different future elements and their possible influences can be identified, clarified and organized. The study finds that several outcomes, both beneficial and unfavourable, are possible in a future where green property services have become more common. The outcomes are classified based on the power to impact, namely, whether they are reached though the actions of the property service provider, or the client organisation. The identified first tier influences include surprisingly complex issues such as lack of expertise in the client organization, or poor occupant comfort resulting from effective energy management. On the other hand, highly positive influences, including intelligent buildings and saved natural resources are also identified as potential influences. The study is the first to employ the futures wheel method to facility services research, and provides a good foundation for further testing of the methods. Furthermore, the findings are a welcomed reminder to both researchers and practitioners of the intertwined and complex nature of sustainability issues within the built environment.

Keywords: commercial real estate, facilities management, futures wheel, green property services, sustainability

1. Introduction

The built environment is a significant cause of environmental impacts (UNEP 2007), and consequently, is often seen key in solving the environmental challenges set to our society. As the environmental impacts related to buildings have become eminent, the need and demand for specialized green property services are also growing. Green property services refer to operative real estate management services, including both property and facility management, which promote environmental, or green, aspect of the services. The role of facility management in building environmental performance is known to be crucial (e.g. Aaltonen et al. 2013, Kyrö et al. 2012, Määttänen et al. 2014a). Green property services can be defined as services that aim at reducing the negative impacts to the environment and human health, while simultaneously fulfilling the needs of occupant's and maintaining the property's condition and characteristics (Määttänen 2014a). In other words, green property services aim at both enhancing the environmental performance of the building and creating value to the end-customer. Määttänen (2014a) concludes that green property services are particularly useful when the end-user company lacks the appropriate resources for in-house environmental management. The increased demand for green property services has also been noted in market-based research, including a recent Green Market Study (Ramboll 2014), which estimates that green commercial facilities will become more common in the future. It has also been assessed that during the next few years property and user service companies will invest more in sustainable practices (KTI 2015). Interestingly, while the clients' green requirements are expected to increase, the willingness to pay premium for green services remains low (KTI 2014).

While it is clear that buildings affect the surrounding society, it should be noted that the surrounding society and different forces of change emerging in the real estate market environment have their own influence on the built environment and associated businesses. Regardless, property management practitioners are not generally aware of the future forces of change and their possible influences on the future development. In other words, practitioners may have to make decisions that will have far-reaching consequences for their business, without sufficient awareness and needed analysis of the possible future development in the field. This study sets out to identify possible future development paths associated with the expected rise in the demand of green property services in the future facilities market. The research uniquely utilizes futures studies methods in the context of facilities management. Futures studies have only recently been introduced in the context of real estate markets (Toivonen 2011; Toivonen and Viitanen 2015; Toivonen and Viitanen 2016). Moreover, previous futures studies based research from the property management field does not yet exist, to the best of the authors' knowledge.

According to previous studies environment pressure has been identified as a significant force shaping the future development of the commercial real estate market (Toivonen 2011; Toivonen and Viitanen 2015). Toivonen (2011) recognized the demand for green property services as a part of the environmental pressure set to the commercial real estate market and also as a phenomenon affecting the future market environment. For the purpose of this specific study, the increased demand in green property services is selected for further research through a method called the futures wheel. Based on Glenn (2009a) the futures wheel is a qualitative method based on expert opinions, and resembles structural brainstorming. With futures wheel different future elements and their possible influences can be identified, clarified and organized (Glenn 2009a). Through a better understanding of the potential future elements, practitioners would be more conscious and they would have better prospects of doing far-reaching and sustainable decisions about their business.

The study finds that several outcomes, both beneficial and unfavourable, are possible in a future where green property services have become more common. The first tier influences include surprisingly complex issues such as lack of expertise in the client organization, or poor indoor comfort resulting from effective energy management. On the other hand, highly positive influences, including intelligent buildings and saved natural resources are also potential. The first tier effects produce a number of second and third tier influences, resulting in possible development paths for the future of green property services. Each of these development paths is presented with a discussion on the positive and negative effects to ecological, social and economic sustainability. The outcomes are also classified based on the target of impact, namely, whether they affect the property service as a business, or the client organisation. The study is the first to employ the futures wheel method to facility services research, and provides good foundation for further testing of the methods. Furthermore, the findings are a welcomed reminder to both researchers and practitioners of the intertwined and complex nature of sustainability issues within the built environment.

The remainder of the paper is structured, as follows. The research methods are introduced in detail in the next section, due to the novelty of the application. The third section presents the findings of the research, and the fourth section discusses implications and limitation of the findings. Finally, the fourth chapter concludes the paper with suggestions for further research.

2. Research methodology

Property services are in a nascent state as a research field, and therefore the explorative, qualitative research methods offer a best methodological fit (Edmundson and McManus 2007). This study takes a novel approach and utilises futures studies methods for the property services research. Future studies methods have been found well-suited for investigating the future development of the commercial real estate market, which is continuously affected by several different external and internal forces (Toivonen 2011). According to Mannermaa (1999), the future is formed based on both conscious and unconscious thinking, planning, decision making and actions taking place in different parts of the society. The future is present in the current situation through several different possibilities that have not yet been realized (Malaska 1993; Seppälä & Kuusi 1993). These different possible development paths can be identified and analysed with the help of the futures wheel method. The following sub-section describes the futures wheel method in detail.

2.1 Futures Wheel

This study utilizes a method called the futures wheel to study the possible future influences caused of the expected increase in green property services. The futures wheel is a qualitative method based on expert opinions, and resembles structural brainstorming. With the futures wheel method, the possible future influences of a studied phenomenon can be identified and clarified. The possible influences are organized into the different circles of the wheel to present primary, secondary and tertiary influences of the phenomenon in question. These influences can be connected to an actor, or to an object (Glenn 2009a; Rubin 2002). The wheels presenting the possible influences can be formed via a joint session with external participants (Benckendorff 2007; Boujaoude 2000; Shakweer and Youssef 2007), or by an internal research team that collects data and organizes it into the wheels (Toivonen 2011; Rantasila 2015). According to previous experiences, the joint sessions allow the participants to interact and develop the presented ideas further together as a team (Benckendorff 2007). This was seen as a significant advantage, and thought to best serve the purpose of the study. Consequently, a joint session among experts was organized to investigate the possible future impacts of the green property services. The experts were chosen to represent built environment researchers, consultants, and green building professionals. Altogether 5 participants took part in the wheel formation session.

The researcher acted as facilitators for the session. In the beginning of the session, the facilitator briefly presented the investigated phenomenon as well as the futures wheel method to ensure that all participants understood what was going to happen during the session. After this preparatory phase, the name of the phenomenon under examination, namely, “Increasing the demand of green property services”, was placed in the middle of the wheel into the centre circle. Next, the facilitator asked the participants “What would happen if the demand for green property services would increase?”. After that, the participants started to discuss the possible influences and the facilitator simultaneously draw the wheel presenting their views. The facilitator encouraged the participants to think further by asking the possible secondary and tertiary influences caused by the influences described in the earlier stage. The primary influences were located on the first ring surrounding the centre circle, the secondary influences derived from the secondary influences were placed on the second ring and the tertiary influences caused by the secondary influences on the third ring. The influences were also connected to each other with lines to demonstrate connections between them. The participants discussed different potential influences and only the influences that were seen possible by all of the participants were chosen to the wheel (see Glenn 2009a). This procedure is seen to increase the reliability of the results. Finally the different rings surrounding the centre circle presented the possible primary, secondary and tertiary future influences of the increasing demand of green property services and their possible future development paths. An example of a future wheel is depicted in Figure 1.

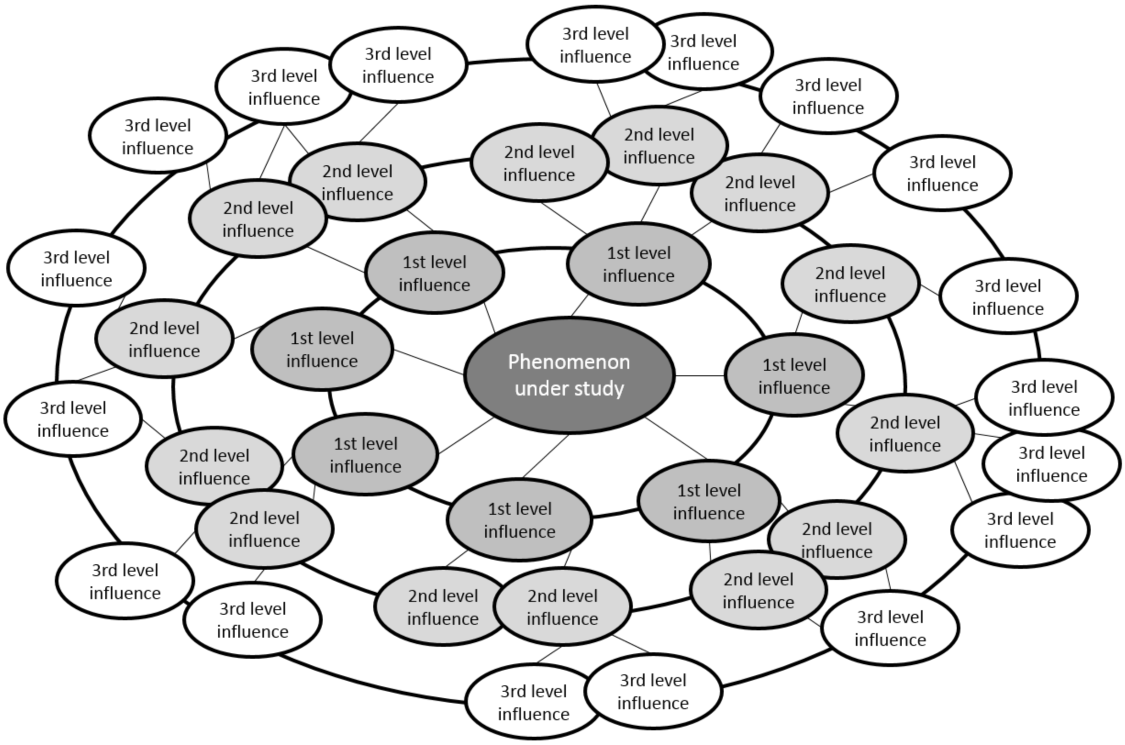

Figure 1: An example of a futures wheel

After the formation of the futures wheel, the influences on the outer rings are analysed and categorised into themes based on their context and power to impact, namely whether the influences concerned the service provider or the end-user. After this, the analysis process continued forward and the formed future themes divided as positive or negative. With the future studies it is possible to combine different value bases with different forecasts. This means that the desirability of different development paths can be evaluated (Bell 2003; Glenn 2009b; Mannermaa 1993). The desirability is derived from the values of every actor estimating the possible development. Futures researchers have presented some values that are universally seen desirable (Bell 2003; 2004; Malaska 1993) but in reality the desirability of different development paths might be viewed very differently among different stakeholders due to their individual position and characteristics (Heinonen 1993). However the desirability of different development paths is an essential part of the future studies while it determines the significance of the forecasts. If some development path is seen either very negative or very positive, it is considered more significant, than a development path that is seen indifferent (Linturi et al. 1998; Meristö 1993). This study analyzed the positivity and negativity of the influences from the service providers and the end-users point of view.

Bell (2003) argues that one of the aims of futures studies is the actualization of the development paths that are seen desirable. According to Bell, the results gained from futures studies should be exploited in practice, and the actors should try to steer the future development towards the desired direction. To be able to do that it is relevant to identify actors that are involved in different development paths. A development path that is seen very desirable will more likely be promoted than a development path that is irrelevant to the actor in question. Similarly, the involved actors will be more willing to try to prevent development paths that are seen very negative (Toivonen 2011). Due to this an analysis concerning the relevant stakeholders that will be affected by the development path and who possess the power of promoting or hindering the development, should be provided. As mentioned above, in this study the investigated stakeholders possessing this power are the service providers and the end-users. Next, the findings of the futures wheel on green property services are introduced.

3. Findings

This futures wheel on green property services identified influences up to the third-tier, and in one case also up to the fourth-tier. Altogether, the futures wheel generated 11 first-tier, 23 second-tier, four third-tier and one fourth-tier influences. The futures wheel on Green Property Services, as originally transcribed and translated from the Finnish research notes is presented as Figure 2.

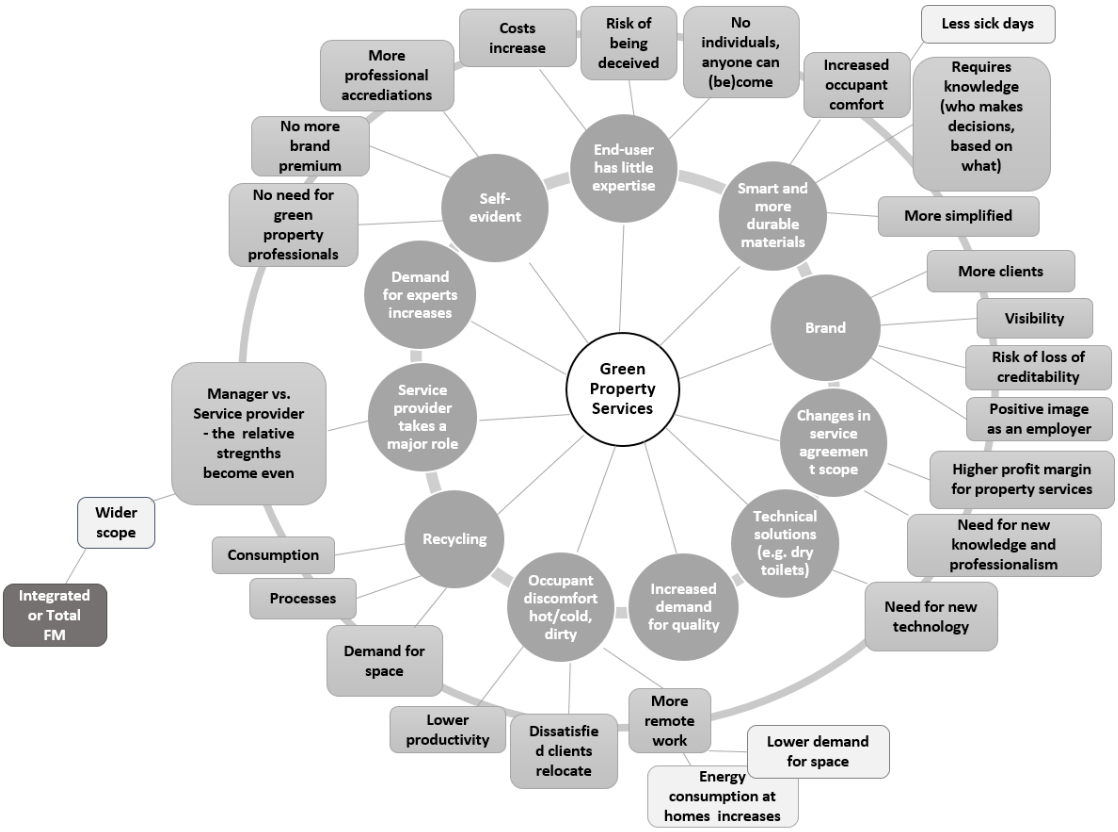

Figure 2: The Futures Wheel on Green Property Services

The first tier impacts were noted to be somewhat neutral, i.e. the influences do not have a clear negative of positive connotation. The identified first-tier influences comprise:

1. *Lack of expertise in end-user organisations*
2. *Changes in service agreement scope*

3. *Increased demand for quality of property services*
4. *The service provider's role is highlighted*
5. *The demand for green property professionals increases*
6. *Green property services become self-evident*
7. *Green brand for property management companies*
8. *Technical solutions*
9. *Recycling*
10. *Smart materials*
11. *Occupant discomfort: too hot, too cold, dirty*

During the second-tier however, even surprising negative potential influences were identified, along with the many positive potential impacts. However, this is considered to present an interesting contradiction that is truly beneficial for the analysis and identification of the future scenarios. Therefore the second-tier impacts were first categorised as either positive or negative. Furthermore, the direction of their impact was included in the analysis and divided into either end-user of service provider related impacts (See Table 1).

Table 1: The identified future themes

Power / *Direction*	*End-user*	*Service Provider*
Positive	*Lower space demand* *Occupant comfort and higher workplace productivity*	*Wider scope: Total FM*
Negative	*Cost and risk of outsourcing services* *Occupant discomfort and lower workplace productivity*	*No more demand for specialized services and no price premium for green services → green FM becomes obsolete*

Based on the findings, it may be argued that the key future scenarios of increased demand of green property services are related to the scope of services, i.e. are connected to the business logic of property services companies. Ultimately, this comes back to the discussion about integrated or total FM (Atkin and Brooks 2000), which was also included in the futures wheel as the final, fourth-tier outcome. Another related key finding is that green property services were thought to become the new norm. Määttänen et al (2014b) found that for example green cleaning could be on its way to becoming a standard service that the tenants expect to have, rather than a specialized green service. This is in line with a previous research. Määttänen et al. (2012) found that service providers should utilize their full potential and expertise better.

For the end-user or client organization, the major influences relate to the workplace productivity of the client organization, which is thought have both positive and negative outcomes. Low level of expertise in-house and outsourcing services were thought to carry some risks, and is therefore categorized as negative. On the other hand, lower space demand was also a result of the wheel, and this possible outcome is viewed as positive.

4. Discussion

This paper set out to identify the different future influences of green property services, which had previously been identified as one force of change in the current facility service field, with the help of an environmental scanning method (Toivonen 2011; Toivonen & Viitanen 2015). The potential influences of the green property services were then analyzed with the futures wheel method. Through analysis of the possible first, second and third tier influences identified with the wheel, the following potential future development paths for green property services were formed: 1) wider scope for service providers, 2) green property services becoming obsolete 3) increased workplace productivity 4) decreased workplace productivity 5) cost and risk of outsourcing services 6) lower cost from outsourced energy and space.

The results of the wheels were found to be partly contradictory with each other. While this contradiction complicates the interpretation of the possible future influences, it gives valuable information concerning the inner conflicts that the phenomenon may possess. Glenn (2009) has seen this as a special advantage of the futures wheel method as it reveals the potential internal and external conflicts that could remain unnoticed. Likewise, Toivonen (2011) recognized this challenge to be an opportunity to increase a holistic awareness of the possible development paths of the phenomenon under study. This in turn allows the actors to prepare themselves for the needed actions to be able to cope with and steer the development of the future conditions. This study divided into either end-user of service provider related influences and analysed the desirability of the influences. This may help the relevant stakeholders to take actions to steer the development towards the desired future development.

This research contributes to the scientific body of knowledge in facilities management by introducing a novel research method. The future wheel as a research method is especially useful when structuring the relationships between different phenomena and influences due to the illustrative nature of the wheels. The method was rather easily applied and enabled structuring the future development paths and possible influences. The findings are in line with previous experiences concerning the method (Benckendorff 2007; Boujaoude 2000; Glenn 2009a; Toivonen 2011; Toivonen & Viitanen 2016). Outside the research field, the wheels could allow practitioners to foresee the potential influences proactively. Furthermore, by recognizing the wide range of different influences, it is possible to analyse who will be affected by the different development directions, and who are the actors possessing the power to steer the development direction. Furthermore, the results allow practitioners to estimate the wanted and unwanted development paths from their own point of view, and possibly form coalitions with other likeminded practitioners to enhance the desired development path. With the connection between forces and influences, practitioners can estimate which development paths are wanted or unwanted, and direct their actions towards the wanted development paths or trying to prevent the unwanted ones, or altogether examine if their future targets are against or in favour of the possible future development and future theme.

4.1 Evaluation of research

According to Mannermaa (1993), it is not possible to analyse the success of a futures study by investigating the fulfilment of presented predictions, as the future does not exist as such in the current situation, and the presented predictions might affect the actualization of the foreseen prediction. For example market actors may change their behaviour after acknowledging the ongoing development thanks to the predictions and consequently change the development path. Due to these reasons the success of futures studies should be analyzed by evaluating the possibility of the presented development paths (Gordon 1989; Mannermaa 1993; Pantzar 1993). Therefore, when evaluating this study, it has to be analysed whether the presented influences could actually occur when taking into account the current knowledge of the present situation.

This study selected only the influences that were jointly agreed by the participants to be analysed in the final wheels, in order to ensure that the results would comprehensively present the possible future influences of the green property services. However, as previously stated by many researchers (Gordon 1992; Mannermaa 2004; Naisbit 1984; Niiniluoto 1993), the presented predictions cannot be perfect and include all the possible development paths. Something will always remain unrevealed. For example some of the influences may have falsely been seen impossible according to current knowledge, and therefore left out from the wheels. On the other hand, the wheels may contain influences that turn out to not be possible in the future. For example technological advancement or legal restrictions might have this kind of effect. Most importantly, it should be noted that the futures wheel method is highly dependent on the participants forming the wheels, as well as on the facilitators guiding the participants to exercise future thinking. This study pursued to include specialists representing the field of sustainable built environment, roles ranging from researcher, consultants, architect and advisor. However, it can be stated that the variety of participants could have been wider and the number of participants could have been higher to better ensure the coverage of the possible future influences. Similarly, the analysis over the desirability of the influences could be developed further. For the purpose of this study, this task was conducted by the researchers but it can be argued if the positivity and negativity should be analysed by the stakeholders i.e. the service providers and the end-users themselves.

Regardless of the aforementioned uncertainties inherent to the futures studies methods, it may be argued that the future wheel method is a suitable tool for investigating unknown future development paths, such as the future development of facility services.

5. Conclusions

The study is the first to employ the futures wheel method to facility services research, and provides a good foundation for further testing of the methods. The findings, which identify a number of contradictory positive and negative potential influences, are a welcomed reminder to both researchers and practitioners of the intertwined and complex nature of sustainability issues within the built environment. A very good example is occupant comfort, which is seen to be affected both positively and negatively by Green FM. Further research could focus on finding more potential forces of change to be analysed with the future wheel, or analysing the now identified potential influences on a more detailed level. As the study identified a number of conflicting and even detrimental potential influences of green property services, both to the environment and FM as a profession, the potential negative influences in particular should receive more research attention in the future.

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State of the Art of Demolition and Reuse and Recycling of Construction Materials

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Abstract

Nowadays, due to globally increasing building densities in cities, demolition works are an inherent part of construction. And they are focal activities related to life-cycle-oriented management of construction materials, which aims at drastically reduce the deployment and consumption of primary non-renewable construction materials. To give an overview on related worldwide existing activities, the state of the art of demolition and of reuse and recycling of construction materials is summarized in a report of selected countries based on reports of these countries. Within this report, first typical structures of the demolition and recycling industry in different countries, typical phases of demolition and recycling processes and involved stakeholders with their characteristic competencies are described. Secondly, leading companies, associations and research institutions in selected countries are outlined. Leading processes are identified by distinguishing between design processes for deconstruction, deconstruction processes on-site and innovative on-site and off-site recycling processes. Thirdly, challenges related to demolition and reuse and recycling of construction materials are identified and analysed in terms of technical, economic, ecologic, organizational and educational and political/legal challenges. Finally, single, country specific, already existing approaches to meet these challenges are identified.

Keywords: State of the art, deconstruction, life-cycle-oriented management, construction materials, reuse and recycling

1. Introduction

Nowadays, due to globally increasing building densities in cities, demolition works are an inherent part of construction. Furthermore, demolition works are focal activities related to life-cycle-oriented management of construction materials, which aims at drastically reduce the deployment and consumption of primary non-renewable construction materials. To give an overview on related worldwide existing activities, the state of the art of demolition and of reuse and recycling of construction materials is summarized in the following report. For this overview, the state of the art in selected countries is analysed based on reports of these countries, firstly by describing typical structures, processes and stakeholders of the demolition and recycling industry. Secondly, by outlining leading companies, associations and research institutions as well as leading processes. Thirdly, by identifying and examining technical, economic, ecologic, organizational and educational and political/legal challenges. Finally, by identifying single, country specific and already existing approaches to meet these challenges.

1.1 Description of the demolition sector

The demolition sector[1] is by no means homogenous and currently displays a wide diversity of sophistication levels, varying within and between regions and countries. Diverse stakeholders, such as clients, planning engineers, emission and contamination experts, decontamination companies, demolition companies, authorities and neighbours, are involved in and/or effected by the demolition process. These stakeholders have different interests and influences on the demolition project. Related to building types, surrounding conditions and sometimes hazardous substances of the building usage phase, the fields of activities are diverse and therefore, a variety of different usually small- and medium-sized enterprises dominate the demolition sector. The demolition sector is assigned to code F43.1 (demolition and site preparation) within the industry branch classification scheme NACE (EC - NACE (2010)). In 2012 nearly 170.000 enterprises of this sector represent 5% of all construction activities in the EU. 95% of these enterprises employ less than 10 persons and only 3.5% have more than 50 employees (EC – Eurostat (2015)).

1.2 Processes of construction materials management

The demolition process of buildings and infrastructures is at least as complex and sophisticated as the construction process. Figure 1 (own representation based on DA (2015)) shows the classical process steps, starting with building auditing to plan preliminary decontamination and site clearance followed by demolition, crushing, sorting, reprocessing and recycling processes. Furthermore, involved stakeholders are assigned to each project stage.

In the auditing and planning stage, the client, planning engineers and depending on the type of structure also authorities formulate the tender specifications. The decontamination and demolition companies audit the structure themselves and bid for the project. During auditing and planning, national guidelines are applied depending on the gross volume and characteristics of the building/infrastructure to be deconstructed.

In the preparation and demolition stages, the accepted company plans the previous steps. Depending on the type of structure and available space onsite, different demolition, crushing and sorting techniques are applied to disassemble building elements and break the material into transportable or reusable pieces. During preparation and demolition, legal regulations regarding occupational health and safety, including impact limits, protection measures, etc. have to be applied. Furthermore, national guidelines are applied regarding best practices in demolition,

[1] In parts of the world, where resource recovery is the standard, the term “demolition” is used synonymously with the terms deconstruction, dismantling and disassembly. But for most of the world, demolition with no thought to materials recovery is the standard and deconstruction is the best practice exception related to the careful disassembly/dismantling of buildings to recover materials for reuse. Hence, in the following, the term demolition is used in general terms.

namely deconstruction, processing and sorting such as in the German standard DIN 18007:2000-05. Especially, the prevalent type of construction, the prevalent materials, space availability, available (state-of-the-art) resources and entrepreneurial calculus determine the choice of technologies and applied resources in deconstruction, crashing, sorting and recycling processes. Within this context, waste fraction types and recycling paths/quotas of deconstruction materials are usually not predefined. Hence, the definition is left to the demolition companies, which face the challenge to constantly produce recycling material of good quality under changing and often not influenceable conditions.

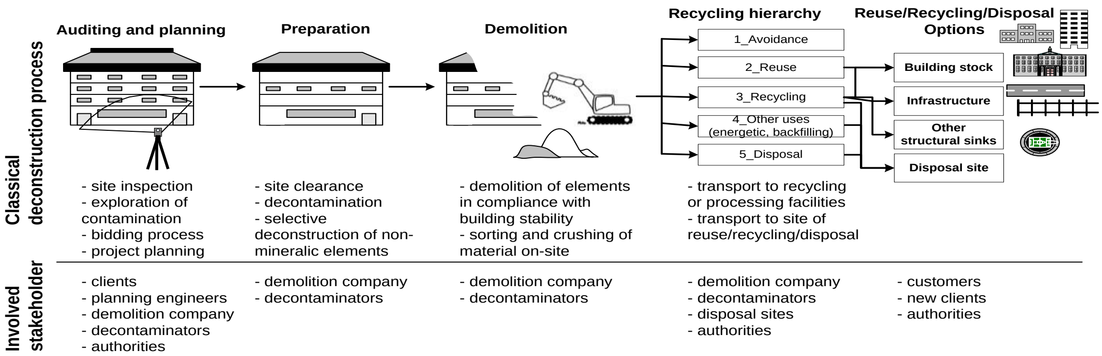

Figure 1: Classical demolition and reuse/recycling process (own representation based on DA (2015))

In the reuse, recycling and disposal stages, materials are reprocessed, crushed, sorted, etc. to gain recycling materials of defined quality (e.g. defined in the German standard DIN 4226-100 for recycled aggregates) or to be classified into waste fractions of different qualities and prices. During reuse/recycling a plethora of legal, often regionally differing regulations have to be applied. These regulations address material quality and waste classifications, contamination limits regarding soil and health protection, allowed reuse/recycling options as well as transportation allowances. Major potential customers of recycling materials are authorities (for instance, regarding road works) and individual consumers with resource-saving attitudes.

1.3 Level of professional competency and business processes

Depending on the diversity of involved stakeholders, education in the demolition sector encompasses very different professions and degrees. Table 1 (own representation based on DA (2015)) gives an overview of the most common professional educations related to the type of stakeholders involved in the demolition process.

Table 1: Overview on educational degrees in the demolition and recycling industry (own representation based on DA (2015))

Stakeholder	***Profession/degree***
Planning engineer	*Architect, civil engineer*
Demolition site manager	*Civil engineer*
Health and safety coordinator	*Architect, civil engineer*
Foreman	*Master craftsmen*
Equipment operator	*Operator*

Skilled worker	*General training related to construction work (brick layer, concrete worker) and special training related to demolition work*
(Unskilled) worker	-

In organizational terms, the demolition process (especially the deconstruction process) has project character, similarly to the “normal” construction process. A client, who is usually consulted by a planning engineer, calls for tenders and then accepts an offer of one demolition company. This company either performs the actual demolition process on site itself or acts as a main contractor and assigns single tasks to subcontractors and experts. Usually, for each demolition project new project teams are created. The engagement of subcontractors often follows long-term cooperation/alliances. In general, at least the removal of hazardous materials is done by a subcontractor. Following demolition on site, deconstruction material is landfilled or recycled, either by the demolition company itself or a special recycling company (DA (2015)).
Demolition works are one of the most dangerous jobs in the construction sector, due to confined space on site, parallel work, time pressure, hazardous materials, harmful impacts, such as noise and dust, as well as regularly unpredictable building statics and working conditions (Gabriel et al. (2010)). Hence, for instance in Germany a coordinator for safety and health matters has to be employed by the client by law, according to the construction site ordinance (BaustellV (2004)), when more than one contractor (including subcontractors) work on site. This coordinator consults the client, the planning engineer, the demolition company and subcontractors during planning and execution of the demolition process (§3, BaustellV (2004)).
Furthermore, often a waste concept has to be designed beforehand, where created debris /recycling material has to be quantified and their disposing has to be clarified. For instance, in Germany demolition companies can receive a quality label for deconstruction works by fulfilling defined and regularly controlled quality criteria, for example related to education and skills of employees and subcontractors as well as quality of equipment (RAL (2015)). In Germany, Denmark and Netherlands, paper-based documentation of buildings is dominating (Brewer and Mooney (2008)). Project progress and performance is almost daily reported to the project planner and controller via tablet or cell phone.

2. Leading Edge

2.1 Leading construction materials management industries

To identify leading companies in the demolition industry, it is suitable to look at major demolition tasks and respective leading companies performing these tasks. Tasks can be roughly divided into two main tasks levels: On the one hand, demolition is performed on different structure types, including complex bridges and viaducts, high-rise buildings, and industrial and chemical plants. On the other hand, demolition works are carried out in different sectors, such as the energy, petrochemical, infrastructure, education, industrial, residential and commercial sector. Related to demolition works in different sectors, there are some synergies with residential recycling, waste-to-energy and landfill gas-to-energy facilities. The tasks within these levels can overlap. As, the industry is scattered into small and medium sized enterprises, an overview of leading companies in the industry according to the outlined tasks is difficult.

Nevertheless, Table 2 (own representation based on the scope of this report) shows a selection of leading companies and associations of different countries based on the scope of this report.

Table 2: Selection of leading demolition and material recycling companies and associations based on the scope of this report

Country of origin	***Company/institutions name***
Australia	*Instant Waste Management; Liberty Industrial (Deconstruction, Remediation & Civil); National Federation of Demolition Contractors*
Canada	*Milestone Project Management, Winnipeg; 3R Demolition*
Germany	*German Demolition Association (Deutscher Abbruchverband e.V., DA); RAL Community of Goods for Demolition Works (RAL Gütegemeinschaft Abbrucharbeiten); Gesamtverband Schadstoffsanierung e.V.*
Netherlands	*Nihot air recycling technology*
UK	*Absolute Demolition Ltd*
US and Canada	*National Demolition Association; Building Materials Reuse Association; Construction Materials Recycling Association*

2.2 Leading life-cycle-oriented management of construction processes

Common practices of deconstruction[2] of the demolition industry are (DA (2015), VDI/GVSS 6202 (2012)): Identification of hazardous materials, such asbestos; inventory listing of materials to determine, where each item will be sent; structural deconstruction starting from the roof down to the foundations and non-structural deconstruction, such as the removal of appliances, windows, doors and other finishing materials, which can be marketable components. Further practices are: cleaning and/or refinishing of materials after separation from the structure to increase the material value; secure and dry storage of dismantled building components; location of material salvage, encompassing non-profit reclamation yards and dismantling contractors and on-site or off-site recycling of materials that cannot be salvaged or taken to landfills. Additional aspects, which are considered especially by leading stakeholders of the demolition industry, are: Bespoke risk assessments and method statements, compliance with standards (such as BS6187:2011) - safe systems of work, state-of-the-art, high-tech demolition specific equipment, experienced and trained personnel and best practice and innovation.
Diverse processes of deconstruction and recycling related to these practices and additional aspects and up-to-date leading deconstruction and recycling processes based on the scope of this report are outlined in Table 3 (own representation based on the scope of this report).

Table 3: Overview on life-cycle-oriented construction material management processes based on the scope of this report

Main process	***Description/content/application***
Integrated design & Design for deconstruction processes	- *Upstream approach considering deconstruction during their design process.* - *Combination of simple construction methods with high-grade, durable materials with visible separation layers and mechanical fasteners such as bolts.* - *Deconstruction, Separation and disassembly of components / building elements.* - *Standardized materials, inventory systems for reclaimed materials (via bar codes,*

[2] The careful disassembly/dismantling of buildings to recover materials for reuse.

	RFID,GIS) and their consistent application throughout the project. - *Avoidance of difficult construction methods and materials in deconstruction such as nails and adhesives.* - *Avoidance of hazardous materials altogether.* - *Avoidance of mixed material grades to improve material quality.* - *Saving/ Adaptation of existing structures to new needs.* - *Modular building elements, that can be reconfigured as desired.*
Deconstruction processes	- *3D Demolition Simulation software for Extreme Loading for Structures (ELS) (Roaf et. al (2004)): used to model the collapse of a building. ELS software is based on structural-analysis using the applied element method (AEM) for tracking of cracks, separation of elements, and collapse of structures under extreme loads. ELS provides demolition scenarios and predictions for structural defects resulting from seismic activity as well as visualisation of forecasted structural responses.* - *Smartwaste software tool developed by Building Research Establishment (BRE): assists in preparing and implementing Site Waste Management Plans and waste monitoring reporting. It includes a calculator for costs of embodied energy of waste and labor for waste disposal as well as an interactive map to find for instance waste management facilities, recycling sites, transfer stations and landfill sites as well as local reclaimed and recycled products and equipment for recycling and reprocessing.* - *ERO Concrete Recycling robot: conceptual robotic concrete demolition machine that also bags the crushed aggregate in the same process.*
Innovative on-site and off-site recycling processes	- *Full site assessment: identifying decommissioning requirements and other separate assets to maximizing material value and recovery. Maintaining the building stability during structural separation and alterations.* - *Soft Stripping: non-structural deconstruction of internal fixtures and fittings.* - *Single stream recycling plants (off-site): sort waste materials.* - *Diversion and Recycling Tracking (DART): online tool used to process waste materials from building construction and demolition sites.* - *Separate handling of building plastic and electronic waste.*
Separation processes	- *Vacuum systems for separating film plastics.* - *Magnets for recovering ferrous metal.* - *Optical-sorting technologies for separating wood and aluminium. For instance, cameras and laser technologies to identify and sort objects and materials.* - *Vibratory Screens for separating small stones and rocks, for reuse in construction.* - *Gypsum plasterboards and blocks "closed-loop" recycling: recycling process separates gypsum from paper and both materials return in their original products.* - *MRF (Material Recovery Facility): can recycle between 80 to 90 % of construction demolition waste in a single skip bin system. The facility extracts a variety of materials, including sand, wood, metals, brick, light materials and concrete by a rotating electro magnet, a flotation tank, a sand oscillation screen and a shredder.* - *Bulk Handling Systems (BHS): automated process for sorting significant percentages of the C&D material which is made up of small pieces. Eliminates inefficient hand sorting and keeps these materials out of the landfill.* - *Air Separation Technology (AST): accurately separates rock, wood and light material by using air pressure, wind shifters and drum separators.* - *Pneumatic vacuum systems for small rubble removal (intended for post disaster demolition process) and commercial machinery used currently only for loose stone such as roof ballast.* - *Brick mortar removing power tools that plane or grind off the mortar.* - *De-nailing guns for nail removal.*

3. Perceived Problems and Challenges and Potential Solution Approaches

Aim of deconstruction and recycling of construction materials and buildings is to drastically reduce the deployment and consumption of primary non-renewable construction materials. Actual barriers in this industry can be found in Nakajima and Russell (2014). Furthermore, challenges faced to design for deconstruction make it difficult for architects to incorporate material recovery procedures into the initial building design (Hobbs & Adams (2012)). In the following different challenges are further described and analysed.

3.1 Technical challenges

Technical challenges of the deconstruction and recycling industry are often caused by unknown material qualities in existing buildings that are deconstructed. Establishing the structural performance of reused components can be perceived to be difficult by engineers who will be hesitant to use salvaged structural components unless they have been tested in accordance with current standards. This hampers reuse and recycling options. Hence, relevant technical developments to enhance reuse, recycling and waste tracking are economical material sampling methods for decontaminations and material quality measurements and documentation. These would enable fast determination of material quality and subsequent options of recycling material usage based on regional material demands. Within this context, actual knowledge on regional demands is required to locally reuse materials, which leads to one issue of organizational challenges (see section 3.4).

Furthermore, the use of non-reversible joints can make the deconstruction of building components difficult or impossible and therefore state technical challenges of design for deconstruction. For instance, in North America wood frame dominates residential low-rise building, which are often difficult to dismantle due to a large number of fasteners (Falk and Guy (2007); Davis (2012)). Framing members such as stick framing or trusses for roofs can be dangerous to remove and may require special equipment or bracing during the deconstruction process. The use of mechanical and easier to loosen joints might reduce this technical challenge.

Also, innovative approaches for automated separation and decontamination of building elements e.g. via robots or self-controlling machines are required. They seem promising for instance, in the context of separation of outer walls thermal insulation composite systems, separation of layer composites as well as decontamination in contaminated sites and in decommissioning and deconstruction of nuclear power plants, such as the system MAFRO (Baulinks (2015)).

Furthermore, technical development of cost effective methods of raw materials sorting and of material processing plants are required to produce secondary raw-materials of constant quality. This also includes optimization of existing processing plants.

Further technical challenges exist in the automation of deconstruction processes, such as the acquisition of building information, processing of analogue and digital building information, operative project planning, emission management or site surveillance and control, e.g. via sensors. The application of digital building models and sensors onsite would enable planners and deconstruction companies to automatically plan, track and document project performance and related impacts on employee’s health or the local environment, such as adjacent neighbours or buildings. However, the demolition industry seldom adapts digital building models and planning methods, yet. At the moment the digitalization is limited to digital building documentation via Word/Excel on tablets.

Moreover, good examples demonstrating effectiveness of design for deconstruction, of selective deconstruction, material recycling and reuse are required to overcome technical challenges.

3.2 Economic challenges

Major economic challenge is the lack of economic incentives to use recycling materials in new constructions in most countries. Reasons are comparably cheap raw materials and low costs of

construction units, expensive material sampling methods, differing material qualities of recycling materials and temporal and spatial divergence of demand and supply.
In many countries the main structural building components are often not salvaged due to a perceived lack of demand. Only single, high value, quick sale items are usually collected by selective deconstruction and often sold to a heritage market. This problem is one of both, supply and demand. Retailers do not carry products that are not demanded and consumers do not buy products they do not know. This is closely related to the awareness of the value of reclaimed building components. Sampling of built-in materials or building elements and tests of reclaimed components for structural integrity are costly and impede material quality determination and material reuse/recycling options. Although there are some national and regional online marketplaces and platforms for recycling materials and used building elements (in Germany on national[3] and regional[4] level; in Austria[5]; Canada[6]; Netherlands[7]), the comparability and quality assurance of the offered materials/elements are not always given. Some clients even specify that they want all "new" materials. Here the liability of designers or recyclers can be a significant concern. "Without legislative action to create an artificial economic driver, the current market for deconstructed material is […] to remain economically feasible" (Nakajima and Russell (2013)). Widely spread recommendations among countries are to "encourage financial burdens on the landfill process through tipping fees or taxes" to force reuse/recycling or "provide financial incentives for efficient designs that facilitated end of life deconstruction" and recycling (Nakajima and Russell (2013)).
Furthermore, the demand is low, as reused building components are currently not available. More work is required by the design team to anticipate material requirements and identify potential sources. The question is, if there is enough of a single used component type to meet the demands of a new construction project. Then, design would need to be adaptable. Furthermore, production costs of recycled concrete aggregate vary depending on its use. Concrete components of existing buildings may need to be stored, moved and transported between sites and locations that might result in higher costs for new construction projects. Moreover, recycled aggregates might contain contaminant residuals, which reduce the compressive strength of the aggregate by up to 18% (Chini, et al (2001)). If the quality of recycled aggregate is lower than the virgin aggregate materials, the price should also be lower. However, the cleaning, processing, inspection, storage, and sale of recycled aggregate can result in higher costs than virgin aggregate. Other materials such as timber are extremely cheap to buy new and clean (e.g. in North America). Also, they are difficult to separate from other building components. Hence, there is very little economic perspective in recycling these materials.
In general, many industry professionals state that deconstruction result in higher overall costs for a project than traditional demolition and landfilling. Without a clear market and value for salvaged products little attention is paid to maintaining quality of demolition products.

[3] http://www.euwid-recycling.de/recyclingboerse.html, http://www.ihk-recyclingboerse.de/, http://www.bauteilnetz.de/bauteilnetz/website/stdws_adresse/bauteilboersen.html
[4] http://www.bauteilboerse-gronau.de/aktuelles.html, http://www.bauteilboerse-bremen.de/, http://www.ihr-umweltpartner.de/Gebrauchtboerse.html?kat=anzeige&ukat=step2&view_boerse_kat=14
[5] http://recycling.or.at/rbb/cake_rbb/
[6] http://www.owe.org/, http://www.greenguide.com/exchange/
[7] http://www.oogstkaart.nl/oogstkaart/

Moreover, according design for deconstruction additional time is often required for architects and engineers to include the added features to facilitate building deconstruction.

3.3 Ecologic challenges

Major ecologic challenges are that information on the life cycle of products as well as planning for end of service life are rarely considered and not yet mandatory at the building design stage (design for deconstruction). Values for use of reclaimed materials are mainly aesthetic and there are health concerns regarding the use of recycled material, which might contain hazardous substances. Environmental benefits are secondary.

Environmental product declarations (EPDs) (ISO (2006)) quantify ecologic information on the life cycle of products, based on Life Cycle Assessment (LCA) studies of independent institutions. EPDs represent a complete, robust and scientifically validated source of information of the environmental impacts of products along their life cycle. Even though they are not yet mandatory, EPDs are defined as a source of quantitative information on product life cycles in a standard way by the European Commission (EC, 2003). When available, EPDs can be used to assess the use of resources and the impact of construction works on the environment, according to the Construction Products Regulation (CPR) (EP (2011)). EPDs of construction products based on recent European standards (CEN (2011), (2013)), with the environmental assessment of construction waste flows, can be an important source of data for decision-making at the end-of-life of building materials and to 'close the loop' in their life cycle. Nevertheless, most EPDs are cradle to gate, including recycled content but no waste management processes or "recyclability" except in uses of steel and other metals, where recycling is more or less guaranteed. Hence, these gaps in reused/recycled materials for standards of life cycle stages, inventory data and allocation rules are major issues in the adoption of LCA.

Furthermore, if design for deconstruction would become a requirement or common practice, the likelihood of major portions of the building being salvaged can be greatly improved and the environmental impacts of that stage can decrease.

3.4 Organizational and educational challenges

A major organizational and educational challenge is a lack of knowledge by designers and builders on issues of component reuse. Designers are often not aware of supply sources and of actual materials. Although this issue has been highlighted by many green building rating programs, it is not highlighted in education programs, which tend to focus on waste reduction on site. The producer responsibility in the construction industry is not well established, and return of materials/components to their source only occurs if they have economic value. Many residential constructions are not big enough to fall under the regulations that do exist. Therefore, the client is not forced to provide a waste management plan and any demolition waste is most often sent to landfill, but may implement material reuse where gains can be created. Furthermore, this lack of awareness makes demolition crews more likely to work recklessly and simply remove components as quickly as possible. Deconstruction and reuse still tend to be a niche activity. Although there are various resources available including scattered retailers and deconstruction practitioners, the mainstream industry seems unaware of the possibilities of reuse and the value of the existing materials. Within this context there is also a lack of consistent standards that include deconstruction. Hence, it is difficult to provide specifications for carrying out deconstruction and/or supervising the deconstruction process.

Besides, there are other organizational challenges due to logistics and scheduling. Demolition is usually on the critical path and contractors are under time pressure. Ironically a building may have sat derelict for years but as soon as a new project is planned for the site there is very little time to carefully deconstruct the building. Hence, deconstruction as a slower process to remove the building is not performed. Additionally, often space and cost constraints prohibit the use of sorting bins for different materials on site. Furthermore, infrastructure is needed to collect, transport, store, and prepare salvaged components. But this infrastructure is rarely available.

Moreover, there is often a lack of cooperation among all parties, including owner, designers, contractors, subcontractors, and waste haulers about resource stewardship. If any of the interested parties do not fully grasp the purpose of deconstruction, it can hinder the entire process. A thorough understanding of the project's plan and goals are often not shared with all parties are not monitored.

3.5 Political/legal challenges

At present there are no legal requirements in any country for clients or contractors to consider deconstruction at the design stage. Furthermore, the obligatory use of recycling materials in the construction sector is not implemented in many countries yet except for concrete in Switzerland and the monetary incentives against landfilling are not high enough. Although many central and local governments are supportive of reducing waste, the issue of reuse is not in the focus of decision makers, such as politicians and clients. Sometimes it is even a threat to existing resource supply industries.

4. Leading national and global initiatives on deconstruction and construction materials management

Finishing the research in state of the art of demolition and reuse and recycling of construction materials, on-going national and global initiatives in the area of deconstruction and reuse/recycling of construction materials are summarized. The entities and stakeholders in charge of these initiatives and developments are associations, research centres and countries. The first type of initiatives is legal actions - such as specific regulations developed worldwide and related to construction material stewardship. Most of them are promoted by national governments. A summary of these initiatives based on the scope of this research is presented in Table 4 (own representation) for raw material extraction, material recycling process and use of recycled C&D material, respectively. The second type are global initiatives with a broader impact, for instance at the European level, such as the European Demolition Association (EDA (2015)). The promotion of European standards on demolition techniques and on recycling of demolition waste are major objectives of this institution.

Table 4: Regulatory initiatives at a national level related to material recycling processes, raw material extraction and the use of recycled C&D material based on the scope of this report

Country	***Specific regulation and content***
Canada	- *Canadian Standards Association CSA Z782-06:2012. guide for deconstruction, disassembly and adaptability of buildings* - *Construction and Demolition Debris Deposit Program of San Jose: regulation on deposits of construction and demolition debris* - *Provincial aggregates royalty fees: royalty fees per tonne of aggregate extracted for instance in Ontario, British Columbia, Alberta and Quebec* - *Environmental Protection Act (EPA) Regulation 102/94. Requirements for waste audit before demolition, source separation (recycling) program*
Denmark	*Tax on extracted raw materials(sand, gravel, stones, peat, clay and limestone) and on waste.*
Germany	- *Closed Substance Cycle Waste Management Act (KrW-/AbfG (2000)): basic principles for waste management and closed loop recycling strategies. Waste management hierarchy - the first goal is waste prevention and avoidance* - *Ordinance about waste treatment (NachwV (2006)): way and scope to proof waste disposal and recycling* - *General technical specifications in construction contracts - demolition and dismantling work (ATV DIN 18459(2012)): extraction, storage and transportation of deconstruction materials/components based on the European Waste Catalogue (EWC)* - *Planned "substitute building materials ordinance". Actual draft as at October 31st 2012: nationwide regulations on mineral alternative construction materials produced out of/ resulting from recycled construction materials* - *Standard of "aggregates for concrete and mortar - part 100: recycled aggregates (DIN 4226-100 (2002)): quality of recycled aggregates and the composition of construction materials with portions of recycled aggregates (concrete and masonry)*
Israel	- *Green Building Standard: voluntary principles for on-site waste management and closed loop recycling strategies* - *EPA: Municipal Solid Waste Landfill Regulations. operation and management of municipal solid waste landfills* - *Mining and Quarrying laws and regulations: planning and operation of quarries, increase efficiency of raw material extraction, such as aggregates, sand and cement* - *Requests for proposals and promoting obligatory use of recycled C&D waste: promotion of policy aiming at obligating contractors to use recycled C&D waste in buildings projects and public infrastructure*
Netherlands	*The Dutch building materials decree: quality criteria for the application and re-use of stony materials and earth used as building materials (Eikelboom et al. (2001)). Reduction of waste material disposal and raw material extraction (Hendriks and Raad (1997)).*
Portugal	- *Guide for the use of coarse recycled aggregates in concrete (LNEC Specification E 471-2009):requirements for coarse recycled aggregates used in concrete (according EN 12620)* - *Law-decree Nr.73/2011, July 17th: mandatory use of recycled materials in public construction*
Sweden	- *Tax on natural gravel: substitution of natural gravel use (Söderholm (2011a), (2011b)).* - *Regional material inventories of natural gravel and alternative materials (Söderholm (2011b)).* - *Quality standards for road construction materials and tender bonus: to tender construction firms to use crushed rock instead of gravel (Söderholm (2011b)).*
Switzerland	*Recycling of aggregates (SN 640740, SN 640743 (1993)): obligatory recycling and use of RC concrete in new construction*
United Kingdom	*Taxes on aggregates: taxes on all extracted aggregates and imports (with the exception of recycled aggregates: sand, gravel and crushed rock used in construction)(Söderholm (2011b)).*
USA	- *Municipal C&D recycling rate requirements in Chicago and Washington* - *Municipal mandatory C&D recycling, materials separation and deconstruction and reuse requirements in Seattle, Portland and Chicago* - *C&D materials landfill ban in Massachusetts*

5. Conclusion

The analysis of the state of the art of demolition and reuse and recycling of construction materials shows that the leading institutions are very fragmented and leading processes are diverse. This reflects the actual structure of the construction and demolition industry, which is

dominated by small and medium sized enterprises and includes diverse stakeholders and processes. Consequently, especially international activities are difficult to implement, as shown by the analysis of leading national and global initiatives.
The major aim of deconstruction and recycling of construction materials is, to drastically reduce the deployment and consumption of primary non-renewable construction materials. The identified challenges related to this aim show that current activities are highly driven by costs. Particularly, country specific regulatory initiatives are identified to meet these challenges.

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FLEX 3.0: an Instrument to Formulate the Demand for and Assessing the Supply of the Adaptive Capacity of Buildings

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Abstract

Market developments show increased demands for flexibility and sustainability by users and owners of buildings. A direct connection can be made between adaptive building and sustainability. The longer a building can keep its functional life cycle instead of becoming vacant or being demolished, the more sustainable a building will be. One way of looking into this phenomenon is the more a building is flexible and able to adapt to changing user demands, the longer it will keep its functional life cycle. In 2014 a paper was presented at the International Union of Architects World Congress UIA2014 in Durban SA, titled Adaptive Capacity of Buildings. A report was given of an extensive international literature survey and the development of a method to determine the adaptive capacity of buildings. In total 147 flexibility indicators were described with accompanying assessment values. The most important recommendation for the next step was the development of an easy to use assessment method in practice with a limited number of important adaptability performance indicators.
Further research led in 2015 to a renewed assessment method with 83 indicators, clustered in five layers with different life cycles. This method was called FLEX 2.0 and a derived version was called FLEX 2.0 LIGHT with only 17 of the most important indicators. This was presented in 2015 at the CIB Conference - Going North for sustainability in London. At the same time this method was used in two separate research projects for an evaluation with experts in practice. One research project concerned the development of school buildings; the other project was related to the development of office buildings. The main conclusions and recommendations of both research projects to evaluate the FLEX 2.0 method in practice with two different types of real estate will be described in this paper. Questions will be answered about the differences and similarities between the two different categories of real estate when using this flexibility assessment method. This will lead to some important conclusions for the next version of the method: FLEX 3.0. Finally a renewed framework for this next version will be presented.

Keywords: assessment instrument, adaptive capacity, building, flexible, sustainable

1. Introduction

Market developments show increased demands for flexibility and sustainability by users and owners of buildings. A direct connection can be made between adaptive building and sustainability. The longer a building can keep its functional life cycle instead of becoming vacant or being demolished, the more sustainable a building will be. One way of looking into this phenomenon is the more a building is flexible and able to adapt to changing user demands, the longer it will keep its functional life cycle. In 2014 a paper was presented at the International Union of Architects World Congress UIA2014 in Durban SA, titled Adaptive Capacity of Buildings (Geraedts 2014). A report was given of an extensive international literature survey and the development of a method to determine the adaptive capacity of buildings (Geraedts 2013). In total 147 flexibility indicators were described with accompanying assessment values (Hermans 2014). The most important recommendation for the next step was the development of an easy to use assessment method in practice with a limited number of important adaptability performance indicators. Further research lead in 2015 to a renewed assessment method with 83 indicators. They were clustered in five layers with different life cycles. This method was called FLEX 2.0 and a derived FLEX 2.0 LIGHT version with only 17 of the most important indicators. This was presented in 2015 at the CIB Conference - Going North for sustainability in London (Geraedts 2015).

At the same time in two separate research projects the method FLEX 2.0 was used for an evaluation with experts in practice. One research project concerned the development of school buildings (Carlebur 2015); the other project was related to the development of office buildings (Stoop 2015). The main conclusions and recommendations of both research projects to evaluate the FLEX 2.0 method in practice will be shortly described in this paper. Questions will be answered about the differences and similarities between the two different categories of real estate when using this flexibility assessment method. This will lead to some important conclusions to develop the next version of the method: FLEX 3.0. Finally a renewed framework for this next version will be presented.

2. Previous Developments

2.1 Determination Method for Adaptive Building

Definition of Adaptive Capacity

The adaptive capacity of a building includes all characteristics that enable the building to keep its functionality through changing requirements and circumstances, during its entire technical life cycle and in a sustainable and economic profitable way. The adaptive capacity is being considered as a crucial component when looking into the sustainability of the real estate stock (Hermans 2014).

Adaptive Capacity Determination Method

In 2014 a method for determining the adaptive capacity of buildings has been developed after an extensive survey of international literature on the characteristics, definitions and assessment instruments of adaptive building and on boundaries of adaptive capacity, sustainability and financial business cases for real estate. The literature survey has resulted in a number of basic schemes with relevant flexibility indicators and their mutual relationships. Next to the literature survey, a substantial number of experts from practice have been consulted. The basic schemes formed the input for discussions in two different expert panels: one with representatives of the clients (demand side) and one panel with representatives of construction companies and suppliers (supply side) in the construction process (Geraedts 2013, Hermans 2014). The adaptive capacity method consists of three different modules:

1. The determination of the adaptive capacity.
2. The determination of the financial-economic viability.
3. The determination of the sustainability impact of the measures chosen.

FLEX 1.0: 147 Indicators to determine the adaptive capacity

In the further research only the first module was elaborated: the adaptive capacity of buildings (the AC Method). This method delivered a clear insight in and an overview of aspects that needed to be taken into account when assessing the adaptive capacity of buildings. The method combined existing knowledge on flexibility and sustainability (Berg 1981, Houtsma 1982, Geraedts 1989, REN 1992, Geraedts 1998, Geraedts 2001, Geraedts 2007, Schneider 2007), Beadle 2008, Geraedts 2009, Wilkinson 2009, DGBC 2013) amongst others into one overview of important aspects to determine the adaptive capacity.

For the owner of a building in total 36 different indicators were formulated with associated values for assessing the spatial/functional flexibility characteristics, and 49 different indicators to assess the construction/technical flexibility characteristics of a building. For the user of a building in total 29 different indicators were formulated with associated values for assessing spatial/functional flexibility characteristics, and 33 different indicators for assessing construction/technical flexibility characteristics. The total addition finally led to 147 indicators to determine the adaptive capacity of a building from an owners and a users point of view. It was the first step in the development of instruments to assess specific projects. Although it was not mentioned as such, one can identify this first version with the 147 flexibility indicators as FLEX 1.0.

The steering group behind this research project and the two already engaged expert panels played an important role for addressing the next research aim: the translation of this first developed instrument into a more accessible and easy to use instrument in the daily construction practice, with less indicators to deal with. This resulted in a renewed condensed method called FLEX 2.0 that will be briefly described in the next paragraph.

2.2 FLEX 2.0 and FLEX 2.0 LIGHT

Combining and clustering in five layers

First of all the double flexibility indicators described for the owner and the user of the building as well, were combined together. To structure and cluster the remaining large number of possible indicators any further, use has been made of the distinction in five layers with a different life cycle of the building and its environment (Brand 1994). As a consequence the number of flexibility indicators in FLEX 2.0 was reduced from 147 to 83 indicators, spread over five layers: Site, Structure, Skin, Facilities and Space plan/Finishing (Geraedts 2015).

Structure of FLEX 2.0: General requirements

To be able to actually use the adaptive capacity of a building or to change the use of a building is it necessary to recognize a number of common important preconditions. Especially some legal, organizational and common constructional preconditions have to be mapped before further actions can take place. Is it possible to change the function of the building or to extend the building according to the actual development plan of the local government? What is the general technical condition of the building, what is the age, when was the last renovation of the building, what type of user utilized the building?

Assessment level, weighting and scores

In this method values are given for each assessment aspect of flexibility performance indicators. Next to the indicator, the related assessment values and remarks, a column is shown to give a personal weight to the various indicators (varies from 1 = not important to 3 = very important) and finally a column to mark the score or level of the specific indicator concerned. There are four possible values for the score: 1 = Bad, 2 = Normal, 3 = Better, 4 = Best. Figure 1 shows an example of the four assessment values of indicator nr.11: Surplus of free floor height. The final score is calculated by multiplying the assessment value and the weighting factor for that indicator (see example in figure 2).

11 Surplus of free floor height	Assessment values of the free floor height	Remark	Weighting	Score
How much is the net free floor height?	1. < 2.60 m (Bad) 2. 2.60 - 3.00 m (Nromal) 3. 3.00 - 3.40 m (Better) 4. > 3.40 m (Best)	The higher the free floor height, the better a building can be rearranged or transformed to other functions, the better a building can meet to changing demands of facilities and the quality of the building or units.	1 = less important 2 = important 3 = very important	Score = assessment x weighting

Figure 1: Example of the four assessment values of flexibility indicator nr. 11: Surplus of free floor height, the assessment values, remarks, weighting and score (Geraedts 2015)

FLEX 2.0 LIGHT: The 17 most important indicators

After the clustering of 143 indicators to 83 indicators, in the next step a second clustering was carried out to find a limited number of the most crucial indicators. This lead to FLEX 2.0 LIGHT with 17 indicators in total, a very easy and fast to use instrument to assess the adaptive capacity of a building. Figure 2 shows an example of a fictive assessment of a certain building with FLEX 2.0 LIGHT. Each of the 17 indicators has been given a weight relative to the other indicators (weighting 1 - 3). Also each indicator is assessed (assessment level 1 - 4). This leads to a score per indicator and summed up to a total Adaptivity Score. At the same way a theoretical minimum score can be found of 17 and a maximum score of 204. With these two borders a class table can be made with five different classes of adaptivity with the total range from 17 to 204.

FLEX LIGHT 2.0				WEIGHTING	ASSESSMENT VALUE				SCORE
LAYER	SUBLAYER	Nr.	FLEXIBILITY PERFORMANCE INDICATOR		Bad	Normal	Better	Best	
1. SITE/LOCATION		01(2)	Surplus of site space	1			3		3
2. STRUCTURE	2.1 Measurements	02(5)	Surplus of building space / floor space	2		2			4
		03(11)	Surplus free of floor height	3				4	12
	2.2 Access	04(17)	Access to building: location of stairs, elevators, core	2	1				2
	2.3 Construction	05(21)	Surplus of load bearing capacity of floors	3			3		9
		06(29)	Extendible building / unit horizontal	3		2			6
		07(30)	Extendible building / unit vertical	1	1				2
3. SKIN	3.1 Facade	08(42)	Dismountable facade	3				4	12
4. FACILITIES	4.1 Measurement & control	09(53)	Customisability and controllability of facilities	2	1				2
	4.2 Dimensions	10(56)	Surplus facilities shafts and ducts	2	1				2
		11(57)	Surplus capacity of facilities	3	1				3
		12(65)	Disconnection of facilities components	2			3		6
5. SPACE PLAN/FINISHING	5.1 Functional	13(70)	Distinction between support - infill (fit-out)	3		2			6
	5.2 Access	14(73)	Access to building: horizontal routing, corridors, gallery	1		2			2
	5.3 Technical	15(77)	Removable, relocatable units in building	3	1				3
		16(78)	Removable, relocatable interior walls in building	3			3		9
		17(79)	Disconnecting/detailed connection interior walls; hor/vert.	3				4	12

Total Adaptivity Score: 95

Adaptivity Class: 3

CLASS TABLE Adaptivity Scores	Score Range
Class 1: Not adaptive	17 - 54
Class 2: Hardly adaptive	55 - 92
Class 3: Limited adaptive	93 - 130
Class 4: Good adaptive	131 - 168
Class 5: Excellent adaptive	169 - 204

Figure 2: FLEX 2.0 LIGHT, a practical and easy to use light version of the assessment method with a limited number (17) of the most important indicators (Geraedts 2015)

In the example of figure 2 the total Adaptivity Score is 95. When looking up this score in the class table, the related Class = 3: the building is Limited Adaptive.

2.3 Matching Demand and Supply: Gap Analysis

With the instrument FLEX 2.0 LIGHT as described in paragraph 2.2 four assessment levels of the different flexibility indicators are possible from 1 = Bad to 4 = Best (see figure 3).

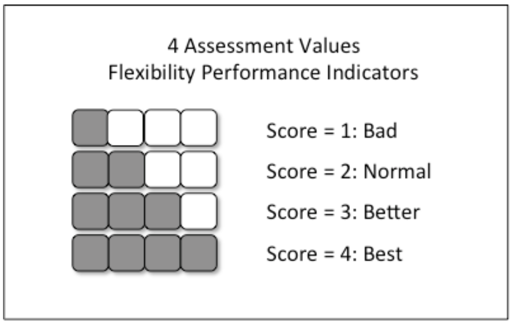

Figure 3: Visual representation of the four possible assessment values of the flexibility indicators, from 1 = Bad to 4 = Best (Geraedts 2014)

A very important aspect of this method is that owners and users of buildings can formulate a flexibility demand profile based on the chosen assessment flexibility indicators and compare this with the supplied building flexibility profile (see figure 4).

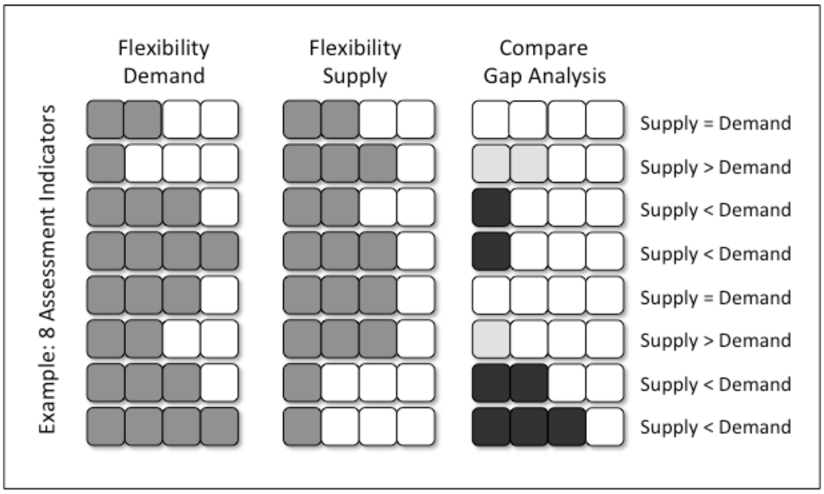

Figure 4: The comparison (gap analysis) between the demand for flexibility and the supplied flexibility in a building; in this example based on 8 flexibility indicators (Geraedts 2014)

3. Evaluation by Research in Practice

At the same time when FLEX 2.0 LIGHT was developed, the more extensive method FLEX 2.0 with 83 flexibility indicators was used in two separate research projects for an evaluation with specific experts in practice. One research project concerned the development of (high) school buildings (Carlebur 2015); the other project was related to the development of office buildings (Stoop 2015). The results of these research projects are briefly presented in the next paragraphs.

3.1 Adaptive School Buildings Determination Method

Methodology

The main research question in this school buildings project was as follows: which indicators determine the adaptive ability of educational real estate and how can these be implemented to create an assessment method which can review the current real estate, and can also be used as a standard for formulating the program of requirements? In order to answer these research questions three research methods were used: a literature review, a panel survey and a Delphi research. A panel of 30 professionals working in the educational sector contributed in this survey. The panel consisted of both users and owners and also experts from the developmental sector. The survey used 83 adaptivity indicators from FLEX 2.0 and the experts reviewed the indicators on their importance for adaptive building in the educational sector (Carlebur 2015).

Results

The experts of the educational sector selected 21 of the most important flexibility performance indicators. They also ranked the indicators based on their importance for increasing the adaptivity of the educational real estate (high school level). Figure 5 shows an example of a fictive assessment of a certain high school building. Each of the 21 indicators has been given a weight relative to the other indicators (weighting 4 - 1). Also each indicator is assessed (assessment value 1 - 4). This leads to a score per indicator and summed up to a total Adaptivity Score (121 in the example). At the same way a theoretical minimum score can be found of 55 and a maximum score of 220. Within these two borders a class table can be made with four different classes of adaptivity (see figure 5). When looking up this score in the class table, the related Class = 2: the school building is Hardly Adaptive.

EDUCATIONAL REAL ESTATE			WEIGHTING	ASSESSMENT VALUE				SCORE
LAYER		FLEXIBILITY PERFORMANCE INDICATOR		Bad	Normal	Better	Best	
CONSTRUCTION	1	Positioning obstacles / columns in load bearing structure	4	1				4
	2	Extendible building / unit horizontal	4				4	16
	3	Extendible building / unit vertical	4		2			8
	4	Rejectable part of building / unit horizontal	4			3		12
	5	Access to building; location of stairs, elevators	4				4	16
	6	Surplus of building space / floor space	3	1				3
	7	Surplus free floor height	3		2			6
	8	Measurement system; modular coordination	3	1				3
FACILITIES	9	Overdesign/surplus of facilities (E, H, ICT)	4			3		12
	10	Modularity of facilities	3		2			6
	11	Customisability and controllability of facilities	3	1				3
	12	Disconnectability of facilities components	1		2			2
SKIN	13	Day light facilities	2				4	8
	14	Location and shape of daylight facilities	2		2			4
	15	Facade windows to be opened	1				4	4
SPACE PLAN	16	Distinction between support - infill/fit-out	3	1				3
	17	Removable, relocatable interior walls in building	2		2			4
	18	Disconnecting/detailed connection interior walls; hor./vert.	2	1				2
	19	Multifunctional building	1			3		3
	20	Horizontal routing, corridors, access	1	1				1
SITE	21	Expandable site / location	1	1				1
							Total Adaptivity Score:	121
							Adaptivity Class:	2

CLASS TABLE EDUCATIONAL REAL ESTATE Adaptivity Scores	Score Range
Class 1: Weak. Not adaptive	55 - 92
Class 2: Moderate. Hardly adaptive	93 - 132
Class 3: Acceptable. Limited adaptive	133 - 172
Class 4: Good adaptive	173 - 220

Figure 5: Example of the fictive assessment of a certain school building, the total Adaptivity Score (121) and the Adaptability Class (2) of the school concerned (Carlebur 2015)

3.2 Adaptive Office Buildings Determination Method

Methodology

This research by Stoop was founded on two perspectives: on the one hand the current context of the office market (vacancy) and on the other hand the absence of a practical and manageable measuring instrument to assess the adaptive capacity of office buildings. The goal of this research project was to elaborate the method from FLEX 2.0 into a manageable version for the office sector with the focus on two research questions: which indicators of the FLEX 2.0 method characterise the adaptive capacity of office buildings? What does an instrument that measures the future value of office buildings based on these indicators look like? To answer these questions, different research methods have been used: a literature study, interviews with experts from practice and a test in two pilot cases.

OFFICE BUILDINGS			SPECIFIC PRIORITY	
LAYER	NR	FLEXIBILITY PERFORMANCE INDICATOR	TRANS	USE
SITE/LOCATION	1	Multifunctional location	x	x
	2	Expandable location	x	
STRUCTURE	3	Building entrance, location of elevators, stairs, cores	x	x
	4	Positioning pipes and shafts	x	x
	5	Storey height	x	x
	6	Insulation between stories and units	x	x
	7	Bearing capacity of floors	x	
	8	Column layout	x	x
	9	Positioning obstacles supporting structure	x	x
	10	Availability of stairs and elevators	x	x
	11	Expanding / reusing stairs and elevators	x	x
	12	Division support - infill		x
	13	Fire resistance supporing structure	x	
	14	Oversized building space/surface	x	
	15	Available floor area	x	x
	16	Size of storey		x
	17	Horizontal grid size	x	
SKIN	18	Daylight entry	x	x
	19	Openable windows	x	x
	20	Insulation facade	x	
	21	Dismountable facade	x	x
SERVICES	22	Overdimensioning capacity installations	x	x
	23	Measurement and control technology		x
	24	Overdimensioning pipes and shafts		x
	25	Location of the supplying installations (heating, cooling)		x
	26	Independance user units		x
	27	Adjustable and controlable installations		x
	28	Distribution / modularity installations	x	x
	29	Distribution heating and cooling installations		x
	30	Dismountable facility components	x	x
SPACE PLAN	31	Accessible facility components	x	x
	32	Horizontal routing, corridors, units	x	x
	33	Detailing joints inner walls - horizontal/vertical		x
	34	Possibility suspended ceiling		x
	35	Possibility elevated floor		x

Figure 6: The 35 most important flexibility indicators for office buildings (Stoop 2015)

Results

In figure 6 the presented indicators characterise the adaptive capacity of office buildings. The first column represents the layers that cluster the indicators. According to Brand these layers distinguish themselves by different life spans (Brand 1994). The second column shows the 35 most important indicators of the adaptive capacity of office buildings. The next two columns address the specific priority of that indicator: Transformation Dynamics (the capacity of a building to react to a change demand of the building function) or Use Dynamics (the capacity to react to a change in user demands). In contrast to FLEX 2.0 LIGHT and a similar instrument for educational real estate as described in paragraph 3.1, the instrument for office buildings does not use a weighting factor between the different flexibility indicators, nor calculates a final flexibility score.

4. Next generation: a new framework for FLEX 3.0

At this moment three different instruments are more or less derived from FLEX 2.0 (the one with the original 83 flexibility performance indicators). In figure 7 these three instruments are presented and combined with each other:

1. FLEX 2.0 LIGHT with 17 indicators and generally applicable (Geraedts 2015),
2. An Assessment instrument for school buildings with 21 indicators (Carlebur 2015),
3. An Assessment instrument for office buildings with 35 indicators (Stoop 2015).

FLEX 3.0 COMBINATION 3 ADAPTABILITY ASSESSMENT INSTRUMENTS				INSTRUMENT			DYNAMICS		
LAYER	Sub-layer	Nr	Flexibility Performance Indicator	Light	Schools	Offices	T	U	
1. SITE		1	Surplus of site space	x			x		
		2	Expandable site / location		x	x	x		
		3	Multifunctional site / location			x	x		
2. STRUCTURE	Measurements	4	Surplus of building space / floor space	x	x	x	x	x	1
		5	Available floor space of building			x	x	x	
		6	Size of building floors			x	x	x	
		7	Surplus free of floor height	x	x	x	x	x	2
		8	Measurement system; modular coordination		x		x	x	
		9	Horizontal zone division / layout			x	x	x	
	Access	10	Access to building: location of stairs, elevators, core building	x	x	x	x	x	3
		11	Presence of stairs and/or elevators			x	x	x	
		12	Extension / reuse of stairs and elevators			x	x	x	
	Construction	13	Surplus of load bearing capacity of floors	x		x	x		
		14	Shape of columns			x	x	x	
		15	Positioning obstacles / columns in load bearing structure		x	x	x	x	
		16	Positioning of facilities zones and shafts			x	x	x	
		17	Fire resistance of main load bearing construction			x	x		
		18	Extendible building / unit horizontal	x	x		x		
		19	Extendible building / unit vertical	x	x		x		
		20	Rejectable part of building / unit horizontal		x		x		
		21	Insulation between stories and units			x	x	x	
3. SKIN	Facade	22	Dismountable facade	x		x	x		
		23	Facade windows to be opened		x	x	x	x	
		24	Day light facilities		x	x	x	x	
		25	Location and shape of daylight facilities		x		x	x	
		26	Insulation of facade			x	x		
4. FACILITIES	Measure & Control	27	Measure and control techniques			x	x	x	
		28	Customisability and controllability of facilities	x	x	x	x	x	4
	Dimensions	29	Surplus of facilities shafts and ducts	x	x	x	x	x	5
		30	Surplus capacity of facilities	x		x	x	x	
		31	Modularity of facilities		x	x	x	x	
	Distribution	32	Distribution of facilities (heating, cooling, electricity)			x	x	x	
		33	Location sources of facilities (heating, cooling)			x	x	x	
		34	Disconnection of facilities components	x	x		x	x	
		35	Accessibility of facilities components			x	x	x	
		36	Independence of user units			x	x	x	
5. SPACE PLAN	Functional	37	Multifunctional building		x		x		
		38	Distinction between support - infill (fit-out)	x	x	x	x	x	6
	Access	39	Access to building: horizontal routing, corridors, gallery	x	x	x	x	x	7
	Technical	40	Disconnectible, removable, relocatable units in building	x	x		x		
		41	Disconnectible, removable, relocatable interior walls	x	x		x	x	
		42	Disconnecting/detailed connection interior walls; hor/vert.	x		x	x	x	
		43	Possibility of suspended ceilings			x	x	x	
		44	Possibility of raised floors			x	x	x	
				17	21	35	44	32	

Figure 7: FLEX 3.0, the integral combination of the three developed instruments to assess the adaptive capacity of buildings with 44 flexibility performance indicators in total

Next to the 'Instrument' column the 'Dynamics' column is shown. The 'T' stands for Transformation Dynamics, the capacity of a building to react to a changed market demand of the building function from an owner's point of view. The 'U' stands for Use Dynamics, the capacity of a building to react to a changed user demands from a users point of view.
This new FLEX 3.0 framework has in total 44 flexibility performance indicators that are all applicable for assessing the transformation dynamics while 32 of them are also suited for assessing the user dynamics of a building. Figure 7 also shows the seven general applicable flexibility performance indicators (most right column). They can be used for each type of real estate. The other 37 more specific indicators can be used for the assessment of specific real estate like schools or office buildings.

4.1 Support - Infill theory for a generic assessment instrument

This paragraph formulates an additional point of view on the gained results so far for explaining the potential future development. Habraken developed in the sixties a theory to distinguish construction components by different life spans (long and short life cycles), by different decision levels (community or individual), by different building levels (urban tissue, support, infill), or by differences in dealing with components (fixed or variable components). This is also known as the so-called Support-Infill theory (Habraken 1972). Similar to this theory it could be possible to distinguish flexibility performance indicators that are general applicable (on 'support' level for each building type (the seven indicators in the most right column of figure 7) and the other 37 indicators (on 'infill' level) that are more specific for a special type of real estate; in this case school buildings or office buildings. Further research in the near future will be necessary to elaborate this theory further and to develop the next version of this flexibility assessment instrument to be very useful in practice (FLEX 3.0).

5. Conclusions

In 2014 report was given of an extensive international literature survey and the development of a method to determine the adaptive capacity of buildings (Geraedts 2014). In total 147 flexibility indicators were described with accompanying assessment values. The most important recommendation for the next step was the development of an easy to use assessment method in practice with a limited number of important adaptability performance indicators. Further research led in 2015 to a renewed assessment method with 83 indicators, clustered in five layers with different life cycles. This method was called FLEX 2.0 and a so-called FLEX 2.0 LIGHT derived version with only 17 of the most important indicators (Geraedts 2015). At the same time in two separate research projects this method was used for an evaluation with experts in practice. One research project concerns the development of school buildings (Carlebur 2015), the other project relates to the development of office buildings (Stoop 2015).
In this paper the three different instruments derived from FLEX 2.0 are described and combined with each other to model the frame for the next version of a general and easy to use instrument to formulate the demand for adaptability on the one hand and assess the supply of the adaptability of buildings on the other hand: FLEX 3.0.

One of the main conclusions of this research project is that real estate experts from practice found the developed methods very useful. Furthermore, more additional research is required to improve the concept. One very good applicable development will be based on Habrakens support and infill theory as explained in the conclusions before (Habraken 1972).

Also financial effects of the costs and benefits of flexibility measures will have to be subject of further research, especially to convince owners and developers of buildings. Some indicators probably require lower initial investments than others. The relation between the investments and the extent of adaptive capacity will have to be studied, with a better judgement about the financial consideration to invest in adaptive capacity as a result.

Finally the assessment values of the indicators were not taken into account in this research. It would be interesting to evaluate if the assessment values are still valid, or if they should be strengthened or expanded. Weighting factors could be linked to the assessment values. Then it would be possible to work towards a certification of adaptive capacity.

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Sustainable Construction in UK Building Projects: Preliminary Findings of a Survey of Clients and AEC Professionals

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Abstract

The awareness of, and need for sustainable construction (SC) is relatively well acknowledged in the construction industry. However, like the concept of sustainable development, it is open to different definitions; the way it is implemented can also vary depending on the perspective adopted. In this paper, the term is used to refer to all decisions and actions during the design and construction of buildings, which are designed to ensure that both the process and outcomes of construction over the lifecycle of a building are sustainable. This paper reports on the preliminary findings of a survey that was conducted to investigate the nature and characteristics of SC with a view to developing an understanding of the potential risks and likely impacts of SC practices on building projects in the UK. The survey was targeted at clients and AEC professionals with information being collected on SC goals, strategies, tools, techniques, risks and benefits for particular projects respondents had worked on. Preliminary findings suggest that the key motivation for SC is to minimise lifecycle operational costs; key goals include the minimization of waste, and ensuring that energy costs are below average. High capital cost was seen as the key risk; the reduction of operations costs, improved marketing and health and productivity gains are perceived benefits. The findings also raise questions for further research, about the impact of project related factors on SC practices and the awareness of professionals of strategies used in a phase of a project that they're not involved in.

Keywords: AEC professionals, building projects, clients, sustainable construction

1. Introduction

The importance of sustainable development for the ongoing sustenance of life and the transformation of our world into a liveable place for all, is now widely acknowledged (WCED, 1987, UN, 2015). The attainment of "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987:43) requires concerted efforts to devise policies and strategies, which have been the subject of many international initiatives. For example, the most recent Agenda for Sustainable Development, which supersedes the Millennium Development Goals has 17 Sustainable Development Goals (SDGs) and 169 targets in relation to people, planet, prosperity, peace, and partnership (UN, 2015). The achievement of these goals and targets requires the cooperation of many stakeholders and sectors to ensure that economic and social development are not achieved at the expense of the environment (Ofori, 2015).

In the construction industry, the consideration of sustainable development is usually within the context of sustainable construction, as the industry can be seen as both a contributor to sustainable development as well as a process that incorporates sustainability principles into its practices (Ding, 2005; Shelbourn et al. 2006; HMG, 2008; Halliday, 2008; Atkinson et al. 2009; Goh and Rowlinson, 2013). This paper reports on the findings of a scoping study, which was aimed at investigating the nature and characteristics of sustainable construction (SC) with a view to developing an understanding of the potential risks and likely impacts of SC practices on building projects. The concept of sustainable construction is explored in the next section, and thereafter the research undertaken and the findings from the survey are presented and discussed. The paper concludes with recommendations for further research.

2. Sustainable Construction

The construction industry has a direct impact on the built environment and plays a central role in promoting sustainability. Through its activities and outputs, it contributes to the economy, enhances the quality of life of society, and impacts the environment (HMG, 2008). In this paper, we define sustainable construction (SC) as: all decisions and actions during the design and construction of buildings, which are designed to ensure that both the process and outcomes of construction over the lifecycle of a building (or other built asset) are sustainable (economically, socially and environmentally). This is in recognition that the construction industry (otherwise referred to as the Architecture, Engineering and Construction (AEC) sector) is essentially project based, and mainly deals with the creation phase of built assets. But there is an acknowledgement that design and construction has lifecycle implications and are influenced by various stakeholders such as clients, governments and regulatory bodies and AEC professionals who use their knowledge, skills and expertise in translating client requirements into completed built assets.

Sustainable construction involves two interrelated dimensions: outcomes and process. These are reflected in the UK government strategy on SC as “ends” (with respect to mitigating environmental impacts and resource consumption) and “means” (with respect to innovative and improved practices and regulation that will ensure the desired outcomes) (HMG, 2008). Goh and Rowlinson (2013) identify nine principles of SC, which incorporate both process (e.g. design process, lifecycle costing) and outcomes (e.g. environmental impact, lifespan), although some principles (e.g. resources and materials consumption) can apply to both process and outcome. The sustainability issues identified by Atkinson et al (2009) also reflect a range of environmental impacts such as climate change, water resources, land take and remediation, etc.

Within the context of the short-term nature of construction projects (in comparison to the lifespan of assets), it is not easy to assess (long-term) outcomes at the immediate conclusion of a project, given rise to the traditional approach of considering time, cost and quality as key measures of project success (De Wit, 1998, Yu et al, 2005). It does suggest that while a good understanding of outcomes is necessary, there should be emphasis on the process to ensure that desired outcomes are achieved.

Against this background (e.g. of different stakeholder involvement in construction), and assuming that the concept of sustainable construction is now fairly well established, the research reported in this paper sought to gain insights into the realities of sustainable construction on building projects; drivers for, and strategies for its implementation in practice (e.g. what lifecycle issues/intended outcomes are incorporated in the design/construction stage); what, if any, are its risks and benefits; and whether there were any project related factors (e.g. type, contract value, duration, etc.) that influenced sustainable construction practices.

3. Research Methodology and Process

The research approach was exploratory in nature, aimed at soliciting views from various stakeholders that will later form the basis of more in-depth studies. It was therefore decided that a questionnaire survey was the most appropriate approach to collect such varied views.

The focus of the survey was on Building Projects in the UK, and it was administered through an online questionnaire developed with Survey Monkey. A pilot survey to test the construct validity of questions was run from October – November, 2012 and was circulated to architects, client representatives, project managers and facility managers (a total of 10 people). The responses to this pilot (70% response rate) was used to refine the final questionnaire. The link to the online questionnaire was circulated to a list of clients and AEC organisations compiled from the Association of Consultancy and Engineering (ACE) in the UK, Architectural firms and Construction Organisations (total of 200). It was also circulated to members of the Co-operative Network for Building Researchers (CNBR), an international email "list for those who have an interest in building research and related fields [academics and practitioners]" with 3858 members (https://groups.yahoo.com/neo/groups/cnbr-l/info), between December 2012 and February 2013.

The 23 questions in the questionnaire were divided into five (5) sections: Respondent Details and Experience (questions on professional background and number of years of experience of construction projects) Specific Project Information on a recent (within 5yrs) building project (e.g. type, sector, contract value; procurement, duration, location and main structural system); Project Sustainable Construction (SC) Goals and Strategies (ranking of SC goals, motivation, key driver(s) for SC project goals., key strategies adopted during design and construction, techniques and tools used to assess project sustainability); Risks and Benefits of SC (risks associated with SC, causes of risks, how risks were addressed during design and construction phases, expected benefits of SC); and Free text comments on SC strategies and implementation on reported project, SC policies and practices in the UK. Respondents were given the option to provide their contact details if they wanted to receive an electronic copy of the survey summary. All those who provided this information were sent a summary of the findings.

4. Survey Results and Data Analysis

The data was analysed using IBM SPSS Statistics version 22 (IBM, 2013). There were 48 responses (on 48 projects) representing a response rate of 24% (using the list of 200, as it was not possible to determine the proportion of CNBR members who could have completed the questionnaire). However, not all respondents completed every question in the questionnaire, and the findings for each question presented below are for actual responses to each question.

4.1 Respondent Profile and Experience

Figure 1 shows the profile and experience of the respondents (43 and 42, respectively) who answered these questions. The majority of respondents were project/construction managers [25.6% (11)], architects [23.3% (10)] and civil/structural engineers [18.6% (8)]. The rest were: building services (mechanical and electrical) engineers, quantity surveyors/cost consultants, client representatives and a building surveyor. Regarding experience of the construction industry, 40.5% (17) had worked in the construction industry for more than 15 years; 9.5% (4) for between 11 -15years, 16.7% (7) for between 6 and 10years, and 33.3% (14) for 5 years or less.

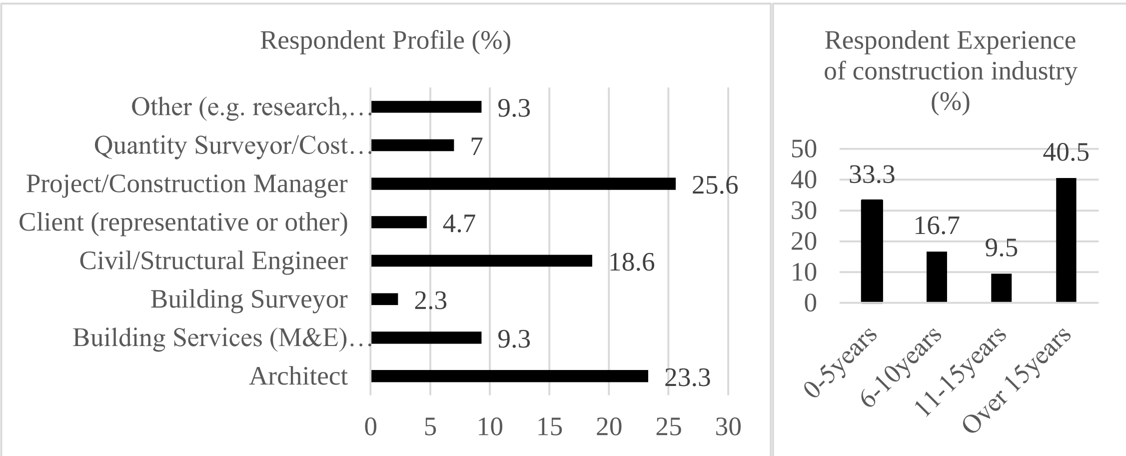

Figure 1: Respondent profile and experience

4.2 Project specific information

Responses for project specific information are summarised in Table 1 and includes information on: project type [majority, 81.2% being new build]; client sector [mostly commercial (37.5%), public sector (37.5%) and residential (21.9%)]; contract value [fairly spread across all categories, with the majority being under £500k (27.3%) and between £5-£10m (21.2%)]; procurement type [majority being procured through traditional contracts (53.3%), followed by design and build (23.3%)]; project duration (construction phase) [majority between 12-36months, followed by those lasting 12 months or less (23.3%)]; and main structural system [with the majority being reinforced concrete framed structures (44.4%), followed by steel-framed buildings (33.3%)]

Table 1: Project specific information

Question	Project specific information	Frequency	Percent (%)	N (%)	Missing (%)
Project Type	New Build	26	81.2	32 (66.7)	16 (33.3)
	Refurbishment	6	18.8		
Client Sector	Commercial	12	37.5	32 (66.7)	16 (33.3)
	Residential	7	21.9		
	Public Sector	12	37.5		
	Other (Education)	1	3.1		
Contract value	0-£500k	9	27.3	33 (68.8)	15 (31.3%)
	£500k-£1m	5	15.2		
	£1m-£5m	6	18.2		
	£5m-£10m	7	21.2		
	Over £10m	6	18.2		
Procurement Type	Traditional Contracting	16	53.3	30 (62.5)	18 (37.5)
	Design and Build	7	23.3		
	Construction Management	2	6.7		
	Management Contracting	2	6.7		
	Private Finance Initiative	3	10.0		
Duration (construction phase)	0-12monts	7	23.3	30 (62.5)	18 (37.5)
	12-36months	20	66.7		
	36-60monhs	1	3.3		
	Over 60months	2	6.7		
Main Structural System	Steel Framed	9	33.3	27 (56.3)	21 (43.8)
	Reinforced Concrete Framed	12	44.4		
	Timber Framed	1	3.7		
	Load Bearing Bricks/Blocks	4	14.8		
	Other (precast)	1	3.7		

4.3 Project sustainable construction goals

The sustainable construction goals that were adopted for the projects reported on were: *minimising waste (e.g. of water, materials, etc.) during construction* (10/11 projects – 90.9%); *ensuring that energy costs are below average for that type of building* where (9/11 projects – 81.8%); *achieving economic regeneration of the area* (11/14 projects – 78.6%); *achieving above-average BREEAM rating* (9/12 projects – 75%). Regarding the motivation behind the sustainability goals, those that were relevant to the reported projects were: *to minimise lifecycle operational costs* (90.9% of responses); *to comply with organisational policy* (e.g. corporate social responsibility) (81.8% of responses); *to comply with government policy (obtaining statutory approval)* (72.7%); to create an exciting building (72.7%); and *to comply with government policy to obtain project funding* (63.6%). Of these reasons, the top two (minimising lifecycle costs and complying with organisational policy) were rated as of high or medium importance by 100% and 88.9% of respondents, respectively. The desire to create an exciting building was rated as of high or medium importance by 90% of respondents to the question. With regards to the drivers for sustainability, the responses showed that clients were the main drivers (10 out of 11, 90.9%) followed by designers and contractors (5 out of 11, 45.5% each), government (4 out of 11, 36.4%), and engineers (3 out of 11, 27.3%). An analysis of sustainable construction goals and project specific factors (Table 2) to see if there was any correlation between the two, showed that there was no association between SC goals and project specific factors.

Table 2: Comparison between SC goals and project specific information

SC Goals and Strategies	Chi-Square /P value	Project Specific Information					
		Project type	Client sector	Contract value	Procurement method	Duration (constr. phase)	Main structural system
Achieving economic regeneration of the area	Chi-Square	0.14	0.99	3.42	1.17	1.73	4.55
	P value	0.71	0.65	0.49	1.00	0.42	0.60
Achieving above-average BREEAM rating	Chi-Square	0.00	0.44	2.26	4.28	0.54	5.40
	P value	1.00	0.51	0.52	0.13	0.76	0.51
Achieving between 0 and 10% carbon emissions	Chi-Square	0.12	0.07	4.53	6.80	3.11	3.33
	P value	0.73	0.80	0.54	0.07	0.46	1.00
Ensuring that up to 20% of energy used in the building is from a renewable source (e.g. wind, solar)	Chi-Square	0.00	1.33	1.45	2.73	2.04	4.95
	P value	1.00	0.25	0.69	0.44	1.00	0.48
Ensuring that energy costs are below average for that type of building	Chi-Square	0.64	0.02	2.93	0.58	0.54	2.04
	P value	0.43	0.99	0.55	1.00	1.00	1.00
Minimising waste (e.g. of water, materials, etc.) during construction	Chi-Square	3.93	1.52	1.32	1.32	0.24	0.92
	P value	0.09	0.25	1.00	1.00	1.00	1.00
There were no clear goals	Chi-Square	0.28	0.74	1.67	1.67	0.28	1.11
	P value	0.60	0.39	1.00	1.00	1.00	1.00

4.4 Sustainable construction strategies in design and construction

Key strategies for SC during design are shown in Table 3. Those adopted on the majority of the 11 projects reported were: *specifying A-rated materials (as per the Green Guide to Specification* – (Anderson et al. 2009)*)* (90.9%)*; building envelope insulation technology* (90.9%); use of *heat recovery systems* (72.7%) and *rainwater harvesting* (54.5%). The relative importance of these strategies (on 10 projects) showed that: *building envelope insulation technology* was of high importance in 7 (70%) projects and of medium importance in 3 (30%) projects; *specifying A-rated materials* was of high importance in 5 projects (50%) and of medium importance in 5 (50%) of projects. This suggests that *building envelope insulation technology* was the top strategy adopted at the design stage to achieve SC goals.

During construction the strategies that were adopted on the majority of the 11 projects for which information was provided were: *applying water saving methods to construction* (90.9%); *off-site prefabrication* (81.8%); *delivery of waste materials to recycling sites for re-manufacture* (81.8%); and *reuse of construction waste (or demolition) materials on the construction site* (80%). The relative importance of these strategies on 10 projects showed a mixed picture: *applying water saving methods to construction* was of high importance in 20% of projects, and of medium importance in 80%. For *off-site prefabrication* it was of high importance in 60%, medium importance in (20%) and low importance in 20%). For *delivery of waste materials to recycling sites* the corresponding figures were 30% (high importance), 60%, (medium importance) and 10% (low importance). For *reuse of construction waste* (9 responses), the relative importance was 22% (high), 56% (medium) and 22% (low). This suggests that while various strategies were adopted during construction, these were not necessarily of high importance in achieving SC goals.

Table 3: Key strategies adopted during design to achieve sustainability goals

Key Strategies adopted during Design to achieve Sustainable Goal for this Project	Relevant to this project	Frequency (Count)	Percent (%)	N (%)	Missing (%)
Rainwater or Greywater harvesting	Yes	6	54.5	11 (22.9)	37 (77.1)
	No	5	45.5		
Heat recovery systems (e.g. CHP systems)	Yes	8	72.7	11 (22.9)	37 (77.1)
	No	3	27.3		
Specifying A-rated materials (as per the Green Guide to Specification)	Yes	10	90.9	11 (22.9)	37 (77.1)
	No	1	9.1		
Passive Solar heating	Yes	3	27.3	11 (22.9)	37 (77.1)
	No	8	72.7		
Use of Photovoltaic panels	Yes	4	36.4	11 (22.9)	37 (77.1)
	No	7	63.6		
Building envelope insulation technology	Yes	10	90.9	11 (22.9)	37 (77.1)
	No	1	9.1		

4.5 Techniques and tools for sustainable construction

The techniques/tools used to assess SC issues are shown on Table 4. Those used on the projects reported (between 8 and 11) were: *BREEAM - BRE Environmental Assessment Method* (9/11 projects); *WLCC - Whole Lifecycle Costing* (8/10 projects); *Green Guide to Specification* (7/9 projects); *RSM Responsible Sourcing of Construction Materials* (5/8 projects); *DQI – Design Quality Indicator* (5/9 projects) and *CSH - Code for Sustainable Homes* (1/9 projects). Regarding the relative importance of these techniques, *BREEAM* was of high importance in 8 (72.7%) projects, of medium importance in 2 (18.2%) projects and low importance in 1 (9.1%) project. For *WLCC*, it was of high importance in 7 (77.8%) projects, medium importance in 1 (11.1%) project and no importance in 1 (11.1) project. For *Green Guide*, it was of high importance in 6 out 8 projects (75%), medium importance in 1 (12.5%) project and of no importance in 1 (12.5%) project. The rating for RSM was, 42.9% (high), 28.6% (medium), 14.3% (low) and 14.3% (no importance); for DQI it was: 42.9% (high), 28.6% (medium) and 28.6% (no importance); and for CSH, it was: 14.3% (high), 14.3% (medium); and 71.4% (no importance).

Table 4: Techniques or tools used to assess sustainable issues for projects

Techniques or Tools used to assess Sustainable issues for this Project	Relevant to this project	Frequency (Count)	Percent (%)	N (%)	Missing (%)
BREEAM - BRE Environmental Assessment Method	Yes	9	81.8	11 (22.9)	37 (77.1)
	No	2	18.2		
CSH - Code for Sustainable Homes	Yes	1	11.1	9 (18.8)	39 (81.2)
	No	8	88.9		
DQI - Design Quality Indicator	Yes	5	55.6	9 (18.8)	39 (81.2)
	No	4	44.4		
The Green Guide to Specification	Yes	7	77.8	9 (18.8)	39 (81.2)
	No	2	22.2		
RSM - Responsible Sourcing of Construction Materials	Yes	5	62.5	8 (16.7)	40 (83.3)
	No	3	37.5		
WLCC - Whole Lifecycle Costing	Yes	8	80.0	10 (20.8)	38 (79.2)
	No	2	20.0		

4.6 Risks and benefits in adopting SC strategies

The risks associated with the adoption of sustainable construction strategies on the 8 projects reported on were: *financial risk* (87.5%), *delays to design schedule* (62.5%), *complexity of construction* (50%), *delays to construction schedule* (50%). Regarding the relative importance of these risks, *financial risk* was of high importance on 6/7 projects (85.7%) and medium importance on 1/7 (14.3%) project. For *delays to design schedule*, it was of high importance on 3/7 (42.9%) projects, medium importance on 2/7 (28.6%) projects and low importance on 2/7 (28.6%)

projects. For *delays to construction schedule* (although not a risk on half of projects reported), it was of high importance on 4/6 (66.7%) projects and low importance on 2/6 (33.3%) of projects. The relative importance of *complexity of construction* was: 3/6 (50%) high importance, 1/6 (16.7%) medium importance, and 2/6 (33.3%) low importance. The biggest cause of risks associated with the adoption of SC strategies was: *high initial cost* (7/8 projects – 85%). The other options to this question (*immature technology*, *lack of skilled staff*, and *immature market*) did not receive meaningful responses.

The top expected benefits from the adoption of SC on the reported projects were: *reduce operational costs* (8/8 projects – 100%); *marketing benefit* (6/7 projects – 85.7%), *health and productivity gains* (6/7 projects – 85.7%); and *new business opportunities* (5/6 projects – 83.3%) All 8 projects indicated that *reduce operational costs* was of high importance. For *marketing benefit* and *health and productivity gains*, only 66.7% and 60% respectively said they were of high importance. For *new business opportunity*, only 40% said it was of high importance.

5. Discussion

The objective of the study reported in this paper was to gain insights into the actual implementation of SC (with respect to goals, strategies, techniques and risks/benefits) on building projects in the UK. Given that almost half of the respondents (48.9% - Fig 1) were professionals (architects and project/construction managers) who normally have an overview of the entire project process (especially for traditionally procured projects), and that two-thirds of them (66.7%) had over 5 years of experience of the construction industry, it is expected that their responses reflected a good knowledge of the industry and of project activities. The predominance of traditional procurement in the projects reported on (Table 1) is also fairly comparable with the findings of a national (UK) survey of construction contracts around the time of the survey (NBS, 2012), which suggest that the findings are based on projects that are fairly representative of projects nationally (at least in procurement type). It is however disappointing that there were poor responses to key questions on sustainable construction goals, strategies, etc. This might have been due to a lack of time to complete all questions, or that respondents simply didn’t know the answers, or indeed that there were no clear SC goals or strategies for those projects. If it was due to ignorance on the part of respondents, it raises questions about the awareness of SC goals and strategies by all participants on a project, or whether indeed these are made clear in project documentation. It might also suggest (as commented by a respondent in the free-text section of the questionnaire) that SC practices are “generally fragmented.” If the missing information was because there were no SC goals for those projects then it raises questions on the extent to which SC is being considered on projects.

The poor responses to key questions undermined any detailed analysis of the relationships between project-related factors and the goals, strategies, techniques, risks and benefits of sustainable construction (as was attempted in Table 2). But there are some interesting insights from the findings. For example, the SC goals that were relevant to reported projects (section 4.3) reflect both the ‘process’ (e.g. minimising waste during construction) and the ‘outcomes’ (e.g. relatively low energy costs) aspects of SC (HMG, 2008), and largely the economic (achieving economic regeneration) and environmental (energy use, high BREEAM rating) aspects of sustainability (economic regeneration can also have social benefits). The motivation behind these goals (e.g. to minimise lifecycle operational costs) suggest an appreciation of lifecycle issues. It is also encouraging that the SC agendas on these projects were mostly driven by clients and their policy for corporate social responsibility (section 4.3). This suggests a more positive view of SC and not just a desire to comply with regulatory requirements for statutory approvals or project funding. It would also appear from the free-text comments of one respondent, that some organisations have developed (and are developing) pioneering policies, "which provide stringent requirements on regeneration, environmental sustainability, health and [wellbeing]"

The relevant strategies for SC during design and construction are to be expected (respondents did not provide additional options to the coded answers given in the questionnaire) but it is interesting to see that during design, the emphasis appears to be more with "outcomes" aspects of SC (lifecycle performance of materials, insulation, energy efficiency), whilst construction appears to focus on waste minimisation, mainly a "process" issue, but with economic and long-term environmental impact considerations. Reported SC design strategies did not appear to be explicitly geared towards the facilitation of SC strategies at the construction stage (probably because of how the questionnaire was framed), but this can be explored in future research.

Regarding risks and benefits, it is not surprising that financial risk (e.g. high initial cost, which is also mentioned in the free text comments of one respondent) and reduction of operational costs were the top risk and benefits, respectively, on most projects reported. Both reflect some form of financial cost or reward and might suggest that financial costs/benefits have a key underlying motivation for SC (this is supported by the declared motivations for SC, and SC strategies at the construction stage). On the other hand, immature technology, lack of skilled staff and immature market, were not considered as causes for SC risks. Does this mean that appropriate technologies and personnel are available to implement SC practices? The evidence from this study might suggest so, but further studies are required to generalise this to the wider construction sector.

6. Conclusions

This paper has presented the preliminary findings of a survey into SC practices on building projects in the UK. The aim was to gain insights in the actual implementation of SC and to explore whether there are any relationships between SC goals, strategies, techniques, risks, benefits and project specific factors. The relatively low responses to vital questions did not allow detailed analysis to explore these relationships. The findings can only be applied to the reported projects as there were insufficient responses to make generalisations to the wider construction sector. Another limitation is that the survey was conducted a few years ago and SC and other project practices might have changed over this period (e.g. a more recent survey of construction contracts in the UK showed that design and build procurement is almost as popular as traditional procurement – NBS (2015) – a different profile from the survey in 2012 (NBS, 2012)). However, the study does provide useful insights and raises questions for further research.

Key findings include the fact that current (at the time of the survey) practice with respect to goals and strategies fairly reflected the understanding of SC in terms of “ends” and “means” (HMG, 2008) although social aspects of sustainability were not reflected as much as economic and environmental factors. The findings also suggest a more positive attitude towards sustainable construction which is not just about compliance with regulations (‘box-ticking exercise). There appears to be however, a strong financial motivation for SC, suggesting that a strong financial case for SC might well encourage more SC practices.

Questions arising from the findings include: the level of awareness of SC goals and strategies by all stakeholders in a project (a subject explored by Rafindada et al. 2014 in their paper on sustainable construction project risks), the extent to which SC strategies are integrated across the project process (e.g. how SC design strategies feed into SC construction strategies), and whether indeed SC practices are widely implemented on building projects in the UK

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Next Generation Healthcare Buildings in South Africa: Complexities and Opportunities for Sustainability

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Abstract

Hospitals are widely recognised to have complex design and engineering requirements. It might be argued that the unique functional constraints and operational demand placed upon the hospital building may counter sustainability imperatives. Yet it stands to reason that, even with this complex building type, there must be opportunity to reduce embodied energy, operational energy consumption, to manage water and waste, and to promote social cohesion without compromising the desired safe, effective, efficient healing environment.

In South Africa there has been a commitment to transform the healthcare sector through the introduction of National Health Insurance which is to unfold over a 14 year period from 2011. While this is primarily a funding mechanism, it seems inevitable that over time the principles of universal coverage, eradication of inequity, and accessibility will be reflected in the architecture provided to support service delivery.

In preparation for the National Health Insurance the South African government has increased spending on healthcare infrastructure and initiated several support projects to strengthen quality and accelerate delivery of capital projects. This includes the development of a comprehensive set of new national norms, standards and benchmarks for healthcare building. South Africa has adopted a contextual approach to determining its new guidelines, norms and standards. Key concepts which have a bearing on sustainability are discussed in relation to constraints and opportunities.

The next generation of healthcare buildings in South Africa has created an opportunity to embed principles of environmental consciousness and sustainability into the policies and practices of built environment professionals in the healthcare sector.

Keywords: Sustainability, healthcare, buildings, guidelines, developing country

1. Introduction

Health outcomes and healthcare service delivery is profoundly affected by the built infrastructure provided to support it. The South African (SA) Constitution confers rights to all citizens of access to health services and to an environment which is not harmful to their health or well-being. This underpins an imperative for health planners and built environment professionals to be vigilant in planning, providing and operating healthcare infrastructure. There is significant work to be done in SA, if it is accepted that it is currently not on a sustainable trajectory, which the 2012 UNU-IHDP and UNEP report contends (p 272). According to the report this is - in large part - due to poor health status and poor life expectancy. The dual epidemics of tuberculosis (TB) and HIV/Aids resulted in a life expectancy dropping from 67 years in 1998 to around 57 years in 2012. Unemployment is estimated to be 27% and climate change is likely to lead to increasing water stress, reduced food security and loss of species and ecosystems (UNU-IHDP et al, p 272). Sustainability is about a balance between economic, environmental and social dimensions.

In SA there has been a commitment to transform the healthcare sector through the introduction of the national health insurance (NHI) system which is to be unfolded over a 14 year period commencing in 2011 (National Department of Health [NDoH], 2011). Whilst ostensibly and primarily conceived as a funding mechanism, it is inevitable that over time the NHI guiding principles of universal coverage, eradication of inequity, and accessibility to services (NDoH, 2011, pp 16 – 19) will be reflected in the built environment. In preparation for NHI the SA government has increased spending on healthcare infrastructure and the NDoH has initiated several support projects to strengthen quality and accelerate delivery of capital projects (2012). This includes the development of a comprehensive suite of new national norms and standards for healthcare buildings (N&S), with the stated objective of providing a "sustainable set for all levels of health care facilities to inform and guide work related to all stages of the life-cycle from strategic planning through to operation and disposal" (Infrastructure Unit Support Systems [IUSS], 2014).

Although SA climate change mitigation commitments, legislation and policy now make it obligatory for built environment projects to address sustainability, there is currently limited guidance on how sustainable development can be integrated in built environment projects. There is also the perception that addressing sustainability in buildings will be expensive and complicated, and that there are a range of competing social, economic and environmental priorities. Hospital infrastructure is widely recognised to have complex design and engineering requirements even without the additional dimensions of environmental, social and economic sustainability. It might then be argued that the unique functional constraints and operational demands placed upon the hospital building as a type may trump greening imperatives, invoking "defensible exemptions".

2. Objectives

The N&S is not intended to be applied in isolation, being required over and above a number of general legislative pieces and instruments. Of relevance to this paper this includes the SA

National Building Regulations (NBR)[1], the National Environmental Management Act (NEMA) and the Infrastructure Delivery Management System (IDMS)[2]. Nevertheless, development of the N&S provides an opportune moment to embed forward-thinking principles of environmental consciousness, as well as social as economic sustainability, into the policies and practices of built environment professionals in the next generation healthcare building.

3. Method

With reference to the current status, and a desired future healthcare estate, researchers discuss the anticipated contributions of N&S over and above the NBR, NEMA and IDMS to the sustainability agenda, as well as identifying "defensible exemptions" and possible shortcomings. The headings of the ten points articulated in the Vision of Sustainable Smart-eco Building in 2030 (henceforth "Ten Point Vision") by Chevalier et al was adopted as a broad framework to structure a qualitative analysis. This is discussed in the subsequent narrative.

4. Ten Point Vision

According to Chevalier et al, European standards and guidelines are inclined to approach the general principles of sustainability in a reductionist and fragmented fashion: Cited are the focus on progressive energy demand reduction and energy generation targets in new and existing buildings in Germany, France, and Italy. The authors posit that sustainable principles need to be SMART (specific goals that are strategic, measurable, assignable, realistic, and time-bound) (Doran, pp 35 – 36) on the one hand, and on the other hand progressive and ambitious. Chevalier et al propose a Ten Point Vision (2009) as a framework for sustainable smart-eco building. Although this is centred on the European context and for general building types over a twenty year horizon, it covers a range of issues, and has been selected by researchers of this paper as a suitable holistic generic framework.

The Ten Point Vision suggests sustainable smart eco-conscious buildings should:

- Apply the general principles of sustainability;
- Be designed or refurbished from a life-cycle perspective;
- Be designed or refurbished to be adaptable throughout the service life, with an end-of-life strategy;
- Have its environmental impact minimised over the estimated or remaining service life;
- Be healthy and comfortable for their occupants;
- Be established with consideration of their economic value over time;
- Have social and cultural value;
- Result from all interested parties' involvement and be designed or refurbished to meet the occupants' needs individually and collectively;
- Be completely integrated into a territorial strategy and accessible for all; and
- Be designed or refurbished to be user-friendly, simple and cheap to operate, with their technical and environmental performance measurable over time.

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[1] Conforming to National Building Regulations is a newly emerging trend in public buildings in SA, many having been declared exempt until circa 2010.

[2] Can be accessed online from http://www.cidb.org.za/ , applicable to the public sector only

Each of these points is discussed systematically below as it pertains to the new draft N&S.

4.1 General principles of sustainability

The first point proposed in the Ten Point Vision is that buildings should conform to the Sustainability **in building construction -** General principles of as described in ISO 15392:2008. These principles are considered in relation to the N&S guidance in their entirety, and without regard for prioritisation and shown in Table 1

Table 1: General principles of sustainability

	Criteria /Achieved?	*Notes*
1	*Continual improvement* *Partial*	*A condition assessment method has been described. According to the published gazettes, compliance with N&S is mandatory, unless a motivated exemption is applied for and granted. This feedback mechanism could facilitate continual improvement of guidelines and by extension, buildings. However, minimal systematic updating has occurred to N&S since April 2014, limited to cost model tools which are updated quarterly for inflation and exchange rates and no means exists for systematically improving N&S.*
2	*Equity* *No/partial*	*The N&S were developed as a means of addressing inconsistencies in quality and expenditure in current capital work programs. As the application is only mandatory in the public sector its adoption will impact on new work in this sector, however is doubtful that will meaningfully impact most significant structural inequity (public vs. private disparity) and as it is not retrospectively applicable will only improve equity gradually (minimum 40 year replacement average).*
3	*Global thinking and local action* *Yes*	*The developers of the N&S have reviewed international literature and studied the Australasian Health Facilities Guidelines, British NHS Estates Standards, American Facility Guidelines Institute guides and concluded that these needed to be adapted to meet the specific opportunities and constraints of the local context. Some examples of SA context-specific considerations are with respect to preferential passive design response to climate opportunities, energy security, affordability constraints and airborne infection prevention and control.*
4	*Holistic approach* *Partial*	*The N&S address only conventional facility-based diagnostic and curative services, and do not address the health-promoting and preventive aspects of healthcare, nor alternative and traditional healthcare. To work toward overall building performance optimisation, interdisciplinary and novel approaches to design may be beneficial. N&S assume consultants retain conventional roles and responsibilities.*
5	*Involvement of interested parties* *Yes, limited to passive feedback*	*During the development phases of N&S, active involvement of identified experts and stakeholder representatives was encouraged through participation in a series of open workshops at which N&S development were discussed in themed sessions. These include participants with both clinical and built environment expertise. There is a dedicated project website which provides an open forum for sharing, dissemination and on-going stakeholder input allowing passive feedback. Involvement of interested parties could be strengthened and more actively pursued by making post-occupancy evaluation mandatory – not currently considered.*
6	*Long-term consideration*	*The N&S were drafted in a non-prescriptive way to allow for professional discretion and innovation. A future-healthcare environments workshop was held in order to anticipate future trends - such as telemedicine - which impact on healthcare infrastructure provision. However, current healthcare infrastructure planning is*

	Partial	*reactive and does not meaningfully take into account long-term dynamics in a structured way.*
7	*Precaution and risk* *Yes*	*The N&S provides guidance on mitigation through building design, material selection for several identified risks such as infection, slip, security (theft, vandalism), human error etc. (Worldwide healthcare associated infections and adverse events occur in 10% of admissions. Comparable studies are not available for SA, but could be expected to be at least in the same order of magnitude.) Precautionary measures for construction activities are discussed. General risk associated with construction, delivery etc. are described in complementary codes.*
8	*Responsibility* *(moral rather than legal/financial)* *No but described in IDMS and statutory councils*	*The public sector is characterised by a complex organisational design. Originating in the Constitution, each province enjoys relative autonomy. Infrastructure stewardship is conventionally split between the custodian (public works departments) and line departments (departments of health). Public works' core business is built environment-related but not necessarily versed in the specificities of healthcare requirements. Selection of built-environment professional consultants is usually based on a roster system. Without the prerequisite for prior experience (preferred by the private sector) there is a broader-based opportunity for participation in public-sector projects. This system does not, however, incentivise consultants to specialise in any public sector domain (including the health sector). User clients (i.e. facility-based health officials) are generally not repeat clients. Team member inexperience and a lack of formal guidance and regulation have led to extreme variation in form, quality, and cost of public healthcare infrastructure. N&S have limited guidance on roles, responsibilities and "rules of engagement". The conventions of practice are customary and described by the statutory professional councils (SACAP, ECSA, SAQSC) and through the IDMS process, however.*
9	*Transparency* *Yes*	*According to the Access to Information Act 2:2000, information related to public capital expenditure, healthcare infrastructure etc. should be available upon request. In practice this is rarely done, and this information is not readilly available. Auditing in the public sector ensures compliance with the Public Finance Management Act 1999. Limited private sector information is disclosed to maintain competitive advantage. However in the spirit of generosity and pursuit of improved healthcare infrastructure, the N&S development process inspired unprecedented cooperation and sharing of information.*

4.2 Life cycle perspective

The N&S includes documents on commissioning; decommissioning and maintenance address life-cycle stages beyond design, but are not explicitly geared for use in the design phases where pro-active measures should be introduced. The discipline of life-cycle analysis for construction materials and eco-labelling is in its infancy in SA and development of the N&S project has concluded without adequate reference to this discipline. Practical guidance on measuring or reducing embodied energy is not, for instance, addressed. The N&S cost model has been developed to take into consideration life-cycle costs. This takes into account that different building elements and materials have different expected service lives and in this way contribute to the quest for an affordable estate which does not solely focus on minimising initial capital costs. A decommissioning document forms part of the suite, but there is no guidance to identify or address end of service life and no mechanism to ensure implementation in practice.

4.3 Adaptable

The Ten Point Vision proposes that sustainable smart eco-conscious buildings should be designed or refurbished to be adaptable throughout the service life, with an end-of-life strategy. Typically hospitals and primary health care buildings are constructed using traditional brick and mortar generally resulting in fixed non-flexible structures. In an environment where technology dives rapid advancement in service delivery possibilities there is generally very limited flexibility built into health projects.

Given highly customised layouts of portions of hospitals (such as operating theatres) as well as the imperative to remain continuously operational, repurposing many components for other uses may be challenging: hospitals as currently constructed may not be good candidates for recycling and reuse. A flexible, adaptable open building systems approach may be appropriate in order to address the system uncertainties and complex specialised infrastructure requirements inherent in provision of healthcare. Open building systems may have the distinct advantage over conventional methodologies in healthcare settings of allowing building adaptation with minimal disruption to simultaneous service delivery or compromise to patient care. Yet services are conventionally provided from fixed, immovable structures which have lifespans of some decades. There is a document in the N&S suite for application of innovative building technologies - which may include open-building technologies - for clinics (i.e. small-scale). The number of larger scale healthcare buildings internationally adopting the open-building technology approach is limited with a few notable exceptions (INO Hospital, Bern, for example). In SA, migration to open building technologies would require non-trivial construction industry reskilling and building material supply transformation. Because of this, it is suggested that the requirement for adaptability be a defensible exemption for the health sector.

4.4 Minimising impact

The Ten Point Vision proposes that sustainable smart eco-conscious buildings should minimise their environmental impact over their estimated or remaining service life.

The National Environmental Management Act (NEMA) requires, inter alia, that building developers and owners must take reasonable measures to ensure that pollution or degradation of the environment is prevented or minimised in development and operation (NEMA Part 28). Local government has the authority to require an Environmental Impact Assessment and this prerogative is frequently exercised, more especially for green-field site development.

In support of the requirements contained in NEMA, the Environment and Sustainability document in the N&S suite (IUSS, 2014) provide a description of sustainable development and translates this into specific sustainable development objectives for the built environment and provides detailed checklists tailored specifically for healthcare infrastructure. These enable the setting of explicit and challenging targets to reduce operational energy consumption, manage water and waste for projects as well as systems to ensure that these are achieved, and provide a framework for self-assessment to ascertain the performance of projects in development and operation.

4.5 Health and comfort

The Ten Point Vision proposes that sustainable smart eco-conscious building should be healthy and comfortable for occupants. Patient and staff experience, healing environments, comfortable workplaces and prevention of healthcare associated infections and other adverse events are prioritised in the N&S.

In order to achieve indoor thermal comfort the Building Engineering Services N&S guide (IUSS, 2014) recommends that interventions should be considered, singly or in combination, in a hierarchy where passive and adaptive comfort systems are considered before fully mechanical systems. While there is a current paucity of detailed local climate data, the publication of local climate characterisation is expected shortly which will enable detailed evaluation of design response. TB, which is communicable exclusively through the air, is the leading cause of mortality in the region. It is recognised that building design and engineering has a role to play in mitigating risk as it impacts heavily on indoor air quality (World Health Organisation [WHO], 2009, CDC, 2005). Healthcare facilities inevitably bring susceptible and infectious individuals into close contact. According to Joshi et al (p 12) and Menzies et al (pp 593-605) and others, healthcare workers in middle and low income countries such as SA are at between four and 135 times more likely to contract TB compared to the background population. To address this major health risk, great care has been taken to describe design and engineering approaches to airborne infection that are locally-driven and are evidence based. The SA approach to building envelope design departs from one found in many European norms in that it does not generally promote hermetic sealing to reduce energy. Buildings are not typically heated or cooled for much of the year. Furthermore, perhaps in addition to considering comfort, sustainable building design could or should address well-being as criteria.

4.6 Economic value and affordability

According to the Ten Point Vision sustainable smart eco-conscious buildings should be established with consideration of its economic value over time.

Increasing expenditure to address the healthcare needs optimally rapidly raises challenges to affordability. There is abundant evidence that increasing expenditure on healthcare systems does not necessarily yield better outcomes (OECD). SA expenditure in health service provision (tracking the global trend) has risen steadily over recent years and there is international concern over the affordability (and hence sustainability) of this growth path. SA spends 8.3 % of its GDP on public and private sector health (The Presidency Republic of South Africa, 2011) and sectors compete for funding from a limited fiscus. An important challenge to the health system is capital, operational funding and staffing resource constraints. The whole healthcare enterprise must be carefully configured to ensure that operation of the full estate is affordable and sustainable. Integrated infrastructure planning which takes staffing, and operational resources which will be manifested over the building's projected life is required. To a limited extent, the N&S cost estimation tools can provide this by means of order of magnitude projections which include indicative operational cost forecasts for the medium term funding horizon enabling long term budget forecasting and reconciliation during planning.

Healthcare spending in SA is inequitably distributed across the public and private sectors. Treasury reports that 48.5 % of expenditure amounting to R120.8 billion is attributed to the private sector in the service of 8.2 million people (16.2 % of the population). Nearly half (49.2 %) of expenditure amounting to R122.4 billion is attributed to the public sector and is in the service of the remaining 42 million people (84 % of the population) (National Treasury, 2012). Although these figures are not directly comparable (the public sector figure excluding infrastructure provision) the contrast in expenditure has seriously undermined aspirations of equity, access to care and social justice. The N&S do not address both sectors and therefore will not have a direct role in resolving this economic value disparity.

4.7 Social and cultural value

In SA healthcare services enjoy great social and cultural value and its infrastructure can be symbolic of societal values of caring. This can be demonstrated in community response to opening and closure of such institutions. In SA there are historical and emergent social and cultural distortions which are expressed in the built environment. Healthcare infrastructure can be broadly characterised according to whether it is privately or publicly funded. This distinction can be linked – albeit with some limitations – (generalisation being crude) to broadly differing capital investment and building stock traits.

The private sector generally embeds lean systems thinking in its projects and values economic return on investment and organisational agility. There is recognition that healthcare built environments are necessarily substantively built-to-purpose, and specialist expertise to brief and designs is valued. The private sector invests in developing briefing and project implementation capacity in-house and cultivates relationships with experienced built-environment professional consultants for competitive limited repeat business. The project managers who implement private sector building projects have decision-making mandate to the extent that it satisfies corporate requirements. Limited experimentation is accepted but there is generally a conservative approach to building design and capital expenditure. The private sector replicates its successes with incremental refinements and adjustments over time. The larger hospital groups have become highly experienced, savvy clients. The private sector has dedicated legislation[3] which describes (amongst other things) some minimum space standards. There is general consensus that this legislation is outdated[4] although it is still in used to regulate some aspects of service provision (such as granting of licenses for hospital beds).

Formerly the public sector was regulated by the now repealed SA Hospital Norms (SAHNorms) with reference to maximum allowable areas and costs. In the absence of national public sector legislation, the public and media tend to benchmark private sector with the public sector, and conclude that the public sector is failing. The disparity in expenditure discussed above is sometimes acknowledged (National Treasury, p 8), but there is widespread despondency and

[3] The Regulation 158 (“the R158”) or Regulation187 in the Western Cape province
[4] last revised in 1993, in the pre-democratic era

lack of morale in the public sector despite significant successes and its crucial contribution to the uninsured majority.

4.8 Stakeholder involvement

Post-occupancy evaluations of three recently completed SA hospitals (van Reenen, unpublished) have found that there is no systematic involvement by communities in the design phase (although communities do get involved in ensuring local community employment in the facility when open and there is a structured national programme to involve local labour participation in the construction programme). There is only limited involvement of client department. For example, detailed mock-ups of rooms to convey actual size was not used as a technique

4.9 Territorial strategy

According to the Ten Point Vision sustainable smart eco-conscious buildings should be completely integrated into a territorial strategy and accessible for all. SA has a healthcare infrastructure platform which reflects the pre-democratic era: Gaps where the majority of population did not receive basic services; overlaps and duplicate services where apartheid structures were separately provided for different race groups; and private sector facilities which emerged in the 1980s, exploded post democracy to serve the insured population. The N&S guidance was originally envisaged to address all life-cycle stages but infrastructure strategic planning was removed from the scope of work. There is no evident coordinated geospatial planning programme and no [published/ discernible/ explicit] territorial strategy. Project, site and service selection does not appear to be systematically supported, except by exception, by study of accessibility and population and demand dynamics. Furthermore, leadership have expressed the perception that healthcare services may not be effectively delimited to nationals only (Lindeque, 2015). If true and unmanaged this could overburden constrained resources. Even if untrue, such perceptions may undermine social cohesion and lead to xenophobia and conflict. Given that the investment in infrastructure is on average a 40 year venture, with enormous concomitant capital, operational and human resource implications, it stands to reason that the absence of a territorial strategy is a credible concern to achieving a sustainable healthcare infrastructure platform.

4.10 User-friendliness

According to the Ten Point Vision sustainable smart eco-conscious buildings should be designed or refurbished to be user-friendly, simple and cheap to operate (i.e. maintainability), with its technical and environmental performances measurable over time. The N&S guidance[5] requires healthcare facility design to address user friendliness for occupants. In addition to the

[5] Ironically N&S guidance material itself is not adequately user-friendly. For convenience, and to satisfy the development time of three and a half years ab initio, the guidance was divided into 46 work-packages and each discreetly developed. This has resulted in unfortunate repetition and an unnecessary volume of material (in excess of half a million words). It is also not easy to locate or navigate in its current repository.

NBR requirements, it dictates that facilities are of inclusive design (wheelchair friendly, well-signposted, clearly laid out etc.) and in this way address user-friendliness. There is an explicit requirement to exhaust passive design technologies first, then hybrid systems and finally mechanical solutions to promote simple and cheap operation as well as to address energy insecurity.

There has been substantial, serious lack of maintenance of public healthcare facilities (with few exceptions) over a period of several years resulting in a general poor condition of infrastructure (SA Institution of Civil Engineering [SAICE], 2011). The N&S include maintenance guidance, encourages adoption of green technologies and specifies that sub-metering is installed in facilities to allow for utility consumption monitoring, benchmarking and maintenance. By contrast, the private sector is already investing in measuring technical and environmental performance and building maintenance (it is tax incentivised). It readily retrofits building to reduce emissions and install green technologies (in order to avoid carbon tax, to benefit from carbon credits and to reduce operational costs).

5. Discussion

SA has adopted a contextual approach to determining its new N&S. The new national guidelines, norms and standards with embedded sustainability practices identified above are published on an open, electronic repository gazetted into mandatory use in the public sector new capital work. The application notes expressly require implementation to be done with due diligence and application. Professional consultants are not absolved of their professional responsibilities of design, engineering and management, and are required to make use of the exemption processes where a conflict arises with professional judgement. Exemption processes are defined, requiring consultants to motivate deviations from the code, and this potentially provides a feedback mechanism to alert administrators of weaknesses in documentation and challenges in implementation, provided that this is actively monitored. As the N&S documentation and software is extensive, a structured capacity building and support programme is required to ensure implementation.

The current replacement rate of SA’s healthcare infrastructure is in the order of 40 years (Abbott et al, 2008, pp 146-183). In order to address building design from a life-cycle perspective a modification of the traditional roles may be indicated. For example building engineering for ventilation and climate control is sometimes limited to mechanical design solutions. Optimised passive ventilation design through building envelop design could result in a more energy- and life-cycle-efficient solutions but may require both redefining the engineer and architect’s traditional roles and methods of interaction, as well as client procurement practice. It seems likely that unless these requirements are anticipated in the pre-project stages (conception of need, briefing and contractual arrangements of consultants) that business will be conducted as usual and that conventional practice will remain pervasive.

6. Conclusion

There is a legacy sectorisation of healthcare provision split between public and private sectors with distorted investment patterns, reflected in current built form for healthcare infrastructure in SA. Emerging policy aims to improve equity and access which could result in a new generation of healthcare architecture over time but needs to be opened to innovation in infrastructure processes as well.

If it is accepted that the European approach to sustainable practice is exemplified in the single workshop, and that it is relevant to South Africa, it can be concluded that the N&S succeed partially in applying the general principles of sustainability. N&S require healthcare facilities to be designed or refurbished from a life-cycle perspective and provides some guidance on an end-of-life strategy. SMART benchmarks have been provided to minimise environmental impact over the estimated or remaining service life. A number of important healthcare-sector and contextually responsive health and comfort approaches have been incorporated. Some infrastructure is established to ensure involvement of all interested parties' and be designed or refurbished to meet the occupants' needs individually and collectively. Design, engineering and refurbishment which is user-friendly, simple and cheap to operate, with its technical and environmental performances measurable over time is discussed from a number of perspectives in the N&S.

It might be argued that the requirement that healthcare facilities be designed or refurbished to be adaptable throughout the service life, may be a "defensible exception", at least in the short to medium term given the complications described above. There are a number of sustainability criteria which may not be adequately addressed in the N&S. Whilst healthcare infrastructure undoubtedly has great social and cultural value, there is concern that sectorisation, and economic value will not be improved through the N&S, and that this is key to achieving a sustainable healthcare infrastructure platform. Finally there may not be the desired sustainable estate unless there is the introduction of a completely integrated territorial strategy in relation to both public and private sectors to attain facilities and services are accessible for all.

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Developing Sustainable Energy Efficient Buildings – A Transnational Knowledge Transfer Experience between Norway and Kosovo

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Abstract

As transnational institutional development programs are often advocated as a knowledge transfer opportunity between the partner universities, this case study "Sustainable Energy Efficient Buildings –Knowledge Transfer between Norway and Kosovo" investigated the knowledge transfer (KT) processes from Norwegian University of Science and Technology to College ESLG in Kosovo. An inter-organisational knowledge of transfer theoretical framework from the business sector was applied to guide the present study. The data was generated through semi-structured interviews with key university officers, professors, and students in continuous education programs from College ESLG and documentary evidence analysis from two partner universities. Based on the thematic analysis of the data, the findings demonstrated that the curriculum mapping process, joint lectures between Norwegian and Kosovar professors, joint research, and joint study visits facilitated the knowledge transfer. While the transfer of knowledge most evidently resulted in institutional capacity development for the Kosovar College unit, that managed the transnational institutional development program, the dissemination of knowledge to other units within the college was more challenging due to communication problems between the Real Estate Department and other units within the college. Hence, other universities seeking to conduct knowledge transfer through transnational institutional development programs need to understand each partner university's intention in establishing the partnerships, identify the beneficiary institutions' needs before seeking knowledge input from the partner university and improve the communication between and within the universities for sustainable benefits. The study has been part of the SEEB project supported by the HERD/Energy 2013-2015.

Keywords: transnational institutional development program, knowledge transfer, case study, Norway, Kosovo

1. Introduction

The Kosovo higher education industry includes 7 public universities: University of Prishtina, University of Prizren, University of Peja, Faculty of Islamic Studies, University of Gjilan, Kosovo Academy of Public Safety, and University of Gjakova (Kosovo Accreditation Agency, 2014). Beside this, the Kosovo Accreditation Agency (KAA, 2014) provides only a list of the evaluations of institutions (around 34) without formal decisions and there is no valuable information on the Ministry of Education, Science and Technology (MEST, 2014a). From the report published by Education, Audiovisual and Culture Executive Agency of European Union (2012) it is understood that there are 23 private higher education institutions. Most of the private and public higher education institutions in Kosovo are involved in a number of international cooperation projects supporting the establishment of new study programs or teaching improvement.

While much of literature speaks positively of the value of transnational programs in assisting institutional capacity development for universities in developing countries, there is a scarcity of empirical research that informs how these transnational programs actually facilitate actual knowledge transfer (Vincent-Lancrin, 2007; Leung and Waters, 2013). There has been limited or no research at all focusing on knowledge transfer, particularly from foreign universities to Kosovar universities through transnational institutional development programs. Therefore, it is timely to investigate the Kosovar College's perspectives about knowledge transfer from Norwegian University of Science and Technology to College ESLG through the transnational institutional development program. The uni-directional knowledge transfer from Norwegian University of Science and Technology, Norway to College ESLG took place as part of Programme in Higher Education, Research and Development (HERD) of Ministry of Foreign Affairs of Norway. Both institutions decided to cooperate in the field of energy because Norway leads in Europe in sustainable and passive buildings. In this regard, the Norwegian Parliament in January 2008, passed the law to consider imposing the passive house level for all new buildings by 2020 (Haase, 2010). In a less wealthy country such as Kosovo, households spent on average 1,210 Euros for electrical energy bills. According to the data of the Agency of Statistics of Kosovo (ASK) for 2012, around 30 percent of household expenses are spent on accommodation, a category in which electrical energy costs are included and covered. Also, Kosovo is faced with an increasing demand for electrical energy. Only during the second quarter of 2013 Kosovo used 857,7GW/h electrical energy of which households are the largest consumers of electrical energy with 56.4 percent (Efficiency for Development, 2014). The energy consumption in Kosovo homes for space heating is estimated at over 80% of total home energy consumption (Bowen et. al, 2013).

The present study focuses on the following research question:

How does knowledge transfer occur in the context of a transnational institutional development program "Sustainable Energy Efficient Buildings/HERD" from NTNU to College ESLG, Kosovo?

In attempting to answer the research question, the present study focuses at first on an inter-university knowledge transfer theoretical framework, adapted from business sector literature to guide the study, and then subsequently discusses the research methodology employed to generate the research results. After outlining the results, the discussion and implications of the study conclude the article.

2. Knowledge transfer

The theoretical framework, which is relevant to the present study, is composed of inter-organisational knowledge transfer theories developed in a business setting and complemented with the literature review on knowledge transfer in the tertiary education (Courtney and Anderson, 2009). Although the term knowledge transfer is used extensively in the modern literature, it is very important to explain what is meant by knowledge transfer as used in the present study. The knowledge transfer is defined as ‘‘the process through which one unit is affected by the experience of another’’ (Argote and Ingram, 2000, pp151).

According to Bauman (2005), the transfer of knowledge means the modification of existing knowledge from a sender organisation (for instance Norwegian University for Science and Technology) for the purpose of addressing issues that a receiving organization (in the context of this research College ESLG) faces. Inter-organisational theories of knowledge transfer argue that knowledge transfer takes place in four stages such as: 1) intention to engage in knowledge transfer through expressing of intention either from the sender organisation or receiving organisation to engage in transnational institutional development program; 2) the structured process of knowledge transfer; 3) the unstructured process of knowledge transfer and 4) the institutional capacity development (Chen and Mc Queen, 2010).

The inter-organisational theories of knowledge transfer argue that at the inter-university level, knowledge transfer begins with the intention of either party to engage in a transnational institutional development program, which explicitly results in a formal agreement or application for a donor-funded program. Robertson and Jacobson (2011) argue that research in the business sector shows that the expression of the intention to either acquire (receiving organisation) or share knowledge (the sender organisation) is critical to knowledge transfer. Both authors argue that the intention to engage in knowledge transfer must be mutual. The receiver organisation must explicitly exhibit the intention to acquire knowledge, whereas the sender organisation also must have the intention to share knowledge (Easterby-Smith et al. 2008). Eldridge and Wilson (2003) further argue that both institutions of higher education must show a genuine interest to engage in knowledge transfer. Huang (2007) argues that for any knowledge transfer to be successful in any transnational institutional development program, both partners must clearly specify the types and scope of knowledge transfer.

A structured process of knowledge transfer includes four phases (Szulanski, 1996). There are: initiation, implementation, ramp-up, and integration. The initiation phase usually takes place by identifying the knowledge gaps in the beneficiary institution. The knowledge gaps must be identified clearly in the partnership agreement. If the knowledge gaps are clearly identified at the initiation stage, then the implementation takes place much more smoothly. During the implementation phase, both institutions work together to ensure that the knowledge shared is what was shared between two universities and that it is also appreciated and valued by the receiving institution. The ramp-up phase follows with the staff members of the receiving university applying the acquired knowledge and resolving the knowledge gaps. Finally, at the integration phase, the acquired knowledge is institutionalized through the production of documents such as course syllabi, teaching methodology manuals and dissemination of the produced documents to other units of the university (Flores et al. 2012).

The knowledge transfer process may also be unstructured, which takes place in a spontaneous, informal, and unplanned manner (Chen and McQueen, 2010). The unstructured process of knowledge transfer depends on arising situational demands and individual dispositions. The unstructured process of knowledge transfer includes copying pre-existing knowledge products from the partner university and adapting that knowledge to the new context of the receiving university, independent of the sender university. In the unstructured knowledge transfer process, lecturers exchange knowledge without formal agreements, and the knowledge acquired can be applied individually or collectively by the lecturers (Chen and McQueen, 2010). In order for the knowledge which was acquired through the unstructured process to be retained and further shared within the institution, the recipient university must institutionalise the knowledge gained through production of documents at the institutional level. Then the knowledge gained through unstructured process has to be merged with the knowledge transfer that takes place through a structured process. This takes place during the integration stage (Argote et al. 2003). Whereas the theoretical framework proposes the unidirectional flow of knowledge usually from the sender to recipient university, authors such as Courtney and Anderson (2009) argue that the knowledge transfer takes place in a bidirectional way and requires interaction between the partner universities to fully appreciate the knowledge being transferred.

3. Methodology

A qualitative research method is used to explore the real interest of complex situations in the planning, which cannot be easily quantified. The qualitative research approach enables us to find reliable answers for research question posed. The qualitative method can provide the intricate details of phenomena, which can´t be derived through quantitative methods (Strauss and Corbin, 1990). The qualitative research technique is a more intrusive technique and less structured as the quantitative method, which enables the interviewer to gain in depth insight regarding the research topic (Jarrratt, 1996).

The present study uses qualitative research method, which includes semi-structured interviews and consultation of documents as two data sources. In total, 120 participants were invited to respond to semi-structured interviews. Out of 120 participants, 108 responded successfully. The successful respondents were: T3 professors from Kosovo participating in the Sustainable Energy Efficient Project, the chancellor of the College, 3 master students who spent one semester at NTNU as students and later, upon graduation, became teaching assistants at ESLG, 10 students who participated in the study visit in Norway, 60 master students who attended lectures that were jointly held by NTNU and College ESLG professors, and 31 participants from the ranks of other stakeholders that participated in conferences and symposia organised by both institutions. The respondents were selected from the ranks of those that were directly involved in the project and knowledge transfer. Although four professors from ESLG were foreseen to participate in the SEEB project according to initial application, only three were involved in all phases of knowledge transfer and throughout the duration of the project. Ultimately, ten students participated in the study visit in Norway and all of them were selected as respondents. These ten students include also three students that took place in a semester exchange, however, the three students participating in two different categories were asked two sets of questions (one regarding knowledge transfer achieved through study visit and the other one regarding knowledge transfer achieved through spending one semester). Also, sixty students were selected from two generations of students that attended lectures and courses with NTNU professors. Forty students were selected from the group of forty students enrolled in the master program of Real Estate Management in academic year of 2013/2014 and twenty students were selected from the class of twenty students enrolled in the master program of Real Estate Management in academic year 2014/2015.

Finally, thirty one respondents that were selected from the stakeholders group were selected from the group of two hundred people who took place in conferences and symposia organized jointly by NTNU and ESLG. Thirty one respondents were selected in the way that they represent main stakeholders such as Kosovo institutions (Ministry of Energy and Ministry of Environment and Spatial Planning), local government (directorates of urbanism of Kosovo municipalities), private sector (construction companies), professional associations in the field of energy efficiency, and various international donor agencies. The names of the participants were coded. The students were grouped into three categories: 1) students that completed one semester at NTNU and upon graduation were promoted to teaching assistants at the recipient university and who also did the master theses with Norwegian professors; 2) students that participated in a study visit in Norway and 3) students who attended lectures with NTNU professors in Kosovo. Table 1 describes the types of respondents, code numbers and their characteristics.

Table 1: Types of respondents, their code number and characteristics

Respondents type/category	***Code number***	***Characteristics***
Professors	*PROF*	*Only planners with ten years of experience that worked in municipality of Prishtina immediately in the period after the war*
Chancellor	*CHAN*	*Chancellor of the College as part of executive of College*
Students that completed one semester at NTNU	*$STUD_1$*	*Only students that completed one full semester at NTNU and completed their theses with Norwegian professors.*
Students that participated in study visit	*$STUD_2$*	*Only students that participated in a study visit at NTNU*
Students that attended lectures with NTNU professors in Kosovo	*$STUD_3$*	*Only students that attended direct lectures by Norwegian and Kosovar professors jointly in Kosovo for a full course*

Other stakeholders involved in the project	*STAK*	*Other stakeholders that attended the transfer of knowledge through organisation of conferences and symposia*

The categorisation of cases is presented in Table 2.

Table 2: Categorisation of cases

Category code	***Category description***	***Case identification code***
PROF	*Professors of ESLG*	*C1, C2, and C3*
CHAN	*Chancellor*	*C4*
STUD1	*Students that completed their semester at NTNU*	*C5, C6, and C7*
STUD2	*Students that completed their study visit in Norway*	*C8 to C 17*
STUD3	*Students that attended lectures with NTNU professors in Kosovo*	*C18-C77*
STAK	*Other stakeholders that attended conferences and symposia*	*C78-C108*

The interviews were conducted in Albanian and translation by a certified translator from Albanian into English was provided. The second source of data was the selected recipient college documents pertinent to the transnational institutional development program “SEEB”. These documents consisted of an application for the SEEB project funded by the HERD program of Ministry of Foreign Affairs of the Kingdom of Norway, annual reports from the SEEB project, curriculum documents such as course syllabi, conference agenda, filled student survey forms, conference participant’s feedback, and transcripts of meetings of the Steering Committee of the SEEB project. In the present study, the documents were categorised as secondary data used to corroborate the primary findings from the interview data.

The key constructs of intention to engage in knowledge transfer were; 2) the structured process of knowledge transfer; 3) the unstructured process of knowledge transfer and 4) the institutional capacity development were examined as specific themes used to investigate the date. Excerpts from the interviews discussing those thematic areas were compared and carefully examined. While there are excerpts relevant to these predetermined thematic areas, there are also excerpts from interviews that do not support the predetermined themes. In the end of analysis of interviews, the themes are determined as dominant if they show up in more than 50 % of the responses of semi-structured interviews. Furthermore, the dominant themes were used to analyse the secondary source of data such as documentary evidence. In order to enhance the credibility of qualitative studies, the triangulation technique was used (Guba, 1981). In order to ensure the triangulation, parts from the documents in line with the dominant themes were grouped together in order to support the dominant themes, which enabled triangulation of the findings from the semi-structured interviews and the findings from the documents.

4. Research results

The present study shows how College ESLG responded to the knowledge transfer processes generated by the Sustainable Energy Efficient Buildings Project (SEEB)/HERD program. College ESLG was a good partner for this project, as the first faculty in Kosovo teaching and researching in the field of Real Estate Management, and with tradition of cooperating with international institutions from Slovenia and USA. Both institutions were interested to develop creative cooperation in the field from research and teaching perspective.

The study found that the Norwegian University for Science and Technology and College ESLG were involved in a structured knowledge transfer process, which means that both parties began negotiations at the initiation stage to apply for a joint project of institutional development of the college in the Western Balkans. Within College ESLG, the project coordinator C3, who is responsible for initiation of international projects within ESLG expressed the following:

> "Yes we engage in a structured process of initiation of collaboration projects with foreign universities. It all begins with the letter of intent and then a memorandum of understanding is signed. Before signing any agreement, we at ESLG identify the areas in which we need support from the foreign universities. It is in our vision to engage in collaborative projects with strong universities that come from the developed countries, from which we can benefit in terms of gaining the necessary knowledge".

Also upon negotiations between College ESLG, NTNU and Multiconsult, the parties signed the memorandum of understanding and also the application for an institutional development project entitled "Sustainable Energy Efficient Buildings" funded by the HERD program of the Ministry of Foreign Affairs of the Kingdom of Norway. As can be seen from the extract below, institutional development, curriculum development, and research capacity development were identified as key areas for knowledge transfer. A two-way interaction was needed to prepare the application for the SEEB project.

Main objectives of the project Sustainable Energy Efficient Buildings are to develop the institutional capacity of ESLG on energy efficient buildings and sustainable refurbishment. This include development of a master study program energy management in Buildings, develop research capacity at ESLG on energy efficient buildings and sustainable refurbishment, and building a network among academia, the construction industry, and authorities in Kosovo (Application for SEEB project, pp4). While the written application for project SEEB documented the jointly agreed intentions to engage in knowledge transfer on both sides, the views expressed by participants (case 1 to case 3) through interviews were not consistent with the written documents. For case 1 to case 3, establishing transnational institutional development program was unidirectional and seen as a way to seek and develop the institutional capacity of ESLG in the area of energy efficient buildings and sustainable refurbishment, as exemplified by the following excerpt.

C1 notes the following: "From the very beginning although the application for SEEB project provided for bi-directional knowledge transfer, we as ESLG were hoping to have more uni-directional knowledge transfer in the field of curriculum development, teaching methodology, research capacity development, and grading standards in the area of energy efficient buildings and sustainable refurbishment, where Norwegians lead in the world. It was our intention to acquire as much knowledge as possible from Norway in order to transfer it further to other stakeholders such as students, authorities, and construction industry". In the above excerpt, we can see the expectation of College ESLG to engage in knowledge transfer that was clearly seen from expressions like ''unidirectional transfer of knowledge'' and ''transfer it further to other stakeholders''. For participants at the school level, as represented by College ESLG Lecturer 1 above, the way to engage in knowledge transfer and development of institutional capacity was through curriculum collaboration with Norwegian University of Science and Technology. From the above excerpt we can see the expectation of College ESLG to have the knowledge transfer through curriculum development collaboration, development of teaching methodology through joint teaching and development of research capacity.

Nevertheless, in the application for the SEEB project we see that the knowledge transfer was planned to take place bi-directionally because also three Kosovar professors were planned to teach at NTNU so students and professors of NTNU also gain some insight about the teaching methodologies that are practised in Kosovo.

Following the initiation stage, the universities moved to the implementation stage. Regarding the teaching methodology collaboration, professors of ESLG that were involved in the project reported positively that they learnt a lot with regards to transfer of knowledge in teaching methodology development.

> "The focus of Norwegian professors on practical methods "learning by doing" has facilitated my teaching process with students of ESLG later. I introduced the same teaching process that Norwegian professors used in the courses I teach" (Case 2).

In the development of teaching methodology through co-teaching and teaching collabolation, all respondents both professors and students think that the same effect would have not been achieved had the professors from Norway stayed only as quality assurers and not as co-teachers too.

C2 noted the diversity of teaching methodologies enriches the experience in the classroom, whereas C3 stated the following: "The methods of co-teaching are not a method of teaching in our country, and I think that this method should become a practice in all our higher education institutions in order to improve the quality of studies. The co-teaching brings more transferable knowledge".

From the category of cases $STUD_1$, C5 notes the following:

> "Through co-teaching a comparative analysis between the situation in Norway and Kosovo was drawn. In this way we were able to acquire more knowledge that now we will be able to transfer it further to other students in our capacity as teaching assistants"

Regarding transfer of knowledge through curriculum development, the answers can be exemplified by the following excerpt:

> "The curriculum development collaboration took place in a structured and unstructured way. The structured way was also foreseen by the application for SEEB project to develop together a master program in Energy Management. Due to requirements of Kosovo Accreditation Agency, the collaboration was focused on development of curriculum for the study program of Energy Management. Norwegian professors submitted us the course outlines and then we developed further the learning outcomes based on the needs of construction industry of Kosovo" (Case 1).

The knowledge transfer through curriculum development capacity is also foreseen in the original application for SEEB project, which states that one of main objectives is to develop the curriculum for the study program of Energy Management at master level (Application for SEEB project, pp5). Nevertheless, the transfer of knowledge in the curriculum development was not an import of everything from Norway. As C1 notes: "Not everything was copy pasted. We customised many of the course syllabi of the Energy Management program to the needs of Kosovo. In other courses of the Real Estate program we tried together to make comparative analysis between situation in Norway and Kosovo with regards to energy efficient buildings".

In this regard nearly all respondents, both professors and students agree that they benefited a lot from the collaboration between Norwegian and Kosovo professors in curriculum development and they appreciate the comparative analysis between Norway and Kosovo. Students responded that they benefited from teaching techniques of Norwegian professors, course syllabi, updated suggested literature, and exercises with different software. In this regard, professors noted that they benefited from joint curriculum development, definition of course objectives and learning outcomes, discussion on literature list for courses, organisation of joint conferences, production of case studies for the courses, and joint assessment of students' research papers and final examinations according to NTNU assessment methods and guidelines. The curriculum mapping process took place through exchange of documents and discussions between Norwegian and Kosovo professors. C2 notes: "We participated fruitfully in an exchange of emails and documents regarding curriculum of Energy Management study program". This is corroborated also by a documentary evidence of transcripts of minutes of the Steering Board of Project SEEB (Minutes of Steering Board of SEEB project, June 2014 – October 2014).

With regards to transfer of knowledge through exchange of students for one semester at NTNU, C5 to C7 all agreed that they benefited a lot in transfer of knowledge especially through practical work in the laboratories of NTNU through involvement of people from the practice in the lectures of NTNU and lectures from practice work at Multiconsult in Oslo. The transfer of knowledge through study visits can be exemplified with the following interview excerpt from case 5:

> "The study visits were a direct benefit for both students of ESLG and professors. The most important thing was to attend lectures in the company Multiconsult and hear people who are involved in direct practical projects. Also visiting the Zero Emission Building Power House in Oslo was a direct knowledge transfer. All the things we have learnt for one semester in

theory in sustainable architecture we learnt through a two hour study visit in that facility" (Case 5).

In terms of knowledge of transfer in research capacity development, the respondents do not think that the transfer happened successfully although it was one of main objectives of application for SEEB project (Application for SEEB project, pp4). All the cases from C1 to C3 stated that they did not have any opportunity to work together in research publications with Norwegian professors. C1 to C3 argue that the research capacity collaboration took place more in an ad-hoc way rather than in a structured manner.

With regard to knowledge transfer through joint conferences and symposia, respondents from the construction sector categorised with the code STAK agree that they learnt a lot from presentations of Norwegian professors. C88 noted the following: "I learnt a lot from the presentation regarding design of zero emission buildings and design of climate adapted buildings". Nevertheless, few of the cases were critical of the content of conferences because as they say they wanted to hear more about sustainable building materials and technologies rather than general concepts of refurbishment.

In the integration stage, the extent of knowledge was rather limited to the level of program of real estate. Regarding integration stage C1 noted the following: "We worked very well in other stages but we did not work together to produce documents that would serve as manuals or documents that we could use college wise. We were supposed to establish a Center of Energy Efficient Buildings, where all the acquired knowledge during the SEEB project would have been transferred to, but we failed to established the center properly due to lack of funding, although the application for SEEB project provided for the establishment of such a center within ESLG. We were able to develop and accredit a study program in Energy together but failed in the establishment of the center".

5. Discussions

The discussion of the present study centres on main findings. Firstly, the present study found the partners' main intentions in establishing the transnational institutional development program were clearly understood by each other. On the other hand, the study found that knowledge transfer occurred through curriculum development collaboration —a structured knowledge of transfer process which was mandated by the application for SEEB project. The study found that also the knowledge transfer occurred through joint teaching of Norwegian and Kosovo professors and although the original role of Norwegian professors as foreseen by the application for SEEB project was to serve as quality assurers, the deviation from the application in ensuring higher teaching collaboration between Norwegian and Kosovo professors turned out to be positive.

ESLG and NTNU had similar aspirations, as presented in the project application for SEEB, which upon project implementation resulted in solid knowledge transfer to Kosovo professors and students. In this regard Leing and Waters (2013) argue that contrasting aspirations between partnering universities in a joint project are the main cause for termination of the partnership and elimination of further knowledge transfer opportunities within the partnership. Mercer and Zhegin (2011) argue that universities must comprehend what each partner university seeks in the joint project or program in order for mutually beneficial activities to be developed and sustained. It is noted that this mutual comprehension took place between ESLG and NTNU and third partner Multiconsult.

On the other hand, although the research capacity development was foreseen to take place according to the application for the SEEB project and annual reports from the SEEB project, the study found that the research capacity development was not properly achieved. Contrary to this, the transnational programs can be seen as one of the main means for knowledge transfer from the foreign university but not the only means available (Gilbert and Gorlenko 1999). In the integration stage, the study found that there was no dissemination of knowledge transfer beyond the level of real estate program to the other units. Omerzel et al. (2011) argues that one way to ensure the retention, documentation, and accessibility of knowledge beyond individual lecturers' knowledge base, is the development of a knowledge management system. The study found that this did not happen as part of the project where all knowledge transfer would be documented.

6. Conclusions

The present research, with the focus on the knowledge transfer in the context of a transnational institutional development program SEEB from NTNU to College ESLG, shows a positive correlation between two institutions. From the findings, all four stages of knowledge transfer were covered: intention to engage in knowledge transfer, the structured process of knowledge transfer; the unstructured process of knowledge transfer and the institutional capacity development. The cooperation was as bi-directional knowledge transfer; however the present research focuses only on the uni-directional knowledge transfer from Norwegian University of Science and Technology to College ESLG. With the help from NTNU a new study program was developed, customised to the needs of Kosovo. Joint teaching of Norwegian and Kosovo professors in Kosovo and students study experiences in Norway was evaluated as a very positive case of knowledge transfer. Both professors and students enriched the College ESLG with their academic and research experiences.

To conclude, knowledge transfer occurred mainly through a structured process which was arranged in the application for project SEEB. Although one of the tasks to establish a Centre for Energy Buildings did not materialise due to the lack of funding, research activities were provided through different ways. The SEEB project has contributed to an institutional development and knowledge transfer for education and research in the field sustainable energy efficient buildings in Kosovo.

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Impact of Prior Distributions of Energy Model Inputs on Prediction of Building Energy Retrofits

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Abstract

In order to reduce the performance gap between the reality and energy prediction, Bayesian calibration of building simulation models have been highlighted since it can take into account the stochastic nature of building systems. However, for the use of Bayesian calibration, quantification of prior information on uncertain inputs is a prerequisite. In general, the prior information on the uncertain inputs are not well established in the literature. Therefore, uncertain inputs are usually determined by subjective judgment of simulation users.

However, the results of Bayesian calibration can be significantly influenced by the prior distributions of simulation inputs. In this paper, the authors aim to assess the impact of the prior distributions of simulation inputs on Bayesian calibration of a given energy model and decision making of building energy retrofits. The author performed Bayesian calibration using two different prior distributions (uniform and normal). Then, two different prior distributions were propagated. Based on the propagated simulation outputs, decision making of building energy retrofit scenarios was studied. It is concluded that the decision making of energy retrofits is significantly influenced by the prior distributions of inputs.

Keywords: Building Energy Simulation, Energy Retrofit, Calibration, Bayesian, Prior Distribution

1. Introduction

It is important to have an accurate energy simulation model since it predicts the effect of Energy Conservation Measures (ECMs) for existing buildings. In developing an energy simulation model for existing buildings, a calibration technique must be introduced because in existing buildings, many unknown inputs usually exist such as infiltration, internal heat generation from people, lights and equipment, indoor room air temperature, etc. Such inputs are usually not deterministic but stochastic.

The model calibration is a process of estimating uncertain inputs to reduce the gap between the actual building energy consumption (observed data) and the predicted value of the simulation model (model output) (Hensen et al, 2012). A number of studies have been conducted on the model calibration and parameter estimation. Recently, a Bayesian inference method has been highlighted since it can take into account the uncertainty of the building' thermal behavior. Tarlow et al (2009) introduced a Bayesian network to construct a simulation model and estimate a building energy consumption. Hawarah et al (2010) proposed a method to predict occupant behavior and energy consumption in residential dwellings based on Bayesian network. Carbonari et al (2014) used a Bayesian network to construct a system model and predict the future state of the system for supporting the model-based optimal control. Booth et al (2012) used a Bayesian calibration method for quantifying the uncertainty in housing stock models. Yan (2013) used Bayesian statistics to predict the energy consumption of a building and performed a diagnosis of the building control systems. However, Bayesian inference results are dependent on prior probability distributions of inputs. Heo et al (2015) found that a Bayesian calibration is influenced by a different information (data) level. Riddle et al (2014) discussed the limitations caused by the size (number) of observed data.

This study aims to investigate the impact of 'prior probability distributions of inputs' on the building energy model. In this study, the authors applied two different assumptions (uniform and normal) with regard to prior probability distributions of inputs. Then, the impact of such assumptions was analysed. Please note that the aim of this study is not to find accurate prior probability distributions of each input, but to identify the influence of such assumption on decision making of energy retrofits.

2. Bayesian Calibration

The calibration methods are divided into a deterministic and a stochastic method. The deterministic method uses an optimization algorithm to search for a set of unknown inputs which minimizes the difference between observed data and simulation prediction (Carroll et al, 1993; Park et al, 2004; Ascione et al, 2011; O'Neil et al, 2012; Dong et al, 2014). However, the deterministic approach tries to find a set of inputs that minimizes an objective function in the optimization process. Therefore, it cannot take into account the stochastic nature of inputs.

For the stochastic calibration, Bayesian inference has been widely used due to the recent improvement of computational speed and development of Bayesian inference techniques (Bishop, 2006). The Bayesian calibration quantifies uncertain inputs in the energy model as probability distribution as well as to propagate the effect (uncertainty) to the output of the simulation model. The Bayesian method requires information on prior probability distributions of uncertain inputs. However, since such information is not well established in the literature, prior probability distributions of uncertain inputs are assumed to be a normal distribution in most studies.

Bayes' theorem is as shown in Equation (1). The posterior distribution can be estimated as a product of the likelihood function and the prior probability distribution.

$$p(\theta|y) \propto p(\theta)p(y|\theta) \qquad (1)$$

where
θ : calibration inputs
y : observed data
$p(\theta)$: prior distribution of inputs
$p(\theta|y)$: posterior distribution of inputs
$p(y|\theta)$: likelihood function

Kennedy and O′Hagan (2001) reported a Bayesian calibration method (hereafter referred to as KOH method) as shown in Figure 1. The relationship between the observed data ($y(x)$), a true system response ($\zeta(x)$) and the simulation model prediction ($\eta(x,\theta)$) is expressed as shown in Equation (2).

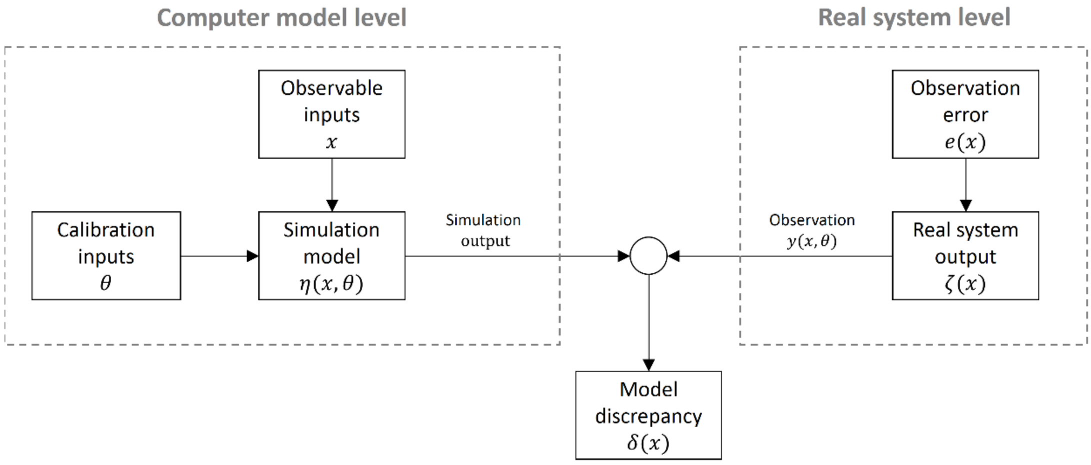


Figure 1. Bayesian Calibration Framework developed by Kennedy and O'Hagan (2001)

$$\begin{aligned} y(x) &= \zeta(x) + e(x) \\ &= \eta(x,\theta) + \delta(x) + e(x) \end{aligned} \quad (2)$$

where
x : observable or controllable inputs
$\zeta(x)$: true system response
$\eta(x,\theta)$: simulation model prediction
$y(x)$: observed data
$\delta(x)$: model discrepancy between $\zeta(x)$ and $\eta(x,\theta)$
$e(x)$: observation error

3. Target building

The target building (Figure 2) is an office building located in South Korea. The building's gross floor area is approximately 8,415m^2. The simulation model was generated using DesignBuilder.

Then, uncertainty analysis, sensitivity analysis and Bayesian calibration were performed using MATLAB script files, executing a batch run of EnergyPlus simulation.

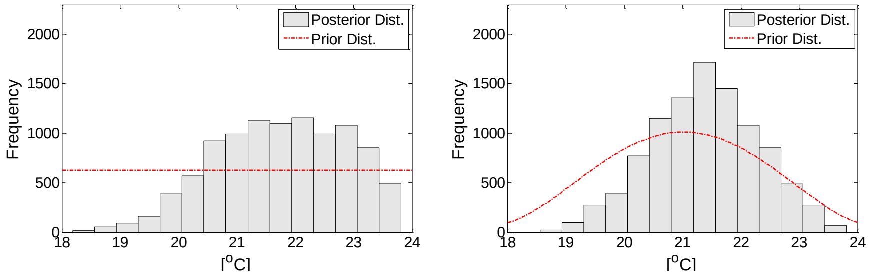
Figure 2: Target Building (left) and simulation model (right)

The values of inputs and their ranges (minimum value, maximum value) were first sought based on the literature (Macdonald, 2002; ASHRAE, 2013a; ASHRAE, 2013b; Hosni et al, 1999; Persily, 1998; CIBSE, 2006; ASHRAE, 2007; Guadalfajara et al, 2012; Garmsiri et al, 2014). In this study, the following inputs were treated as uncertain: thermal properties of the building's envelope (conductivity [W/mK], density [kg/m^3], specific heat [J/kgK] of opaque parts, U-value[W/m^{2}K], SHGC[-] of transparent glazing), occupant density [person/m^2], sensible and latent heat from people [W/person], lighting density [W/m^2], equipment density [W/m^2], operation hours [h], heating and cooling set point temperatures[°C], infiltration rate [m^3/s.m^2], ventilation rate [m^3/s person], fan efficiency[-], pump efficiency[-], heating and cooling system's efficiency[-], elevator electricity use [W].

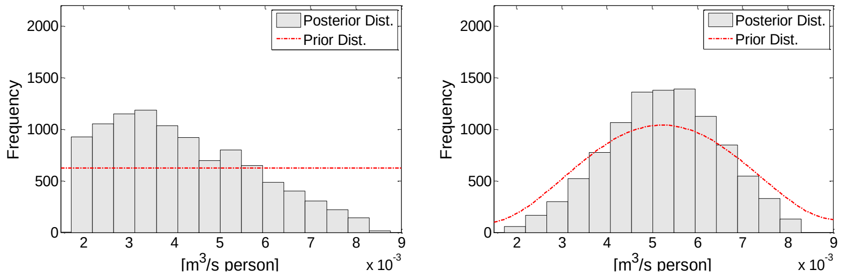
Morris method (Morris, 1991) were used to find dominant inputs. In Morris method, the influence of inputs on the output is determined using Elementary Effect (EE). The mean of EE for each parameter represents the influence on the simulation output. As the result of Morris method, top eight dominant inputs were selected as follows: heating set point temperature, infiltration rate, cooling set point temperature, occupant density, ventilation rate, equipment density, lighting density, absorption chiller's efficiency.

4. Comparison of posterior probability distribution

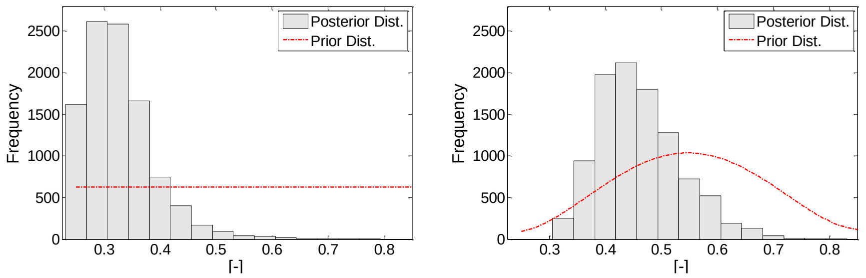
Bayesian calibration was carried out based on two different prior probability distributions of inputs (uniform, normal). The results of calibration (the posterior distributions of inputs) are shown in Figure 3.



(a) Probability distribution of heating set point temperature (left: uniform, right: normal)



(b) Probability distribution of ventilation rate (left: uniform, right: normal)



(c) Probability distribution of absorption chiller efficiency (left: uniform, right: normal)

Figure 3: Comparison of posterior distributions

As shown in Figure 3, the posterior distributions of inputs differ from each other. When the prior distributions of inputs were expressed as a uniform distribution, the estimated posterior distributions are not similar to uniform distribution but are inclined towards either the minimum or the maximum. On the other hand, when the prior distributions of inputs is assumed to be in a normal distribution, the posterior distributions are similar to a normal distribution.

5. Comparison of energy retrofits

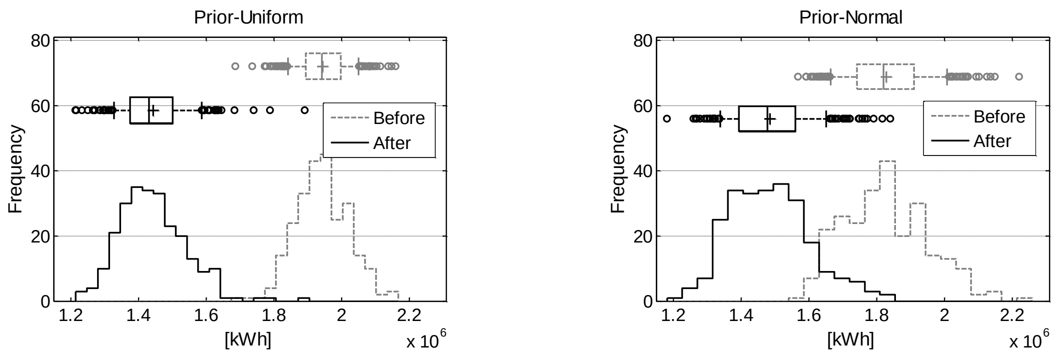
The ECMs of the target building are summarized in Table 1. The old windows are to be replaced with new windows. New windows were selected based on ASHRAE (2013b). The old absorption chillers are also to be replaced with new efficient ones.

Table 1: Energy retrofits

ECMs		before	After
replacement of windows	U-value	4.0 W/m^2K	1.12 W/m^2K
	SHGC	0.65	0.23
Replacement of Chillers	COP	Figure 3(c)	0.75

Figure 4 shows energy consumption distributions of design alternatives before and after retrofit. The expected energy consumption distributions are different from each other according to the prior distributions. When the prior distributions of simulation inputs are set to a normal distribution, the range of the uncertainty becomes greater (Figure 4(b)). It is noteworthy that there is an overlapped area between before and after the retrofits.

The determination of the range and distribution form is an unresolved issue in building energy simulation (Tian, 2013). The probability distribution of uncertain inputs need to be defined before performing stochastic analysis (e.g. uncertainty analysis, sensitivity analysis, stochastic calibration). However, prior information or knowledge with regard to uncertain inputs are not well established (de Finetti, 1974; Gao and Chen, 2005; Qiu et al, 2014). In previous studies (Booth 2012; Heo 212; Tian, 2013), the ranges or distributions of inputs were mainly dependent on the level of information and subjective judgment by experts. It can lead to inaccurate prediction of retrofit alternatives. The retrofit decision must be based on the objective and validated prior distribution. The prior distributions of uncertain inputs are usually determined by simulation users' subjective judgment and therefore, decision making of energy retrofits based on such outcome can be biased.



(a) Prior distribution – Uniform *(b) Prior distribution – Normal*

Figure 4: Energy consumption distributions before and after retrofit

6. Conclusion

The paper reports a Bayesian calibration study investigating the impact of assumptions on the prior distributions of uncertain inputs. It is concluded that if there is no enough information on uncertain inputs, the energy model prediction can be biased depending on the assumption of prior distributions of inputs. At present, if Bayesian calibration is to be applied to the simulation model of existing buildings, careful attention should be paid to the assumption of the prior distributions of inputs. As a future study, the data collected through the Building Energy Management System (BEMS) can be utilized in order to overcome the aforementioned disadvantage (lack of knowledge about uncertain inputs).

Acknowledgement

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A Framework for Measuring the Performance of Green Building

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Abstract

There is a diversity of factors responsible for inspiring green infrastructure action which can work either independently or in combination with one another; however, the South African built environment has been slow in adopting and implementing green principles in building construction projects. The lack of evidence with respect to green progress may suggest that indicators for assessing the performance of green buildings are not yet at the forefront of the construction industry agenda. This paper emphasises that green building benefits are real, and also shows the decision maker that even though there are risks factors involved when going green, there are critical factors and indicators as well, to ensure the successful implementation of green building. The purpose of this paper is to develop a framework aimed at promoting the growth of green building. The proposed framework is synthesised from a review of literature and current best practice. The framework suggests 31 performance indicators, the presence of which may assist construction industry stakeholders in pursuing the green agenda. The indicators can also be useful to monitor progress towards the economic, social and environmental goals of going green. This paper is part of on-going research, which aims to investigate the critical factors that inhibit the growth of green building in the South African built environment in order to accelerate the understanding and implementation of green infrastructure in the country.

Keywords: Criteria, green building, evaluation, performance indicators, sustainability

1. Introduction

As the field of green design evolves, various research studies (see Srinivas, 2009; Furr 2009; Naumann *et al.*, 2011) are focusing on measuring the actual benefits of these designs, thus the performance of buildings that are considered ‘green’. Numerous projects in the United States of America (USA), and other countries are attempting to define the qualitative and / or quantitative measures of green buildings, and the data needed to implement and assess these measures. These relentless efforts are important to determine whether the expected impact on human health and the environment has been achieved, and the related additional cost or saving (Todd & Fowler, 2010). Many types of tools are available to the construction industry, including sustainability assessment indicators, used for providing summaries and to focus and condense the complex surroundings into a form of manageable indicators (Suopajarvi, 2011). Building rating systems, also known as ‘building rating tools’ are one such type of sustainability assessment indicator. Green building cost and performance metrics (Todd & Fowler, 2010), the metrics include measurements for the cost and performance impact of water, energy, maintenance and operations, waste generation, purchasing, occupant health and productivity, and transportation. The metrics and protocol are being applied in the USA where green building designs are compared to similar buildings with more historically typical designs (Todd & Fowler, 2010). According to Gibberd (2011), the objectives of and criteria for green building designs should integrate environmental, social and economic performance requirements. In addition, the objectives and criteria should be aligned with good practice and government policy. However, studies demonstrates that historically green building performance indicators have been predominantly developed to assess some environmental issues and that, few of them could currently be considered to adequately assess the full range of sustainability issues (Lowe & Ponce, 2009; GBCSA-WGBC, 2013). On the socio-economic front, very little research has been undertaken to ascertain the linkages between green building practices and the socio-economic performance of green buildings, especially in the long term for purposes of sustainability evaluation (Kalua, 2015; Kamali & Hewage, 2015), and particularly in the context of developing countries. The reasons for this are in themselves, a potential area of further research but are likely to be, at least partially, due to the fact that environmental issues are typically easier to quantify and can therefore be assessed objectively. However, social-economic sub-issues are often difficult to assess either relying on subjective judgment, or complex calculations which do not sit well in assessment systems that aim to be objective and time / cost effective to use (Lowe & Ponce, 2009).

In the context of South Africa, the Green Building Council of South Africa (GBCSA) released its first assessment tool that improves or has the potential to improve environmental performance during the design and construction phase (GBCSA, 2014a). Furthermore, it should be noted that the GBCSA has also released its existing building performance tool for pilot application. The credits of the rating tool fall within three broad categories, and will consider measurable performance indicators such as water, energy and waste management, lease agreements, management contracts or procurement policies that define performance requirements, and building attributes that inform performance (DPW, 2013; Business Report, 2013). The rating tool will address demand from an entirely new segment of the property market in South Africa and allow effective and objective measurement of an existing building’s environmental performance in operation. However, specific design solutions with respect to how to achieve key performance indicators have not been prescribed (Business Report, 2013). Most recently, the GBCSA has also released Green Star SA Socio-Economic category indicators for piloting (GBCSA, 2014b). The Socio-Economic Category Framework has been established with key considerations and boundaries, such as building scale, stage of life, prioritisation, and objective assessment measures. The framework in terms of building scale addresses individual buildings only, excluding community, precinct or neighbourhood projects (GBCSA-WGBC, 2013). In terms of stage of life, the framework focuses on what can be

achieved mainly through the design and construction phases. However, the framework does not address the long-term operational phase of the building (GBCSA-WGBC, 2013).
These challenges reflect the need to develop an all-inclusive indicators that are based on accurate scientific data as well as indicators that are easy to understand for the public and decision-makers (Sustainable Cities International, 2012).

Against this backdrop, the aim of this paper is to develop a framework aimed at promoting the growth of green building by establishing the need to engage with the balance of environmental issues as well as economic and social imperatives. This is a review paper and it significantly draws from reviews of literature deemed to be relevant to the aforementioned aim. The study is grounded in the context of developing countries such as South Africa. In order to enhance the growth of green building, monitoring and evaluation of green building performance should be carried out. It will also be necessary to establish a baseline of building typology performance, formulate an appropriate set of national indicators, measure progress in building performance, measure compliance to annual targets, and to project a trajectory toward meeting national goals (DPW, 2011). Gibberd (2002) affirms that to facilitate the application of knowledge developed, as well as the monitoring and evaluation of green building assessment, indicators, rating and labelling systems specific to Africa is required. Although the CSIR has developed an assessment system (see Gibberd, 2002) suitable for use in Africa, it relies on the further development of indicators specific to the challenges experienced on the continent (Du Plessis, 2005).

2. Research methodology

The research methodology adopted for this paper was to conduct a critical review of the literature, which explored key performance indicators for green building mainly on the basis of academic literature. According to Fink (1998), "A literature review is a systematic, explicit, and reproducible design for identifying, evaluating, and interpreting the existing body of recorded documents." The analysis of documents pursues the aim of uncovering material that does not have to be created on the basis of data collection by the researcher. The objective for surveys of the literature are two fold; firstly, to summarise existing research by identifying patterns, themes, and issues. Secondly, this helps to identify the conceptual content of the field (Meredith, 1993) and can contribute to theory development. This study also follows a deductive approach. According to Goodwin (2002), a deductive approach takes the form of top-down reasoning from more general (by developing theory) to the more specific, whereas the inductive is the bottom-up logical process of reasoning from the specific to the general (theory). Mouton (2001) contends that the most common forms of deductive reasoning in science are the following:

- Deriving the hypothesis from theories and models, and
- Conceptual explications: when the meaning of a concept is clarified through the deductive derivation of its constructive meaning.

The Cape Peninsula University of Technology (CPUT) library databases 'Compendex Engineering Village' and 'EBSCOhost GreenFILE', were used to retrieve the appropriate journal and conference articles. Key words used were combinations of: 'Green building', 'measurement', 'sustainability', 'performance', 'indicator', 'criteria', and 'evaluation'. These articles were further refined by reviewing abstracts and conclusions as suggested by Kamali & Hewage (2015). The common Key Performance Indicators (KPIs) were prepared, modified, and combined to form the refined KPI set for each of the sustainability dimensions using the content analysis method. A broad definition of content analysis according to Holsti (1969) is "any technique for making inferences by objectively and systematically identifying specified characteristics of messages." All forms of documents, including electronic and printed, such as letters, books, survey reports, organisational papers, and advertisements, can be used as references.

2.1 Definitions and basic concepts

There are a number of key terms used in this paper and their definitions are as below.

Green building: is defined "as a construction project that is either certified under any recognised global green rating system or built to qualify for certification." (Bernstein & Mandyck, 2013: 5)

Performance evaluation: This refers to the process of assessing or evaluating the performance of the whole building or its component parts, according to a set of performance targets, criteria or requirements (Foliente & Tucker, 2007: 1).

Performance indicators: Performance indicators are a set of measures that reflect the environmental credentials or performance of a building. It should be noted that in research literature, a distinction is made between environmental or 'green' assessment and 'sustainable' assessment; the latter includes the indicators covered in the former and extends its scope to include social, economic, and other indicators (Foliente & Tucker, 2007: 1).

Performance criteria: This is an expression or statement of the level of performance an indicator is required to achieve. It includes two elements: (a) a performance indicator, and (b) an acceptable value or range of values and grades (e.g. 1 star to 5 stars). Performance criteria may be quantitative or qualitative, or mixed (Foliente &Tucker, 2007: 1).

Sustainability: The WCED, which is known as the Brundtland commission of 1987, defines sustainability as ''a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development, and institutional changes are made consistent with future as well as present needs.'' (WCED, 1987)

3. Rationale for key performance indicators

Performance indicators are quantifiable performance measures used to define success factors and measure progress toward the achievement of stated goals. The measures are typically referred to as Key Performance Indicators (KPIs) and used within a balanced scorecard as a method of consolidations (Feifer, 2011). KPIs are metrics (financial and non-financial) that are used by organisations and individuals to check compliance with stated requirements or to define and measure progress towards stated goals or objectives (Lowe & Ponce, 2009). Consequently, a KPI can be described as a "key part of a measurable objective which is made up of a direction, a target, a benchmark, and timeframe" (Jones & White, 2008). Foliente & Tucker (2007) contend that occasionally, an assessment should be undertaken to check if the KPIs meet the performance targets set beforehand. In other cases, an assessment is done to obtain a snapshot of performance to which current and future facility improvement works can be compared (Foliente & Tucker, 2007). Lowe & Ponce (2009) affirm that the rationale for performance measure seeks to establish position and to monitor progress because organisations want to communicate performance to shareholders or costumers in order to stimulate interest. To Foliente & Tucker (2007), the objective may be to benchmark a particular building's performance intended or in service to others of similar type and / or size. Actual in-service performance matters most because impacts and consequences or benefits are real, it serves to validate design or refurbishment intent, and it contributes to knowledge and could improve future practice (Foliente & Tucker, 2007). Usually, KPIs are embedded within performance measurement and benchmarking systems (Lowe & Ponce, 2009). According to Newman & Jennings (2008), indicators are important in holding governments and communities accountable to their sustainability targets and goals. In addition, indicators provide data to guide policy-making and allow for comparisons to be made across local authorities, municipalities and provinces.

4. Identification and classification of performance indicators for green building

When identifying and defining key performance indicators for buildings three different performance levels can be distinguished, these are environmental performance, social performance as well as economic performance (Kamali & Hewage, 2015; Gibberd, 2011; Todd & Fowler, 2010). Traditionally, most green building rating systems have understandably tended to focus exclusively on environmental impacts. However, internationally within the green building movement there appears to be an increasing interest in the inclusion of social and economic impacts as well, and a shift in this direction (GBCSA-WGBC, 2013). Some researchers have argued that green building performance indicators should address two criteria (see Gibberd, 2011; Feifer, 2011), for instance Gibberd suggested environmental and building Criteria. Other researchers (see Ugwua & Haupt, 2007; Sham & Ma, 2013; Kamali & Hewage, 2015) have expressed contrasting view that green building performance indicators should address three criteria since the concept of sustainability usually spans three factors: social, economic and environmental. In recent years, building owners and designers, researchers, and academics have begun performing studies related to the costs and benefits of green design. Some of these studies attempt to address the full impact of green building designs, while others emphasise the economic aspects, the environmental impacts, and the social aspects separately (Todd & Fowler, 2010)

4.1 Economic performance indicators

In the context of developing countries such as South Africa, economic performance of green buildings is aimed at employment creation and economic opportunity. Employment creation is to encourage and recognise developments, which create employment opportunities through design decisions, and construction practices that include facilities for micro-enterprises, targeted employment for priority groups, and labour-intensive construction methodologies. More so, economic opportunity is aimed at encouraging the growth and development of small, micro and medium sized enterprises (SMMEs) through interventions during the design, construction and operational phases of a building, including procurement of goods and services, and enterprise development support programmes (GBCSA, 2014b). Naumann *et al.* (2011) express similar sentiment that economic performance indicators are aimed at creation of permanent jobs in maintenance of green infrastructure, benefits for businesses including contractors, tourism and leisure businesses, land and natural resource, based enterprises, and the creative industries. Feifer (2011) contend that economical dimension contains four general indicators, covering the cost of a building up front and seen over years, maintenance and costs for operations, suitability for conversions, and number of refurbishment cycles. Other studies revealed that economic indicators encompass two aspects. For instance Sham & Ma (2013) research show that the two indicators cover asset value and building maintenance. On the other hand, the work of Andrade & Bragança (2011) classified these two aspects as cost and bureaucracy.

4.2 Environmental performance indicators

To Boyer, Creech & Paas (2008), the goal of environmental performance indicators is to contribute to conservation and sustainable management of resources. There are three general indicators within the environmental dimension, limited to the assessment of environmental impacts and aspects of a building on the local, regional and global environment. The quantifiable indicators are expressed mainly as a lifecycle assessment and with some additional quantifiable environmental information (Feifer, 2011). Environmental criteria should include; energy, water, indoor environmental quality, land, materials, and transport. Building criteria includes; greenhouse gas emissions, lighting power densities, potable water consumption, ventilation rates, electric lighting levels, individual comfort control, daylight, topsoil, recycling, and public transport (Gibberd, 2011; Sustainable Cities International, 2012).

4.3 Social performance indicators

Social performance indicators is the least studied and least understood aspect of building performance since the parameters to be included in this category have not clearly defined. It is often challenging to measure the actual effects of a given building on social, community, and health indicators according to Todd & Fowler (2010). Social performance indicator is to provide income or employment to community beneficiaries and contribute to community livelihood and well-being (Boyer *et al.*, 2008), as well as social benefits through education, skills, volunteering, and community engagement (Naumann *et al.*, 2011). The social dimension covers five indicators, mainly the impacts of a building related to its occupants, expressed by quantifiable indicators (Feifer, 2011). These factors were clustered into three key priority themes: employment and economic opportunity, education and skills development, health and safety, equality and community engagement, and benefit (GBCSA-WGBC, 2013). For instance, education and training in new skills for green buildings can help to sustain existing economic activities more efficiently and effectively as well as diversify the economic base of communities (Boyer *et al.*, 2008). Because green building presents an opportunity to address some of the issues and problems that affect construction workers, such as the promotion for social dialogue in decision-making, providing equal access to opportunities and retraining of workers [International Labour Organisation (ILO, 2011)]. Improvements in community health and wellbeing that result from increased income, new skills and stronger community organisation can be signalled by more children attending school and improved access to health care.

Observing and documenting such changes for annual reflection will help triple bottom line enterprises ensure that the downstream social benefits are in fact being realised by their target beneficiaries (Boyer *et al.*, 2008).

However, in the South African context, the performance indicators are categorised into two main groups. The first one is the environmental aspect and the second is the amalgamation of the social and economic aspect to form socio-economic category. The key performance indicators are summarised in table 1

Table 1: A summary of the key performance indicators

Category	***Criteria***	***Performance Indicators***	**Key Reference**
Environmental	*Energy*	• *Lighting power densities*	*Gibberd (2011)* *GBCSA (2014a)* *Sham & Ma (2013)*
	Water	• *Potable water consumption*	
	Indoor environmental quality	• *Ventilation rates* • *Electric lighting levels* • *Individual comfort control* • *Daylight*	
	Land	• *Topsoil*	
	Materials	• *Recycling*	
	Transport	• *Public transport*	
	Emissions	• *Greenhouse gas (GHG)*	
Socio - Economic	*Employment creation*	• *Targeted employment during construction* • *Facility provided for micro-enterprise*	*GBCSA (2014b)* *Boyer et al. (2008)* *GBCSA-WGBC (2013)* *Naumann et al. (2011)*
	Economic opportunity	• *Small and medium sized business development support.* • *Procurement*	
	Skills development and training	• *Cost of skills development and training as a proportion of total employment* • *Compliance with CIDB standard for developing skills*	
	Community development	• *Inclusion of a community/ public benefit facility*	
	Empowerment	• *Implementing the principles of Broad-Based Black Economic Empowerment (BBBEE).*	
	Safety and health	• *Safety and health for workers* • *Impact on local community* • *Security of infrastructures* • *Safety and durability* • *Usability* • *Thermal quality* • *Acoustic quality* • *Indoor air quality* • *Lighting conditions* • *Ventilation conditions* • *Materials toxicity*	

	Mixed-income housing	• *Facilitating mixed-income housing* • *Staff accommodation*

5. Strategies to selecting and improving key performance indicators

A systematic selection and monitoring of performance indicators as well as evaluation of projects and policies based on a common methodology would be necessary to continuously improve the development of performance indicators in the South African built environment. The approach to selecting indicators generally falls into two general categories, top-down or bottom-up. The top-down approach means policy makers define the goals and accompanying indicators, the data collected is usually highly technical and requires experts to interpret (Sustainable Cities International, 2012). Therefore, Buys & Hurbissoon (2011) contend that tertiary institutions or other service providers should provide green building training opportunities for all built-environment stakeholders to take up the challenge in transforming the green building sector. The bottom-up approach is community-based and involves extensive consultation with stakeholders to select appropriate indicators. The key difference in the two approaches is complexity. Top-down processes involve more tools that allow for greater depth of analysis, while bottom-up processes are more basic and broad. It is possible to combine the approaches to create a hybrid approach; however this depends on the context. These two approaches reflect the need to develop indicators that are based on accurate scientific data as well as indicators that are easy to understand for the public and decision-makers. A solution to this problem that has been put forward is to select a set of 'core' indicators, which span the breadth of a community's sustainability goals. These core indicators should be easily understood and demonstrate the linkages between multiple sustainability goals (Sustainable Cities International, 2012). Thus adequate understanding and knowledge of KPIs is a desirable first step towards achieving the educational goals. It is also one of the main underpinnings for successful institutional transformations, and efficient decision making in design, specification and construction, at various project-level interfaces, using appropriate decision-support tools (Ugwua & Haupt, 2007).

The effectiveness of green performance guarantees in practice should be assessed, including the existing tools and technical monitoring systems (for water, energy and waste) that are applied (UNEP-SBCI, 2014). Through performance guarantees, developers / owners can address the risk of not achieving a stated indicator of green performance, such as a level of certification according to a green building rating tool or a specified energy performance with associated financial benefits. The most common performance guarantee addressing green or resource efficiency includes water and Energy Performance Guarantee (EPG) (UNEP-SBCI, 2014). However, in South Africa, the development and implementation of Energy Performance Certificates (EPCs) is at its infancy stage as a draft standard of the EPCs has been developed by a working group under the auspices of DPW and DoE (DPW, 2013). More so, Water Performance Certificates (WPCs) are not available in South Africa, but the Green Building Council of South Africa (GBCSA) has introduced a Water and Energy Benchmarking Tool which provides a basis for comparing a building's water usage to measured benchmarks. The Water and Energy Benchmarking Tool is however limited to office type buildings (DPW, 2013). Therefore the continued advancement of mandatory performance indicators for new buildings would serve as powerful incentives for change in the green building sector (Globe Advisors, 2012).

6. Conclusions

Significant research gaps still exist in terms of key performance indicators for green building in developing countries. The situation in developing countries such as South Africa clearly requires further implementation of policy measures as well as further research as many developing countries have not yet introduced or are just about to introduce policy instruments to enhance the development of key performance indicators for green buildings. The outlined literature indicates growing interest in research with respect to a three dimensional performance indicators for green building in both developed and developing countries. However, the socio - economic dimension is often difficult to assess either relying on subjective judgment or complex calculations which do not sit well in assessment systems that aim to be objective and time / cost effective to use. These challenges reflect the need to develop an all-inclusive indicators that are based on accurate scientific data as well as indicators that are easy to understand for the public and decision-makers. It should be noted that this paper is part of an on-going comprehensive research project currently being conducted by the authors regarding the critical factors that inhibit the growth of green building in the South African built environment in order to accelerate the understanding and implementation of green infrastructure in the country. Only very few evaluation studies are currently available and even fewer include quantitative data on effectiveness of green building performance indicators in South Africa. Therefore, the long-term objective of the research agenda is to conduct an empirical study to identify:

- How the public, decision makers and practitioners perceive the level of importance and the degree of utilisation of key performance indicators as related to green building?
- What progress has been made in implementing / enforcing these indicators in South Africa?
- What are the most significant challenges associated with the implementation of the indicators?
- The development of a method for identifying the impacts of socio - economic indicators on a green building construction and assessment.
- The need to be able to determine the level of performance and how it compares to a more typical building in the same climate, with the same occupancies.

- Measures on how the indicators can further be developed and how this can be introduced into the economy to improve sustainability in residential building.
- A framework for post occupancy evaluation for green buildings according to a set of performance targets, criteria or requirements.

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Environmental Life Cycle Assessment (LCA) of Road Pavements: Comparing the Quality and Point of Application of Existing Software Tools on the basis of a Norwegian Case Study

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Abstract

Various software tools have been developed to evaluate the life cycle performances of roads to provide decision supports for road authorities and contractors. It is therefore important to compare the strengths and limitations of these software tools to understand the appropriate application and to identify the points for optimization. This study evaluated EFFEKT 6.6, EKA, and LICCER software tools, by applying the environmental life cycle assessment following the ISO 14040 standard. The assessment was based on an open-air road (excluding tunnels and bridges) with a functional unit of one kilometer and greenhouse gas emissions as well as embodied energy indicators were evaluated in the considered software tools. The open-air road was modeled for each software tool with respects to road class H9 characteristic in Norway, classed as a national road. The assessment showed that the system boundary and purpose of use differed between the considered software tools. This resulted in performing the assessment only over A1 – 4 and B6 modules according to EN 15978 standard for the hypothetical open-air road to provide a comparable boundary condition. The results demonstrated that EFFEKT overall yielded higher values for greenhouse gas emissions and embodied energy compared to the two other software tools, while, the three software tools quantified nearly the same amount of asphalt use within the 20-year analysis period.

Key words: LCA, asphalt, GHG emissions, embodied energy, road

1. Introduction

Roads as part of the transport infrastructure contribute to job creation and growth of GDP. However, roads are also corresponding to natural resource use, land usage, emission and waste creation. And, every year new roads are built, maintained and rehabilitated due to an increased demand for new roads and deterioration of existing roads. This growth in demand and increase in cumbersome issues (like availability of resources, environmental awareness etc.) puts decision-makers in a challenging position to address and comply with the various challenges.

Environmental life cycle assessment (LCA) is a well-established and standardized method and has been widely used due to the increased awareness in importance of environmental stewardship (ISO, 2006). LCA is a method that evaluates potential environmental impacts for a product or service over its full life cycle (ISO, 2006). And so far, different LCA studies have been conducted in the area of road infrastructure in order to better understand the environmental impacts associated with roads and road products such as ECORCE2, DuboCalc, PaLATE, SEVE, etc. (Zukowska E. A. et al., 2014). In spite of availability of different road LCA software tools (Hammervold, 2014), different areas of coverage could be found in the domain of software that might be due to various system boundaries and intended applications. This leads to the fact that some LCA software tools may show unexpected results.

The present work is aiming to evaluate three currently used software tools based on a hypothetical Norwegian road, especially regarding the results achieved in terms of embodied energy and greenhouse gas emissions. The considered software tools are EFFEKT 6.6[1], EKA[2] and LICCER[3]. The hypothetical road is chosen from manual 017 "Road and street design" (NPRA, 2013b) and categorized as road class H9 with a total distance of one kilometer with annual daily traffic above 15 000 vehicles.

2. Methodology

Environmental Life cycle assessment (LCA) is a well stablished method and has been widely used due to the increased awareness of importance of environmental stewardship (ISO, 2006). LCA is a methodology that analyzes and evaluates the environmental impacts associated with a product system, service or activity in a systematic way through its entire life cycle (Baumann and Tillman, 2004, Lindfors et al., 1995, ISO, 2006). The entire life cycle or "cradle-to-grave" refers to the whole value-chain of a product that can be simply comprised of extraction, manufacturing, transportation, use, and disposal activities. These stages are explicitly illustrated by EN 15978 standard in figure 1.

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[1] http://www.vegvesen.no/
[2] http://www.trafikverket.se/
[3] http://www.eranetroad.org/

LCA is often performed to compare different product systems with a same functional unit, to find critical stages and/or processes (hot spots), or to document environmental performances as internal reports (Robèrt K. H. et al., 2002, Baumann and Tillman, 2004).

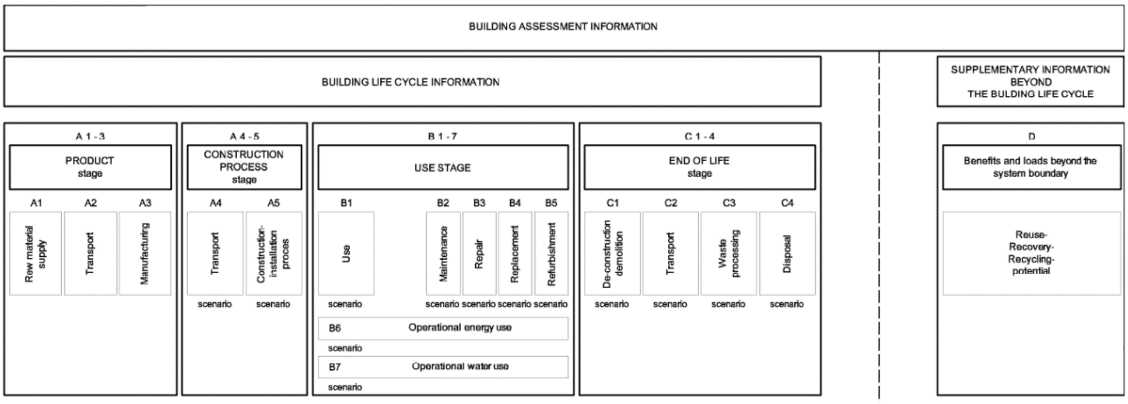


Figure 1: Modular information for building life cycles (CEN, 2011).

Based on a description that has been provided by International Organization for Standardization (ISO) within ISO 14040:2006 standard (ISO, 2006), a LCA is comprised of four main stages: goal and scope, inventory analysis, life cycle impact assessment, and interpretation (see figure 2) (ISO, 2006).

- Goal and scope describes what the target, purpose, and relevant choices are.
- Inventory analysis identifies input/output material, energy, and corresponding emissions.
- Life cycle impact assessment measures the potential impacts from the developed inventory in a qualitative way.
- Interpretation explains the results in each stage to increase the transparency and to help make more informed decisions.

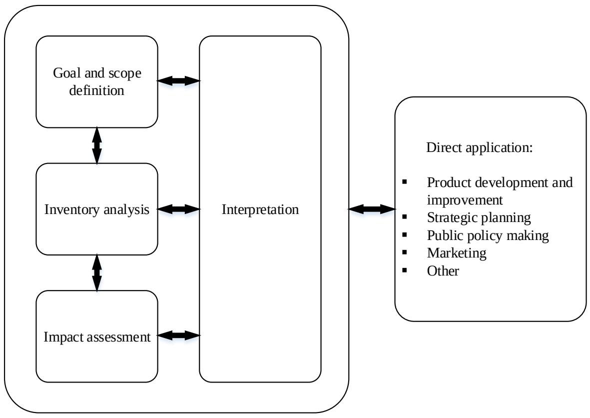


Figure 2: Four stages of an LCA (ISO, 2006)

3. LCA tool

The three software tools, which are in the scope of assessment of this paper, are EFFEKT6.6, LICCER and EKA. Here, a brief description for each software tool is provided to represent the focus area of the LCA tools.

3.1 EFFEKT 6.6

EFFEKT is a software program that is developed by the Norwegian Public Road Administration (NPRA) (Hammervold, 2014). It is a tool that assesses cost-benefit and socio-economic analyses of road infrastructures. EFFEKT is particularly developed for and regularly used during early stages of road infrastructure planning (Miliutenko S. et al., 2014a), aiming at roughly estimating the consumption of inputs, cumulative energy use and GHG emissions in a context when little data for a new road project are actually available. EFFEKT is carried out to assess the impacts from alternative routes of a road projects compared with a reference scenario (baseline) that helps for selection of solutions or prioritization of route alternatives within a road project (NPRA, 2007, Martinsen J. A., 2008). EFFEKT includes *production*, *construction* and some modules of *use* life cycle stages as shown in figure 1, but it excludes *end-of-life* and *potential benefits and loads* life cycle stages from its assessment (Liljenström, 2013). The main focus of the calculations is on impacts from major material production activities and selected construction activities.

3.2 EKA

EKA was developed by the Swedish Transport Administration to calculate inputs, cumulative energy and GHG emissions of different road maintenance activities for various asphalt types (Martinsson, 2014). The tool covers the entire asphalt production value chain (from input materials to the finished products) based on Swedish production techniques. This means EKA incorporates submodules A1 – 4, and also, it covers some parts of *use, end-of-life* and *potential benefits and loads* life cycle stages in its assessment. The final asphalt products in EKA tool are: hot mix asphalt, warm mix asphalt, half-warm mix asphalt, remixing (recycled asphalt), tank coating (surface treatment), and thin-layer coating (Martinsson, 2014).

3.3 LICCER

LICCER was a research project funded by ERA-NET with the aim at developing “an easy to use model based on existing tools and methodologies for Life Cycle Assessment of road infrastructure” (Brattebø H. et al., 2013). LICCER was to a certain extent motivated by EFFEKT and it evaluates inputs, GHG-emissions (in ton CO_2-eq/year) and cumulative energy demand (energy use in GJ/year) in early planning of road infrastructure (open-air roads, bridges, and tunnels), as well as road furniture (O'Born R. et al., 2013, Brattebø H. et al., 2013, Liljenström, 2013, Miliutenko S. et al., 2014b, O'Born R. et al., 2015). LICCER includes *production*, *construction* and some modules of *use* as well as *end-of-life* stages, but it excludes *potential benefits and loads* life cycle stage from its assessment.

4. Case study

Manual 017 (NPRA, 2013b) entitled “Road and Street Design” was a guideline used in this study. The manual developed by the Norwegian public road administration (NPRA) provides technical requirements for the design of roads and streets and it does not discusses non-traffic related conditions (like landscape condition, geology, etc.) (NPRA, 2013b).

Based on the manual 017 (NPRA, 2013b), there are various road classes for construction of national main roads. Here, road class H9 is selected for the assessment, which is classed as the national main road. The road class H9 has a motorway standard with the speed limits of 100 km/h. The road must be built as a 4-lane road with driving lane and hard-shoulder of 3.5 and 3 meters wide, respectively, and it consists of a 23 meter wide roadway in total (NPRA, 2013b). Figure 3 illustrates the schematic view of the road cross-section.

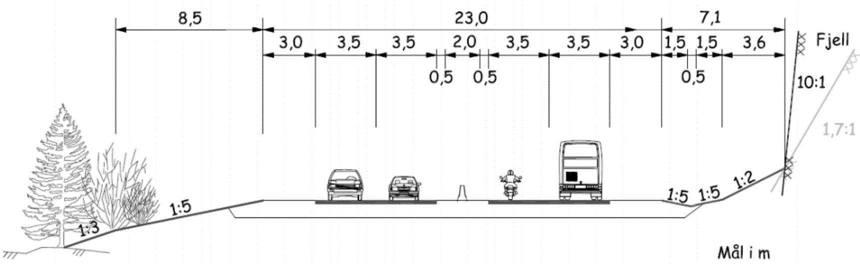
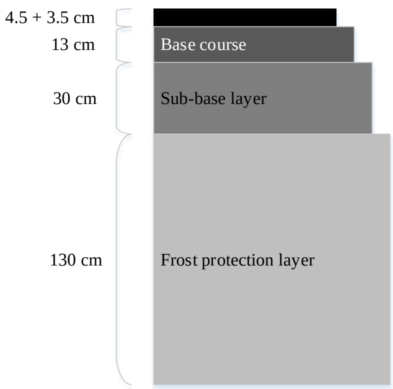


Figure 3: The cross section of national main road H9 (NPRA, 2013a)

Due to the fact that there was no reference model for a typical pavement structure corresponding to design class H9, it was necessary to design a hypothetical road first in order to assess the environmental impacts from the road in a next step. To do so, empirical pavement design is selected based on chapter 51 in the manual N200 (NPRA, 2014). By means of manual N200, it is possible to design an empirical road pavement with some prerequisite input data such as subgrade condition, traffic load, road construction materials, climate condition and standard structure.

Table 1: The structure of designed pavement for road class H9

Layer	*Material type / thickness*
Wearing course	*4.5 cm asphalt concrete*
Binder course	*3.5 cm asphalt concrete*
Base course	*13 cm asphalted gravel*
Sub-base	*30 cm crushed rock*
Frost protection	*130 cm crushed rock*
Total thickness	*181 cm*



In the designing stage of a hypothetical road pavement, it is assumed that the road is located in Malvik municipality. The ADT in the opening year is assumed to be 15 000 vehicles[4] (with 12% share of heavy vehicles) and it is assumed that annual heavy vehicles traffic growth is 1.4%. The frost amount F100 is 18 000 h°C (it is assumed that the maximum correction factor is 1.3; annual mean temperature is 5.4°C and average frost amount F_{100} is 18 000 h°C) and road subgrade

[4] Annual daily traffic (ADT) above 20 000 vehicles is suggested for the road class H9 (according to manual 017); however from a hypothetical viewpoint in this paper, it is assumed the road provides service to ADT above 15 000 vehicles in its initial operation year.

consists of clay with Cu T4. Table 1 presents a theoretical pavement layers that designed for the hypothetical road.

5. Results

Although the introduced software tools have intentions to quantify GHG emissions and embodied energy associated with road projects, they slightly differ where they draw their system boundaries. EFFEKT 6.6 on the one hand covers production, construction and (some modules of) use stages (B1, B2 and B6) in its system boundary. And, LICCER covers more life cycle stages compare to EFFEKT 6.6 by including production (A1 – 3), construction (A4 – 5), use (B1, B2 and B6) and end-of-life (C1 – 3) phases. EKA on the other hand has a more limited coverage. EKA does not consider construction phase of a new road (stage A5) like earthworks, drainage system, unbound layers etc. in its assessments. Instead, it only evaluates embodied energy and GHG emissions associated with bound layer products within maintenance activities.

With respect to the described dissimilarities between the LCA software tools, it became clear that performing a full lifecycle “cradle-to-grave” was not applicable due to limitation in the system boundary of the EKA tool and not full lifecycle coverage by EFFEK 6.6 (as it is explained in EN 15978 standard (CEN, 2011)). Thus, in order to run a fare comparison between these three software tools, it has been decided to evaluate them based on the *stages* and the *modules* that they have in common. By doing so, it could be said that the maintenance module from the *use* stage (B2) as well as A1 – 4 modules are mutually covered by these three software tools (see figure 4).

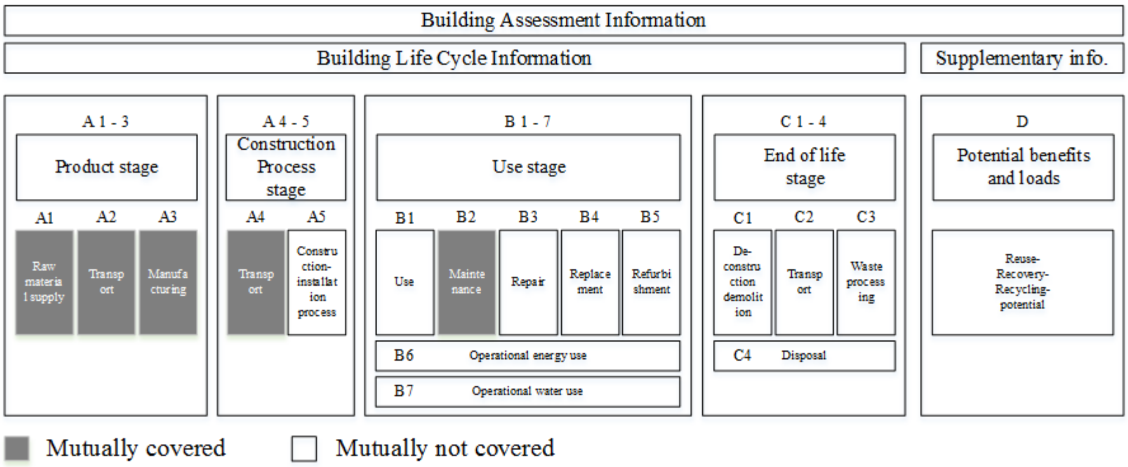


Figure 4: Life cycle stages and modules shared mutually between the three software tools.

EFFEKT 6.6 in general does not require any calculations regarding the amount of material inputs for the maintenance of a road. Instead, it only demands information on the length, number of lanes, layer thicknesses, widths, traffic volume etc. that were all described in the case study of this paper (see chapter 4). LICCER in this regard inquires inputs similar to the EFFEKT tool, but as an alternative the user can insert project-specification data in LICCER if such data are available. Nonetheless, the condition is different for EKA. EKA needs more detailed data (like, production rate, tons and corresponding thickness of materials etc.) to calculate the GHG emissions and embodied energy. Therefore, in order to quantify the masses of input data for each maintenance activity, the following equation is conducted to quantify tonnage of asphalt pavement.

$$AS[ton] = (\mathrm{T} \times \mathrm{L} \times \mathrm{B} \times 2.5) \quad (1)$$

In formula (1), AS is the total tonnage of asphalt wearing course; T is the thickness of wearing course; L is the length of road; B is the width of road; and 2.5 (ton/m^3) is material density of asphalt.

Formula (1) is the same equation that is introduced by EFFEKT 6.6 in its manual (Straume A. and Bertelsen D., 2015) to calculate the amount of an asphalt wearing course. LICCER also proposes almost a similar formula, the only difference is the asphalt density. LICCER considers a density of 2.24 ton/m^3 as a default for asphalt product, instead of 2.5 ton/m^3 in EFFEKT[5]. Whereas both tools assume that a typical hot mix asphalt (corresponding to 96% of production of asphalt product in Norway) consists of 94% aggregates and 6% bitumen.

As many roads are designed based on certain standards to fulfil the pavement serviceability, various influential parameters influence the maintenance intervals (like traffic volume, climatic zone, subgrade strength, frost depth etc.) over years (Garbarino E. et al., 2014). In this paper, maintenance intervals are taken from report no. 358 (Straume A. and Bertelsen D., 2015) that suggests pavement lifetimes with respect to different traffic volume. It is also assumed in each maintenance activity, 0.04 meter of road is milled and replaced by new asphalt wearing course.

By inserting all the input values to the three LCA software tools, the following results can be observed (table 2):

Table 2: Results of the Norwegian hypothetical national road within a 20-year analysis period with three LCA tools.

	EFFEKT 6.6	*EKA*	*LICCER*
Greenhouse gas emissions (ton CO_2.eq)	*487*	*344*	*296*
Embodied energy (GJ)	*28 108*	*5 786*	*27 400*
Amount of re-asphalting (ton)	*8 330*	*8 400*	*7 526*

6. Discussion

With respect to table 2, it became clear that the application of three different LCA tools to compare the hypothetical Norwegian national road (over a considered period of 20 years), led to different absolute and sometimes conflicting results. EFFEKT 6.6 showed higher GHG emissions compared to EKA and LICCER. However, by comparing embodied energy and asphalt, LICCER

[5] As a simple solution to calculate asphalt consumption, it is proposed by NPRA that 1 cm of asphalt has approximately 25 weight per square meter (kg/m^2) (NPRA, 2005).

and EFFEKT 6.6 showed a close similarity in their results. Also, EKA and EFFEKT showed the amount of consumed asphalt with only small differences (less than 1%). Due to the differences in absolute numbers gained by the application of the three LCA tools, the main drivers need to be identified

A more in detail analysis reveals that the level of details in data compilation and assessment were not the same in the software tools. EFFEKT showed its results in an integrated approach to indicate GHG emissions and energy as well as materials consumption (might be due to this fact that EFFEKT is intended to have a more informative way to communicate its results). Such a limitation in EFFEKT is because of high level of aggregation that makes it hard to see what the attribution of different attributors are for each material. For instance, a typical asphalt pavement consists of different input materials (like aggregates, bitumen and other additives) that have different transportation patterns and corresponding embodied energy, which in EFFEKT all attributors are aggregated and shown as one representative attribute. Nevertheless, LICCER and EKA showed an advantage over EFFEKT 6.6 due to giving a possibility to their users to go through different spreadsheets in their software tools in favour of finding the reference assumptions.

Concerning the illustrated disparity in the magnitude of the results (table 2), a possibility to do calculations manually would be seen as a large benefit. Equation 1 represents how the tonnage of asphalt wearing course can be quantified for all the three software tools. By replacing variables with their representative values, the tonnage of asphalt pavement during each maintenance activity can be quantified. The results from the calculation showed that LICCER and EKA quantify 1881 and 2100 tons of asphalt pavement are consumed in each maintenance cycle, respectively. The results demonstrate (if the maintenance activities are happening 4 times in the period of 20 years) that the numbers are aligned with the results shown from LICCER and EKA in table 2.

However, the calculation of consumed asphalt for EFFEKT was not straight forward because it is based on cost principles in its analysis. This means EFFEKT considers a yearly cost for every year in the analysis period due to expected future maintenance activities, which might be based on expert opinions. In the road example taken in this paper, EFFEKT calculated two different maintenance cycles through the analysis period of 20 years. It considered one-sixth of maintenance in the first maintenance cycle[6] that would be attributed to the first year after construction of the road. However, in the remaining years (from the 2nd year till the 20th year), EFFEKT considered the maintenance activity would happen every other fifth year over the following 19 years (Kroksæter A., 2015).

$$Year\ 1: ((0.04 \times 1000 \times 21 \times 2.5))/6$$

$$Year\ 2\ -\ 20: ((0.04 \times 1000 \times 21 \times 2.5))/5 \times 19$$

[6] This mean that the first maintenance cycle is taking place after six years.

In the above formulas, 0.04 is the thickness of wearing course; 1000 is the length of road; 21 is the width of road; 2.5 (ton/m^3) is material density of asphalt; 5 and 6 are maintenance cycles after five years and six years, respectively; and 19 is the number of years between year 2 and year 20.

One reason that LICCER shows a lower value in GHG emissions is because of the lower asphalt concrete density that is assumed in the section of material specification. In EKA and EFFEKT, the density of asphalt concrete is assumed to be 2.5 ton/m^3; however, LICCER considers asphalt density of 2.24 ton/m^3 as its default value. By only adding 0.26 to the presumed asphalt concrete density in LICCER tool, i.e. assuming the asphalt concrete is 2.5 ton/ m^3, the amount of bitumen consumption in each maintenance activity increases from 112.9 tons to 126 ton. This alteration in the amount of bitumen usage can correspond to additional 5.63 ton CO_2.eq. In addition, LICCER considers 5.99 kg CO_2.eq/ton corresponding to asphalt mixing plant in its assessment, which has the lower ratio compare to the other software tools. EKA considers approx. 21 kg CO_2.eq/ton for asphalt mixing plant, while, EFFEKT only shows one aggregated number (58.5 kg CO_2.eq/ton) for 'asphalt' that consists of GHG emissions from material extraction to placement on the road.

EKA showed a disproportional embodied energy compared to the two other software tools within the analysis period of 20 years. One of the rationales for such a deviation in the result is due to differences between values of bitumen embodied energy. EKA considers energy value of 720 kWh/ton (2.59 GJ/ton) for bitumen, but LICCER considers 52 GJ/ton (almost 20 times greater). This inconsistency in the result for the embodied energy of bitumen might be due to dissimilarity in the boundary of bitumen values chain. If we compare the results more in depth, it can be said that bitumen corresponded to approx. 85% of energy consumption in LICCER, but bitumen only had approx. 20% of contribution in EKA embodied energy. Furthermore, the results were compared with ecoinvent version 3.01 'Pitch' production process[7] (ecoinvent Center, 2013). The process by means of CML V4.01 impact assessment method showed the embodied energy is approx. 51 GJ/ton for bitumen production at the refinery. Given results and comparison with ecoinvent value show that the calculation done by LICCER is aligned with ecoinvent assessment. However, one should be consider is that the result in addition to data input consists in methodology of choice because the result may differ if another methodology is chosen. It is hence very important to carefully control for this dissimilarity via a systematic approach (as it is explained in the European Standard 15804:2012+A1 (CEN, 2013)) to reduce any miscalculation and successive misperception of results.

It became obvious that the three LCA tools have a focus only on greenhouse gas emissions and resource consumption, which raises the question why other environmental metrics (impact categories) are not considered. In fact, having a shorter list of impact categories makes the interpretation of LCA results easier for decision-makers, as it is all about comparing different product systems with a same functional unit. However, taking decisions on only a few LCA indicators carries multiple risks. In addition, it was not clear (except for EKA[8]), how the greenhouse gas emissions have been calculated in terms of considered greenhouse gases and

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[7] Pitch (Europe without Switzerland) | petroleum refinery operation | Alloc Def, U.
[8] EKA includes solitary three climate gases in its greenhouse gas emissions that are: CO_2, CH_4 and N_2O.

impact factors. Due to this fact that Kyoto Protocol only covers six greenhouse gases in its first commitment period, which results in excluding short lived climate gases (e.g. black carbon) from its target. In fact, these short lived climate gases cause approx. 60% of overall global forcing (Rhodes S. P. and Schultz T., 2014). Hence, this is essential to be aware of climate gases that are not included in the assessment of GHG emissions, as they may have significant influence in the overall results.

Although this study by means of the three LCA software tools showed a range of results, it was essential to compare the results (from this study) with an Environmental Product Declaration (EPD) report (Nielssen C. S. and A., 2011) to evaluate the magnitude of similarities. The report showed that production and placement of asphalted gravel concrete (Agb 11) contributes to 56 kg CO_2.eq and 1141 MJ per ton of asphalt pavement. By scaling up the result of the EPD based on the assumptions given earlier in this paper, the greenhouse gas emissions from the asphalt manufacturing in the 20-year period sums up to approximately 470 tons of CO_2.eq, which shows roughly similar to what has been shown by EFFEKT 6.6 tool. However, the result of embodied energy shows 9584 GJ during the same time period, which is not aligned with the results of the three software tools in this study. The reasoning of having similarity or dissimilar results for the embodied energy and the GHG emissions has not been possible to be farther assessed. Due to the fact that the EPD report used another way of demonstrating the results, which made it impossible to compare the values with the other software tools.

7. Conclusions

To conclude, it can be stated that LCA needs a critical review in order to diagnosis any possible hidden errors in life cycle inventory and LCA results. Given the fact that a small error can accumulate through the life cycle assessment and consequence a substantial error in the overall results. This study was performed with the intention to evaluate three LCA software tools (EFFEKT 6.6, LICCER and EKA) to magnify the area of their coverage, strength and limitation of each software tool.

This paper assessed the software tools by comparing the results for a hypothetical road. The assessment covered resource consumption and greenhouse gas emissions as its proxy and considered road class H9 as it is hypothetical road. Although the supporting tools were intending to assess environmental performance of road projects, they had dissimilarities in their system boundary conditions. Therefore, the system boundaries for assessment were narrowed down to the maintenance phase within a 20-year analysis period.

In spite of the fact that the assessed tools addressed GHG emissions and embodied energy, there was no consistency in the results. These variations in the magnitude of results may lead to decisions on false grounds when it comes to making a comparison between different road options for decision makers. Therefore, having a transparent scope in LCA and explicit documentation make it possible for readers and future decision-makers to have a better insight into and therefore make more informed decisions based on LCA analysis. In addition, limitations and recommendations are additional pieces of information that need to be delivered at the end of LCA works to declare and highlight the accuracy level for the intended users and readers.

It will be necessary that future LCA software tools integrate more details and additional data into their inventories in favor of making the LCA results more comprehensive and transparent. In addition, it would be beneficial to consider the pavement-vehicle interaction and the effect on energy consumption due to rolling resistance and geometry of roads as well. Winter service and effect of it on winter maintenance strategies, especially in cold climatic zones, can bring more dimensions to the scope of assessment. Including more environmental impact categories and using comprehensive database as well as impact assessment methods are very critical and need to be carefully handle in order to provide more thorough and fair environmental impact assessment. End-of-life material policy should include more than material transport after maintenance activities. It should cover more data like; amount of waste asphalt generated and stored in storage sites, maximum permissible storage time of waste asphalt in depots, etc.

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Functional Requirements and System Architecture for Decision Support of Energy Efficient Building Design in Retrofit and Maintenance Stage

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Abstract

This paper describes development of a methodology to support better retrofit and maintenance with optimised energy consumption using evolving technologies in material, components and systems both at building and neighbourhood levels. It is based on a retrofit and maintenance scenario focused on specification of the functional requirements, databases requirement and system architecture for the construction and operation of the decision support tool. Decision support (DS) tools have already been developed for architects and building designers to choose best building design options with retrofit and maintenance in mind. However, there is a lack of understanding of the required data structures, databases, definition of the functional requirements and the variety of the possible system architectures for this application. The proposed DS tool will support Facility Management (FM) to design their option on Building Information Model (BIM) file by making best retrofit and maintenance decisions for improved energy efficiency (EE) without needing full knowledge of the latest technologies in any required subject and without being expert in building energy performance analysis and simulation. A detailed retrofit and maintenance scenario and its corresponding process map are developed and explained in details. Database requirements are extracted and discussed, leading to specification of the necessary structure and content with a level of details. The functional requirements for retrofit and maintenance design scenario are discussed and an exhaustive list is generated. The decision support tool was structured using four building blocks: (i) energy performance and simulation block; (ii) retrofit and maintenance options generator; (iii) optimisation block and; (iv) a decision making block based on Multiple Criteria Decision Making (MCDM) method.

Keywords: Decision Support, BIM, Building Energy Performance, Retrofit and Maintenance.

1. Introduction

This paper describes functional requirements and system architecture for decision support of energy efficient (EE) building design in retrofit and maintenance stage. Decision support (DS) tools are becoming more and more necessary for architects and building designers to make best energy efficient (EE) design decision, and support retrofit and maintenance projects (Ferreira et al., 2013). However, little has been done to identify the databases requirements to enable EE design that does support FM during operations. This paper draws the stages of the process for design of a decision support system including its required databases and decision making criteria. Functional requirements and system architecture are also elaborated in details toward development of the proposed DS tool. This is aimed to support facility management (FM) to design their maintenance or retrofit option on building information model (BIM) file through making best decisions for improved energy efficiency (EE) without being experts in the latest technologies of the required subject or being experts in building energy performance analysis and simulation. The necessary tools' architecture includes the alternatives generator tool, the energy performance assessment tool and the DS tool.

In order to achieve sustainable development of our society, retrofitting existing buildings to improve their energy efficiency has become an inevitable task for the government of several countries (DOE, 2009), (Green Deal, UK GOV), (CBRE, Retrofitting Existing Buildings). Generally, a sustainable building retrofit programme consists of five key phases, from the project setup and pre-retrofit survey phase to the validation and verification phase (Ma, 2012). In this process, identification of retrofit options using reliable data is essential for a successful building retrofit project. To provide reliable evidence for selecting suitable retrofit measures, dynamic building performance simulation tools, such as TRNSYS (Santamouris, 2007), EnergyPlus (Chidiac, 2011), (Wei, 2014), (Ascione, 2011), IES VE (Ben, 2014) and DOE-2 (Zmeureanu, 1990), have been used widely in real projects. Design4Energy (D4E) is an on-going EU research project, consisting of 17 partners from several countries in Europe, such as Spain, UK and Germany (Design4Energy). The project is aiming to develop an innovative Integrated Evolutionary Design Methodology, which can allow the stakeholders to predict the current and future energy efficiency of buildings and make better informed decision in optimizing the energy performance during the building life cycle. The work presented here is particularly focused on retrofit and maintenance stages. Within D4E a novel decision support tool based on dynamic building performance simulation therefore is being developed, and it meant to first be usable for building retrofit and maintenance projects to help stakeholders choose the most suitable retrofit/maintenance measure(s) for their projects (Fouchal, 2014).

The main decision making process focuses on using building simulation to predict the effectiveness of various retrofit or maintenance measures (alternatives) and inform the current development of a dedicated decision support tool for FM. Also the system relies in particular on adequate definition of database requirements in terms of components, parameters and indicators to automatically generate all possible retrofit or maintenance options. A set of databases are being developed for the decision support tool, this development includes identification of the requirements for IT systems, components, energy systems and, materials. Analysing existing database solutions was the first pre-requisite, then identification of databases' characteristics using focus groups of potential users (architects, energy designers and FM) and finally tuned to suite the type of decision support tool being developed. Decision support tools have been key in the providing smartens of many design platforms for building practitioners, the system architecture in question here is the main engine of the Design4Energy (D4E) platform (D4E, web1). These platforms do provide basis for collaboration and knowledge sharing with updatable databases. The value of design platforms is in their workflow speed and quality, facilitating team contribution integration, and rapid feedback on energy performance (NREL's OpenStudio, June 2015). OpenStudio started as an open source project to create a collection of software tools for energy modelling. For these platforms databases is essential for their functioning. While xBIM is another open source development platform, which allows creating application for BIM based on the IFC standard (xBIM, June 2015). TNO BIM Server is another open source development platform, which allows creating application for BIM based on the IFC standard (bimserver, June 2015). The Building SMART Data Dictionary (bSDD) is a reference library or a framework that aims at supporting improved interoperability in the building and construction industry. It can connect software applications to product databases or attach specific attributes to construction designs. These references can include information from a product manufacturer, typical room requirements, cost data or environmental data (ifd standards, June 2015), (ifd-library, June 2015).

Multiple Criteria Decision Making (MCDM) integrates multiple indicators into a single meaningful index to allow ranking and comparing options for decision making, see figure 1 (Fouchal, 2015). It is an efficient statistical method to combine component indices arising from all the information sources into a single overall meaningful index, therefore ranking and comparing are feasible. MCDM has the ability to weight different alternatives and make judgement on various criteria for possible selection of the best/suitable alternative(s). A typical MCDM problem is when there are a number of criteria to assess a list of alternatives. Each alternative is represented by a single value for each of the criteria to permit the assessment and/or ranking, see figure 1. Complex decision requires consideration of multiple criteria (Zeleny, 1982).

Analytic Hierarchy Process (AHP) method as proposed by Saaty (1994) that is based on priority theory decomposes a complex multi-dimensional decision making problem into a system of hierarchies. It uses the relative importance of the alternatives in terms of each criterion. The AHP has the ability to logically incorporate data and expert's judgement in the model for measurement and prioritising intangibles. As a complex and unstructured situation is broken down, its components are arranged into a hierarchic order including criteria and alternatives.

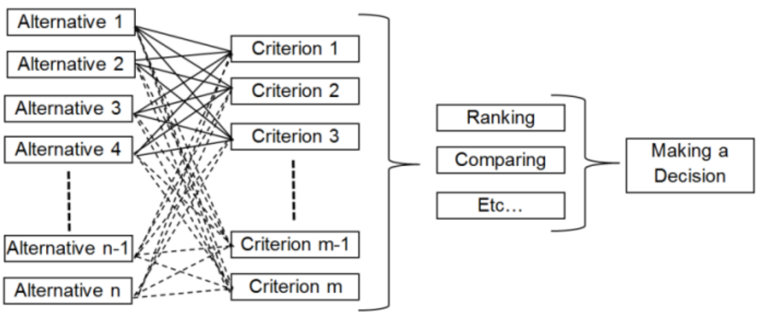

Figure 1 Multi criteria decision making (MCDM) process being adopted in D4E

Component catalogues relational databases are accessible through internet protocols. The Building Component Library (BCL) by NREL provides searchable information about EE related technologies and a list of measures to meet energetic issues (Fleming et al., 2012). The included information can represent physical characteristics of buildings such as windows, walls, and doors, or can refer to related operational information such as occupancy, equipment schedules and weather information. Each measure and energy system can be downloaded as a XML, RB and OSM file describing these components (bcl.nrel, June 2015). Data Repository ISES is another cloud-based data repository. It contains information such as climate data or stochastic templates but most interestingly energy product and material catalogues containing energy properties of products and materials (ISES D4.1, 2014). The library uses the PLIB ontology model (based on ISO 13584). All information is saved in the ifc file format (ISES D4.3, 2014). The MagiCAD Product Database is a product catalogue or database that contains over one million products from over hundred manufacturers. A designer can choose components through a plugin directly via the CAD-tool interface. This interface is connected to a plugin on the manufacturers' site (MagiCAD, 2014).

In the following sections are presented the retrofit and maintenance scenario, the process map, the functional requirement and database requirement to finally develop the system architecture for the decision support tool.

2. Retrofit and maintenance scenario

A detailed retrofit and maintenance scenario is developed and described here; the corresponding process map is also developed and explained in details in the section to follow. The scenario starts with the facility manager evaluating the operation stage and maintenance data of an existing building and reveals some building performance changes which require serious attention such as undertaking some repair or upgrade to the building. An architect takes over and starts analysing historical data of operation, maintenance records as well as user behaviour data, monitoring data, the map of neighbourhood energy nodes and cost data. From this analysis it becomes apparent that some of the data is not compatible with building's energy anticipated performance. He/she therefore request a thorough investigation of the causes of the energy consumption mismatch with original design in specific parts of the building which involves the heating system (Wei, 2015). A heating system expert is called in and identifies an old boiler as the source of the problem. The architect in collaboration with a building services engineer sketch a retrofit or maintenance design using a BIM model on the D4E platform. In doing so, the architect takes into consideration a number of parameters such as the local weather profile, facility management reports, financial status of the building owner and looks into other case studies to decide the best option forward for optimisation of energy level ahead of the conceptual design completion. At this stage, the architect considers the market and the various options for the energy performance of the project's life cycle and cost of future operation and maintenance to prepare to discusses various design options with the client to make a decision.

Mainly two routes become possible depending on the budget in hand and existence of information on new source of district heating to become available in the near future within the vicinity of the building. These options are analysed and evaluated by the designer comparing the retrofitting improvements versus maintenance action. The D4E platform supports the designers by highlighting critical building zones. The designer can filter out the existing building data for transferring them to certain design tools (CAD, etc.). Using the different design tools the designers can develop retrofitting variants for further integration and analysis in the collaborative platform. The simulation tool integrated in the system enables running a number of analyses to assess the impacts of the proposed retrofitting or maintenance variants on the energy efficiency and compare them to historical data of similar existing buildings. The design is then passed on to the mechanical and electrical engineers as a BIM model. The 3D collaborative environment provides them the possibility to explore what-if-scenarios, they can drag components from the database library to modify and optimise the design. Furthermore the platform provides them with cost estimation of the different options on different terms (short to long). The information required during these activities will be stored into a common database.

3. Process map

During the operation of the building the stages described in figure 2 are followed. The process of identifying building issues during the operation phase are described, where the building's under-performance is identified and adequate measures are undertaken through D4E platform.

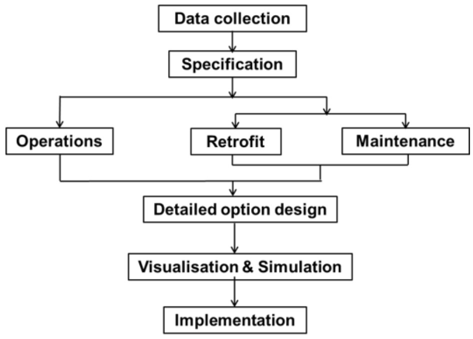

Figure 2 operation of the building including retrofit or maintenance

However, the process map being developed has no specific focus in terms of the type of the building requiring retrofit and maintenance. It is developed on a higher level and aims to cover all possible requirements of domestic and non-domestic buildings. However, in the case of industrial and buildings with specific uses (e.g. health care centres) adjustments would be required for the process map to be applicable, including the need for appropriate population of the databases with relevant information. For the purposes of this research, to verify the retrofit and maintenance process proposed and to validate the decision support tool, a case study of 20 domestic buildings is used. The main limitations and potential of the developed tool are highlighted. Additional testing of the decision support tool would be required to further validate its applicability in different types of buildings.

3.1 Monitoring building operation (client & FM):

During the operation stage of a building the client (user/owner) and the facility management team undertake scheduled monitoring and/or observation of the building performance, generally using electronic monitoring devices such as energy meters, which measure the energy consumption and store it periodically into a file using common format such as Excel. The operational monitoring data are produced in the form of sensor data (of energy systems, of energy used by equipment, user behaviour, indoor air quality and moisture level), operation bills (of energy/utilities) and maintenance/repair bills. The client gets signals from daily use and observation of the building behaviour in terms of indoor air quality (e.g. thermal environment, visual environment and acoustic environment), sensors/energy monitoring data and operational cost. If the building's indoor air quality level and moisture level have changed it may suggest that the building envelope or the energy systems have changed in a way that is not expected. Furthermore if the operational cost such as the energy bill has changed similar cause may apply. Under this kind of circumstances the client reports any observations to the facility management team. Similarly the FM team can make similar observations from the available monitoring data or studying reports from the client (written, emails or verbal), see figure 3. The data collected can be clustered as: (i) Building survey; (ii) Sensors and monitoring data; (iii) Client report & user interview; (iv) Review of maintenance strategy; (v) Access BIM files / As built drawings.

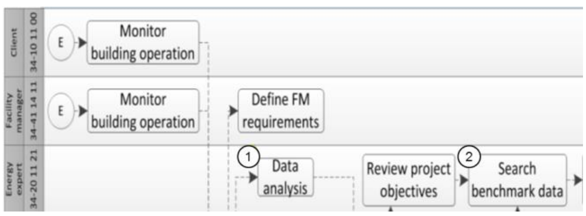

Figure 3 defining the need for retrofit or maintenance

3.2 Requirement, data analysis and review of project's objectives

Based on operation data the facility manager defines their requirement to re-establish the normal operation of the building or to upgrade the performance level for example to comply with new regulations or simply respond to the client request. The energy expert and other energy system experts such as HVAC engineers will use Tool 1 to assess the reported building energy performance issue and set targets for remedy or upgrade. The target setting will involve selection of key indicators and defining the operating ranges for each indicator. The energy expert reviews the objectives traced to meet the use and operation needs, these are identified on the basis of the FM requirements and the expected energy performance of the building.

3.3 Search benchmarks and finalise key target setting

The benchmark browser and search tool will be used to set the benchmarking related targets. The standard methods and benchmarks for consideration in this project include CIBSE (Chartered Institute for Building Services Engineers) TM22, TM46, TM39, TM46 and TM 47, the AM11 Building Energy and Environmental Modelling (BEEM) (CIBSE Applications Manual 11) and the EPBD (Energy Performance of Buildings Directive), IPMVP (International Performance Measurement and Verification Protocol) in the USA, as well as the Performance Contracting Program standards ISO. Setting key target levels will be based on benchmarks and client requirements by setting the range extreme boundaries for each indicator being.

3.4 Retrofit or maintenance options generation and selection

Choosing of energy options, then run a feasibility study and produce a feasibility report for retrofit and maintenance will be carried out by the energy expert first through selecting variables to be used to form the options, see figure 4. These variables will be displayed to him/her under a list of drop down menus providing all possible and available variants of each component or action to incorporate of performed. This process will be possible by manual generation of options by the energy expert using a set of integration parameters which help to combine the variables in various ways to produce a list of possible options with potential to achieve the targets being set.

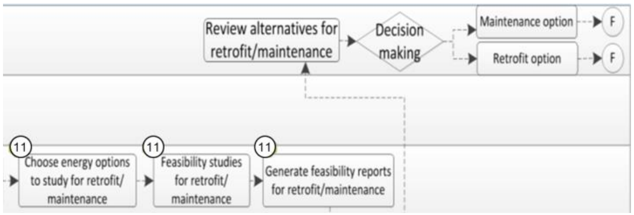

Figure 4 decisions making on whether to do maintenance or retrofit

The energy expert will use new methods to verify the process and the generated options while still having the power to alter the process of selection or add/reduce possibilities.

3.5 Decision making by the client and Produce of retrofit brief

At this point of the process a review of alternatives will be undertaken by the client using the decision support tool 11 to make an initial decision which is more suitable for the project, maintenance or retrofit. The feasibility results will be prepared in a format that will simplify the decision making of the client.

If decision is to retrofit, a model has to be created. It starts by the client producing the brief which contains the expected energy performance, the KPIs and setting up the targets. The next step is defining the specification of the ideal solution in relation to the given client requirements.

3.6 Creation of retrofit alternatives concept designs

The remaining stages of the model will be completed by an Architect who will conduct an environmental analysis and building performance assessment. The architect generates a project program. Using Tool 4 which is the BIM design tool he/she sketches the spatial outlines of the retrofit alternatives onto the existing BIM data on the basis of the defined indicators. The produced LOD4 models will be analysed by the architect taking into consideration the site implication and adaptability to the surrounding.

3.7 Improve retrofit model

The BIM model is then improved with material data for better energy efficiency performance and CO2 emissions reduction. In this phase the architect takes into account the embodied energy of the materials, use recyclable materials whenever possible, introduces new materials, figure 5.

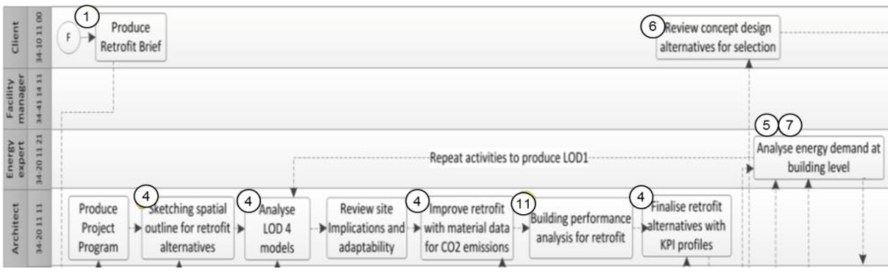

Figure 5 modelling of the retrofit alternatives and undertaking of performance assessments

3.8 Performance analysis for passive design

The architect has the option to choose to undertake some building performance analysis under the proposed retrofit alternatives using the energy efficient BIM. This procedure will mainly help to reduce the number of options that can be considered and even provide enough information to make the ranking on the basis of the chosen criteria from the list of the performance indicators. This procedure is conducted via the decision support tool 11 which is built on the top of an energy simulation tool, such as EnergyPlus, which is one of the most popular tools for dynamic building performance simulation. The decision support tool will perform building performance simulations to all possible retrofit scenarios preliminarily defined by the client and rank them using the chosen selection criteria.

3.9 Design concept and review by client

The architect finalises design alternatives with KPIs profiles using BIM and generate a design concepts for each potential alternative. Through the collaborative environment Tool 6 the client reviews the produced design concepts taking into consideration of his/her main requirements which include energy consumption, the construction cost and LCC.

3.10 Analysis of energy demand and Analyse energy alternatives at neighbourhood level

The energy expert will conduct an analysis of building energy demand using the energy simulation performance tool based on eeBIM Tool 5 and the energy match optimiser tool 7. Following this analysis the client via the collaborative environment will review of energy options for the selected retrofit options and narrows down the number of options which would be passed onto the architect on the collaborative environment Tool 6 to verify the BIM models of the selected alternatives in term of their energy matching potential. The energy expert will analyse the remaining retrofit alternatives from the previous steps for their higher potential to address the requirement already specified in the project and the pre-set targets using the target setting tool 1. The aim of this run of analysis is to evaluate the energy matching at neighbourhood level and rank them in their order of potential offered by each using a set of indicators which include energy price mode, renewable energy that is available or/and potential in the coming future and the existing or potential for energy production. At this stage the architect on the collaborative environment will review using the updated BIM models (with embedded energy matching results) with selected alternatives for their energy matching potential at neighbourhood level.

3.11 Final approval of selected alternatives by client

The improved BIM models for the selected retrofit alternatives will be accessed through the collaborative environmental tool 6 by the client for final approval. At this stage if there is more than one alternative they will be listed in a ranking order on the basis of the most important indicators to the client to enable fast approval. If the decision that all requirements are meet by one alternative, it is then final approved and the corresponding concept design is also approved.

3.12 Maintenance options and analysis of maintenance options

If the initial review alternatives (at defining the options for retrofit or maintenance stage) by the client using the decision support tool 11 has resulted that maintenance is the most adequate approach to follow then a number of maintenance alternatives will be generated. The FM will lead this activity and start by analysing the LOD4 BIM model. Originally the feasibility results (Retrofit/maintenance) are prepared in a format (ranked on the basis of most important criteria only and presented it on the collaborative environment at high level of information only) to simplify the decision making of the client. The FM will study all the maintenance options that can be considered. He/she will check the potential for site implications to identify the metrics for the relevant indicators. The ranges for these indicators will be used together with the indicators for energy matching at both building and neighbourhood levels, complying with existing regulations and the client requirements. The decision support tool 11 with its energy simulation feature will be used to analyse the building energy performance, shown in figure 6.

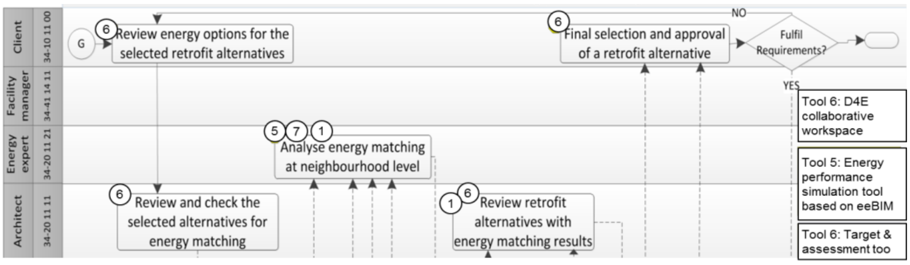

Figure 6 checking the retrofit solutions and evaluate the energy matching potential

3.13 Selected options, review by client and ready for execution

Key performance indicators will be used to narrow down the maintenance alternatives. Maintenance solutions will provisionally be ranked on their performance feasibility.

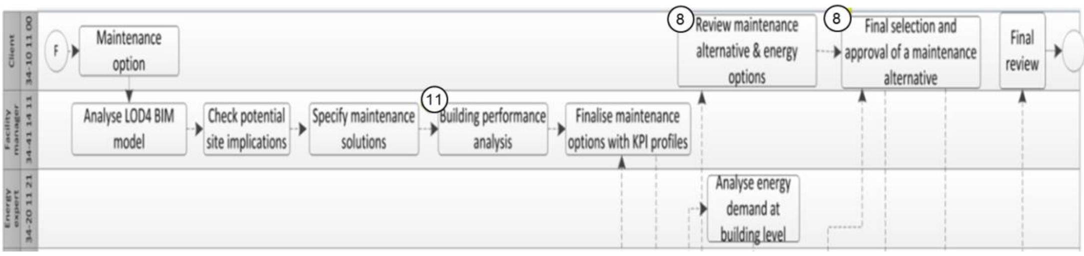

Figure 7 studying of maintenance options and making final selection

As shown in figure 7 the client will use the collaborative environment Tool 6 to review the maintenance alternatives and the energy options that are made available by the FM study. At a high level of information the client review will consider the analysis provided by the energy expert on solutions for their potential of reduced energy consumption, cost and LCC, energy matching at building and neighbourhood levels. This review process will result in a single maintenance alternative being approved by the client. Through the collaborative environment tool 6, various experts that are relevant to the different components included in the final solution will be invited to access the BIM model which embeds the maintenance solution. The HVAC engineer will use tool 8 (BIM HVAC design and simulation tool) to analyse the final solution for its feasibility, compliance and adequacy to fulfil all relevant stake holders' requirements. Similarly the electrical engineer will use Tool 9 (BIM electrical design and simulation tool) to verify that the solution selected is adequate to respond to the identified requirements.

4. Specification of the functional requirements for DS tool,

The decision making in retrofit and maintenance projects is supported by the energy simulation and actions for environmental influence through provision of energy system performance data and physical characteristics of building materials; cost simulation over the life cycle through e.g. the provision of data from similar real cases; design process through possibilities to share design results; owners' decision through providing information on the utilization and sustainability aspects of existing components and energy systems; and FM decision in choosing the optimal action for the available boundary conditions. The functional requirements for retrofit and maintenance design scenario are discussed and an exhaustive list is generated. Most of these requirements will be focusing on components identification, compliance with regulations and how to undertake the adequate modelling and simulation for retrofit and integration. Table 1 shows the identified different requirements for the different users.

Table 2 requirement for the different users

User	**Function required**
Owner/Facility manager	Digital trading function
Architect	Decision support / optimisation function
	Energy simulation function
	Energy matching & consumption estimation function
Building Energy designer	Information acquisition function
Information exchange	Filtering data & interlinking function
	Interaction with 3D sketch service
Building energy designer	Neighbourhood information acquisition and analysis function
	Visualization functional module

5. Databases requirement

These will be captured from: Original brief from clients; Assessed against: building regulations; building design standards from ASHRAE, ISO and CIBSE, or commercial building performance rating methods such as BREEAM and LEED. Furthermore, through engaging existing users in workshops or through organised surveys. Some relevant examples could be requirement for more double glazing to meet the new standards; measurement of air tightness; measurement of natural daylight; need for smartness to support day to day activities; review of design life of different components; analysis of sensors data. The methodology adopted to identify the DB requirements for FM decision support included: Questionnaires and interviews with relevant end users. 30 responses were collected from different sectors, see Figure 2 and 3. 23% are Architects and designers, and another 20% are technology and solution providers.

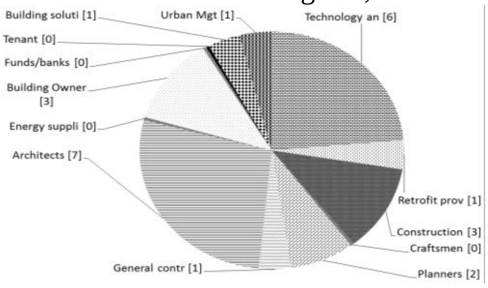

Figure 2 Stakeholders participation

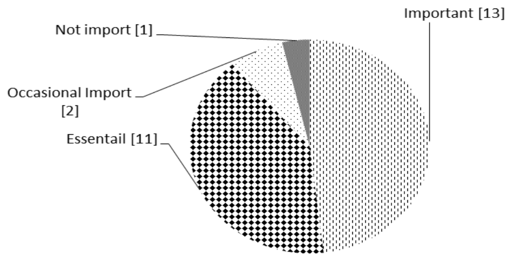

Figure 3 Opinion on building component

Building components initially have to be manually stored by users. The DB requirements as reported from the literature search included: (i) User, through interaction has to provide a direct link to BIM models; (ii) Visualising data, choices of building architecture; (iii) BIM models, have to be accessible by relevant stakeholders such as engineers for energy systems; (iv) Solutions with their operational attributes, maturity, deterioration, experienced costs or best practices of similar projects; (v) Material characterization (e.g. type, functionality, thickness, thermal conductivity, density specific heat, internal and external solar absorption, and emissivity); (vi) Team management.

5.1 Operation and maintenance data requirements

Table 4 Indicators for retrofit and maintenance

	Indicator		Indicator
1	Occupant involvement	15	CO2 reduction targets
2	Client awareness	16	ROI
3	Building performance assessment	17	Potential for energy generation
4	Building fabric assessment	18	Potential for natural ventilation
5	Building operational history evaluation	19	Potential for thermal energy (heat) recovery
6	Operations issue	20	EE potential of wall insulation thickness
7	Historic data analysis	21	EE potential of window glazing layers
8	FM reports quality	22	Lighting efficiency and control
9	Fault pin-pointing/detection	23	Boiler/central heating efficiency
10	Contractual arrangement	24	Compliance with regulation
11	Performance of Energy using Products (EuPs)	25	Refurbishment option ranking
12	Performance of Energy systems	26	Hot water generation & distribution system efficiency
13	Energy bills	27	Energy use vs. comfort conditions
14	Energy reduction targets	28	Client/user satisfaction.

The methodology adopted to identify the database requirement in terms of design for operation and maintenance besides of review of relevant literature, included standards and guidelines to first highlight the generic domains of requirement. The survey was conducted with the aim of gauging more specific requirement to different usage groups on databases which will support design for building operation and maintenance. During a workshop with experts in retrofit and maintenance the database requirements are extracted and discussed leading to the specification of the necessary structure and content with a certain level of details. Table 4 shows the list of indicators for retrofit and maintenance are used to characterise the requirements.

6. System architecture of the decision support system

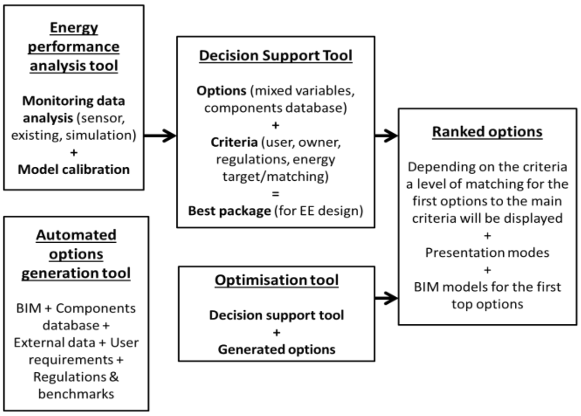

Figure System architecture of the decision support system

The decision support tool was structured using four building blocks which are: (i) energy performance and simulation block; (ii) retrofit and maintenance options generator; (iii) optimisation block and; (iv) the decision making block that is based on Multiple Criteria Decision Making (MCDM) method. Decision support tools have already been developed for architects and building designers to choose the best building design options with retrofit and maintenance in mind.

The proposed DS tool would support Facility Management (FM) to design their option on building Information Model (BIM) file through making best decisions during retrofit and maintenance for improved energy efficiency (EE) without having full knowledge of the latest technologies in any required subject and without being an expert in building energy performance analysis and simulation.

Within Design4Energy which is the sponsoring EU project of this work three architects and other end users of the retrofit and maintenance decision support tool are partners and are active members who were involved in shaping and testing the work being described in this paper. An initial exploration has also been undertaken with a larger number of external architects and facility managers to agree and feedback on the format and the content of the decision support tool and its corresponding components. At later stage of this development it is intended to embed it into a holistic design platform during which a program of validation and demonstration will be conducted with a much larger pool of end users.

7. Conclusions

An identification of the required data structures and databases to support designers and enable Facility Management (FM) to make decisions on best retrofit and maintenance for improved EE has been conducted. The databases requirements and functionalities have been detailed. A set of necessary databases were proposed to enable optimal decision making by FM and perform adequate design of new build. The level of detailing the database requirements is provided in terms of information technology (IT), components and systems, materials and the stakeholders. To complete the study a validation by FM of the database is conducted using the new decision support tool for maintenance and retrofit to be used. The work focused on using building simulation to predict the effectiveness of various retrofit measures and inform the current development of a dedicated decision support tool for FM in particular definition of database requirements in terms of components, parameters and indicators to automatically generate all possible retrofit or maintenance options. Analysing existing database solutions was the first pre-requisite, then identification of databases' characteristics using focus groups of potential users (architects, energy designers and FM) and finally tuned to suite the type of decision support tool being developed. Decision support tools have been key in the providing smartness of many design platforms. System architecture was therefore developed for embedding the set of decision making tools into the platform. A retrofit and maintenance scenario was used to follow through the decision making process for which the necessary tools were specified in terms of their functionality and then designed.

8. Acknowledgements

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A Settlement of the Internal Heat Gain Schedule of LES (Living Environment Simulator) Using Statistical Data

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Abstract

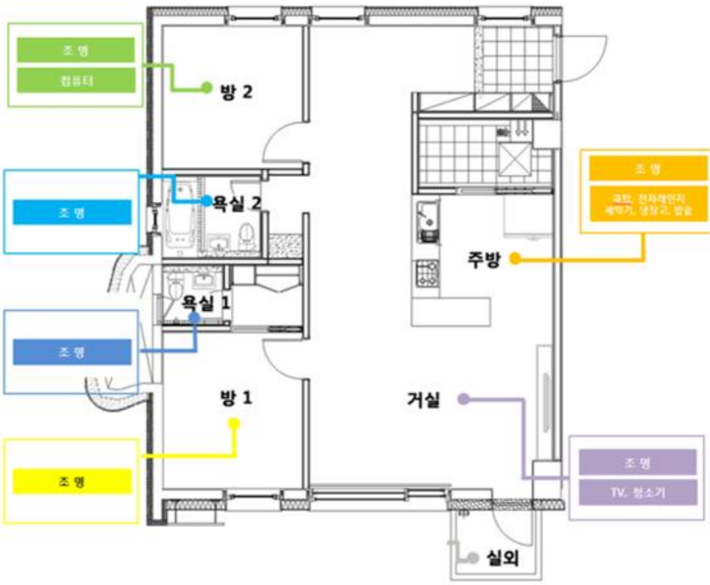
The purpose of this study is to set internal heat gain schedule of LES (Living Environment Simulator) using statistical data and suggest total daily electricity consumption and time of maximum power generation based on set schedule. The result indicates that time of maximum power generation is individual and household labor activities and total daily electricity consumption is 6.5 kWh/day in weekday and 7.5 kWh/day in weekend. An additional study is required to review total yearly electricity consumption through setting internal heat gain schedule in winter and summer season on the basis of this work.

Keywords: Occupancy Schedule, Lighting Schedule, Equipment Schedule, Electricity Consumption

1. Introduction

As of 2008, approximately 12% of total energy consumption in buildings in the country is consumed in homes, and electricity consumption accounts for the highest ratio among the energy consumption in homes. The electricity consumption in homes is expected to increase gradually due to the improvement in the standard of living and enlargement of home appliances, and in order to reduce electricity consumption, it is necessary to estimate electricity consumption in the building and identify the form of energy consumption in the building by analyzing the pattern of home appliances usage which is directly and indirectly related to electricity consumption and the behavior pattern of occupants. However, there is no objective and reliable methods regarding setting of home appliance usage pattern and the behavior pattern of occupants presented in the country currently, and preliminary data required for estimating electricity consumption in the buildings is also insufficient.

Based on this background, the purpose of this study is to set the occupancy, lighting and equipment schedules of LES (Living Environment Simulator) implemented in Zero-carbon Green Home of Korea Institute of Civil Engineering and Building Technology (KICT) by using Statistics Korea's report on the time use survey1) and Korea Power Exchange's report on investigation of



home appliance distribution rate and electricity consumption pattern at home2) and present electricity consumption on LES home for one day and the time of maximum electricity consumption.

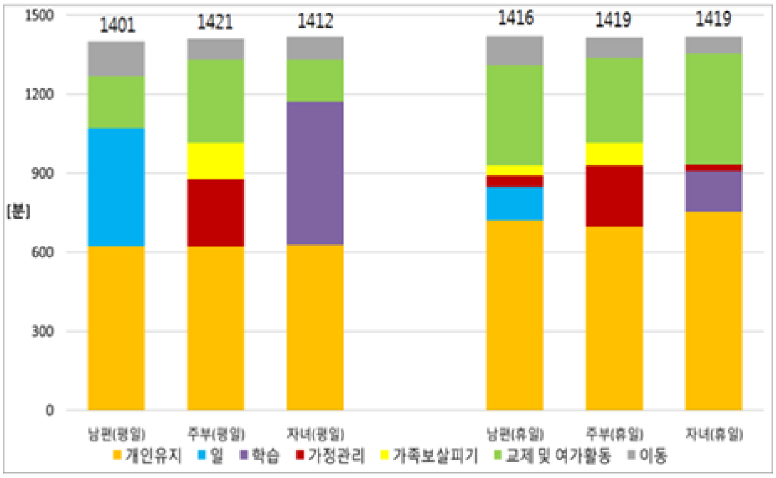
2. Setting of Internal Heat Gain Schedule

2.1 Summary of LES(Living Environment Simulator)

LES was implemented for the purpose of optimizing the operation of Zero-carbon Green Home by monitoring the quantitative electricity consumption while controlling the uncertainty of living environment.

The area of LES implemented house is 58 ㎡ consisting of the living room, kitchen, room 1, room 2, bathroom 1 and bathroom 2, and home appliances including lighting, TV, computer, refrigerator, washer, rice cooker, microwave oven, cook-top and vacuum cleaner are installed in the house. 3 household members were set for LES by referring to the 2010 Population and Housing Census Report3) and single-income family with a junior high school student was assumed by referring the gender and age distribution of householder. For the household members, 6 sets of bodies that humidification and heating control were available were established and placed on the living room (3 Sets), room 1 (2 Sets) and room 2 (1 Set).

Figure 1: Floor plan of LES



2.2 Selection of representative behavior of household members and linkage of home appliances

Since electricity consumption is affected by the behavior of occupants, it is necessary to set the schedule by determining major behaviors of occupants that consume electricity. In this study, the major behaviors of occupants were selected by referring to Statistics Korea's report on the time use survey in 2009. In the report on the time use survey, the result of sample survey and estimation of people aged 10 or older how they utilized 24 hours a day for 5 years is presented separately by class.

In this study, the representative behavior time of household members was selected separately into weekdays and weekends based on the average time of householder, his spouse and a child in middle school of single-income family, and any behavior corresponding to less than one percent of 1,440 minutes a day (approximately 15 minutes) was excluded.

Table 1 above shows the relevant actual lighting and home appliances related to the representative behavior selected earlier. For the home appliances, only home appliances placed in LES home were applied, and the refrigerator and rice cooker not presented in Table 1 were set to operate 24 hours.

Figure 2: Mean Time of Representative Behavior

Table 1: Relationship Between Behavior and Home Appliance

Behavior		Lighting	Appliance
Individual activities	*Sleep*	-	-
	Meal	*Kitchen*	*TV*
	Refreshments	*Kitchen*	*TV*
	Washing	*Bathroom1,2*	-
	Dressing	*Room1,2*	
Household labor	*Meal preparation*	*Kitchen*	*Microwave, Cooktop*
	Dish-washing	*Kitchen*	-
	Clothing management	*Living room*	*Washing machine*
	Cleaning	*Whole Room*	*Vacuum*
	Purchase of goods	-	-
Human relations & Leisure activities	*Human relations activities*	*Room1,2*	-
	Learning	*Room 1*	-
	Media use	*Living room*	*TV*
	Religious activities	-	-
	Outdoor leisure activities	-	-
	Hobby activities	*Room 2*	*Computer*
Learning	*Regular classes*	-	-
	Individual learning	*Room 2*	-
Family care (Holiday)		*Room 1*	-
Labor		-	-
Travel		-	-

2.3 Setting of Internal Heat Gain Schedule

Before setting the indoor heating gain schedule, the procedure to set 1,440 minutes for the sum of average representative behavior time of household members and the procedure to adjust the home appliance use time at 5-minute interval were carried out.

As shown in Figure 2, the sum of average behavior time of each household member for each weekday was less than 1,440 minutes because the behavior not to use home appliance was excluded in the procedure to link the representative behavior of household members and home appliances so that the time for the relevant behavior was omitted. In order to set 1,440 minutes for the total sum, the procedure to add the omitted time to the relevant behavior by considering the ratio of average time of each behavior to total time was carried out, and it is presented in Table 2.

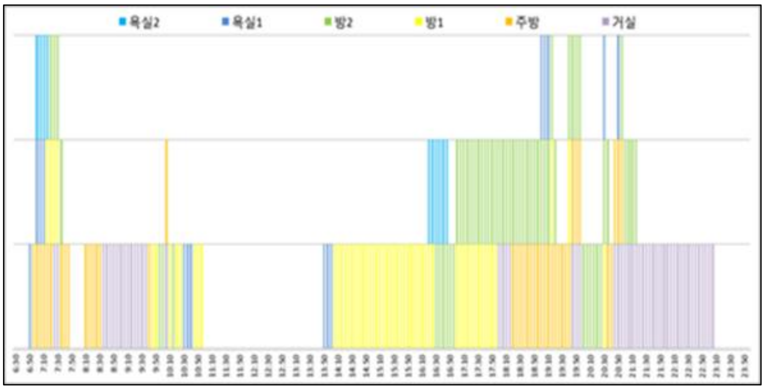
Table 2: Rearranged Mean Time of Behavior

Behavior	*Weekday[minute]*			*Holiday[minute]*		
	Householder	*Spouse*	*Child*	*Householder*	*Spouse*	*Child*
Individual activities	*630*	*630*	*630*	*720*	*700*	*760*
Household labor	*0*	*270*	*0*	*50*	*250*	*30*
Human relations & Leisure activities	*210*	*330*	*180*	*390*	*320*	*410*
Learning	*0*	*0*	*540*	*0*	*0*	*180*
Family care	*0*	*130*	*0*	*40*	*90*	*0*
Labor	*480*	*0*	*0*	*120*	*0*	*0*
Travel	*120*	*80*	*90*	*120*	*80*	*60*
Sum	*1440*	*1440*	*1440*	*1440*	*1440*	*1440*

The time of home appliance usage was adjusted at a 5-minute interval by referring to statistical data of Korea Power Exchange's report on investigation of home appliance distribution rate and electricity consumption pattern at homes, and 50 minutes a day were set for the time of cooktop usage which was not presented in the report by considering the average home management time.

Table 3: Time Use of Home Appliances

Item	*Report[minute]*	*Rearrangement[minute]*
TV	*350*	*350*
Washing machine	*92*	*90*
Computer	*211*	*210*
Electric rice cooker	*535*	*1440*
Microwave	*20*	*20*
Vacuum	*35*	*35*
Refrigerator	*-*	*1440*
Cooktop	*-*	*50*



The internal heat gain schedule on weekdays during intermediate season (March ~ May, September ~ November) was set based on the average behavior time of household members and the time of home appliance usage and presented in Figures 2 ~ 4, and the weekend schedule was omitted for lack of space. The schedule of relevant behaviors was set first for the occupancy schedule of household members by referring to bedtime, wake-up time, time to start to eat, eating time, time of movement presented by Statistics Korea and other behaviors were set by referring to the time of home appliance usage and the number of bodies installed on each room. Lighting was set to operate while a household member occupied regardless of the intensity of solar radiation brought into indoor, and hourly usage rate on weekdays and weekends presented in Korea Power Exchange's report on investigation of home appliance distribution rate and electricity consumption pattern at homes was referred for the time of home appliance usage, and setting method was classified based on the time of home appliance usage. In case of a home appliance which was used for a long period of time, it was set to use at the time that exceeded the average daily usage rate, but in case of vacuum cleaner, washer and microwave oven that were used for a short period of time, it was set to use at the time of highest usage throughout the day.

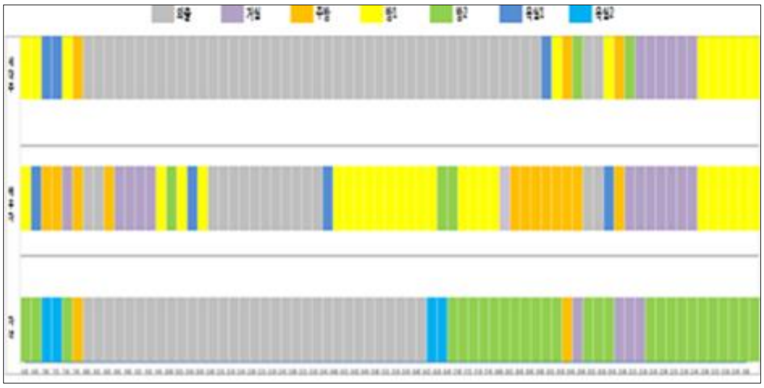


Figure 3: Occupancy Schedule

Figure 4: Lighting Schedule

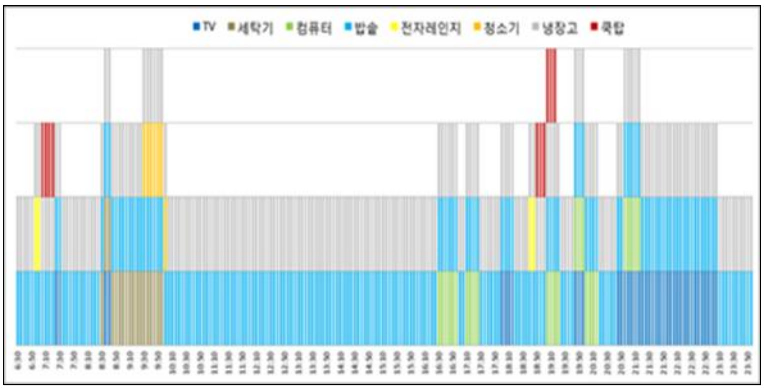


Figure 5: Equipment Schedule

3. Calculation of amount of electricity used

Based on lighting and equipment schedule, the calculation result of amount of electricity used for each hour on a weekday during intermediate season (March~May, September~November) was shown in Figure 5. The calculation result showed that the largest amount of electricity used on weekdays and weekends occurred between 7:30 AM and 8:30 AM and between 7:30 PM and 8:00 PM on weekdays and between 9:30 AM and 10:00 AM and between 6:15 PM and 6:40 PM on weekends which were the home management and personal maintenance activity times. The daily total electricity consumption was approximately 6.5 kWh/day on weekdays and approximately 7.5 kWh/day on weekends which were lower than 10 kWh/day presented in the precedent study4) used for comparison and verification with actual electricity usage. However, the electricity usage was calculated by designating only home appliances placed in LES as the items for calculation, so in order to draw the result which is close to actual electricity consumption in future, a study will be carried out by adding home appliance items.

4. Conclusions

In this study, the occupancy, lighting and equipment schedules of LES were set by utilizing the statistical data of Statistics Korea and Korea Power Exchange, and the time of maximum power generation and total daily electricity consumption at LES home on weekdays and weekends were presented based on the set schedules.

The annual amount of electricity used will be reviewed in future through winter and summer schedule setting by considering the heating and cooling apparatus.

Acknowledgements

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Life Cycle Cost-Efficient Near Zero Energy Hall Building for Nordic Climate

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Abstract

Finland’s first nearly zero-energy single-storey commercial/industrial building was completed in the spring of 2015 in Hämeenlinna. Built on the campus of Häme University of Applied Sciences (HAMK), the building is used for R&D and teaching purposes by the university and Ruukki Construction. There are only few years before the EU near-zero energy requirements will come into effect and thus it’s important to get real experiences of solutions before design of these buildings will be started. As a main result, the construction project was able to show that a building meeting these requirements and exceeding today’s strict energy-efficiency requirements by over 60 per cent can be built at a profit. In order to achieve the targets, special attention was paid to the steering of energy and life cycle efficiency during the whole project from early phase planning to the execution. Smart design and combination of different techniques including renewable energy sources enabled the end result that meet clearly forthcoming nearly zero energy regulations. Several techniques were utilized in the building. First, the energy need was minimized for example by extreme air-tight envelope and effective heat-recovery in the ventilation as well as by day-lighting utilization. Renewable energy sources have been utilized with an innovative way with building integrated solutions. In the ground energy system, the foundation piles have been utilized for heating and cooling energy extraction. Solar heat collectors have been used for boosting the energy pile system by charging the soil with solar energy. The life cycle optimization was based on integration of building energy simulations and cost calculations. This enabled to find the most cost optimum total solution to meet the future high energy targets.

Keywords: near zero energy building, energy pile, day lighting, life cycle costs, cost optimum

1 Introduction

Energy efficiency has risen to the same level as construction quality and cost efficiency to become one of the most important factors guiding construction projects. Investments in energy efficiency have already been made, particularly in residential and office construction. Single-storey commercial and industrial facilities are one of the most important building segments for steel construction in the EU. This building segment also has a relatively short life span, thus the building stock renews quickly compared to many other segments. These factors combined will validate the importance of energy-efficient solutions in new construction in this particular segment. In energy efficient concepts, buildings must be designed and executed as complete entities – not split up into subareas that are sub-optimized separately. This approach is almost contrary to present-day construction, in which design and build are split up across several parties without the overall entity being properly managed. The execution of commercial, industrial and logistics buildings could be managed by, for instance, so-called alliance agreements, in which the parties involved are bound to share responsibility for executing buildings in accordance with customer requirements (in addition to technical cooperation).

More complex construction requirements, such as cost efficiency, quality, energy efficiency and environmental friendliness, also underline the need to plan and manage entities as a whole. Finland's first nearly zero-energy "big-box" type single-storey building (nZEB) for commercial, logistic or industrial use was designed and constructed to meet an objective: to be a building with an economical lifecycle that saves energy and uses existing renewable energy sources (See Figure 1). In this project, special attention was paid on the co-operation with different parties and commitment to the common targets.

The new structure was designed and executed to enable economic use of the building and optimization of construction solutions. Optimization means selecting solutions based on investment outlays, additional usage costs and future savings. A well-insulated and airtight envelope in the building's walls and roof enables savings in energy requirements, and the use of solar power, day-lighting and geothermal energy harness renewable energy for use in the building. The building's economic performance was estimated by comparing the investment costs and life-cycle costs of a reference building and an nZEB building. The reference building level was agreed with the customer and designers.

Figure 1: Completed nearly zero-energy building in Hämeenlinna, Finland

2 Technical solutions for the nearly zero-energy building

2.1 Building envelope

The shell of the building walls and roof are highly significant for its energy efficiency. For this reason, the outer walls of the building are fitted with sandwich panel system, with ultra-airtight panels and carefully designed and executed seals between the panels, plinth, roof, windows and doors. The sandwich panels are composed of a glass-wool insulating layer between two thin steel sheets. The thickness of the insulation in both the wall and the corner panels is 230 mm, with a U-value of 0.16 W/m^{2}K. The building's roof incorporates a new type of prefabricated PIR roof elements with a U-value of 0.12 W/m^2K. Airtightness of the entire building has very big role in the heating energy demand. The measured airtightness of the entire building was as low as q_{50} = 0.76 $m^3/h,m^2$. Based on energy simulation, the heating energy need of this building with this level is 28% lower than that of the building with minimum air-tightness of q_{50} = 4.0 $m^3/h,m^2$, based on Finnish energy regulations.

Figure 2: Energy panels with decorative printing.

2.2 Utilization of day-lighting

The sizes and directionality of the building's windows are optimized for energy efficiency. The large windows are aimed south-west. The need for artificial lighting is reduced by the windows, due to their directionality and surface area. Traditional large windows bring light in – but also conduct heat out. In this building, the glass windows facing south have been replaced by cell windows made of polycarbonate (See Figure 1). These "daylight" windows isolate heat well – the warm rays of the sun during the summer do not heat the premises. During periods of bright daylight, light coming through traditional windows in indoor areas causes glare. Instead of this, daylight windows distribute light into the premises in a pleasantly even manner without glare, and blinds are not needed. The building is equipped with a day-lighting control to reduce artificial lighting. The U-value of these day-lighting windows is approximately 0.84 W/m^2K. The north-east wall of the building incorporates Ruukki Construction energy panel system clear windows, forming a dense structure with the panels. Lighting simulations, carried out by Tallinn Technical University, showed that the lighting energy saving potential is over 50 % in those spaces where day-lighting windows were used (high part of the building). Comparison of the lighting energy use with different lighting levels is shown in Figure 3.

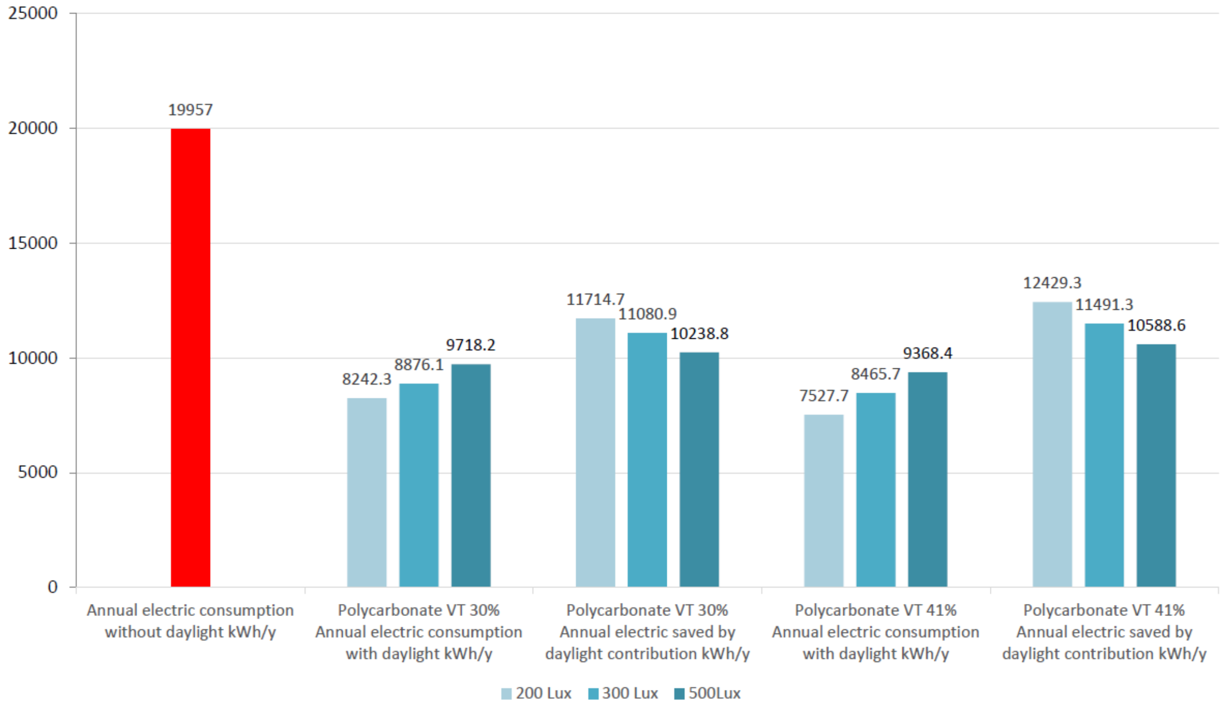

Figure 3: Energy saving potential of the day-lighting control (Building use: weekdays 8-17) for different lighting levels and different light transmissions (VT) of polycarbonate sheets.

2.3 Heating, cooling and ventilation systems

New types of radiation-based heating and cooling profiles developed during the project are installed in the building. The profiles are affixed to the underside of the roof element as shown in Figure 4. The radiation profiles generate either cools or heats the interior, depending on the season and the desired indoor temperature of the building. Radiant profiles work with a low temperature difference to the ambient air, allowing the heat pump installed in the building to perform well. The radiant system also reduces temperature variations on each floor in the building, thereby considerably increasing usage comfort and improving well-being at work and productivity.

Figure 4: Ruukki radiant profile and installation

Heating and cooling performance of the new product was studied with Comsol Multiphysics program by Finnish company Granlund Oy. Product properties such as material, colour, tube diameters and geometry were optimised with the tool to achieve high performance system. Share of the radiant part of the total heat output is about 76% and the total heating power is 77 W/m with average fluid temperature of 45ºC. In cooling mode, the cooling power is 31 W/m with average fluid temperature of 16,5 ºC. Temperatute distribution of the studied system in heating mode is shown in Figure 5.

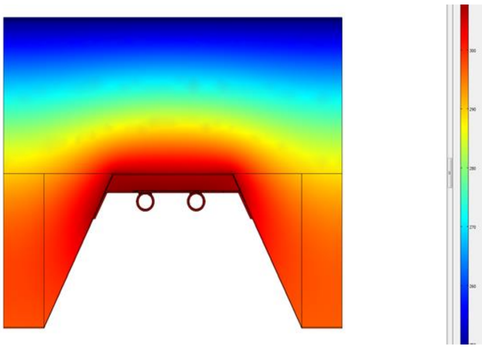

Figure 5: Ruukki radiant profile integrated into the roof panel.

A new type of indoor heating and cooling system also reduces energy consumption compared to air-heating systems. A ventilation airflow is now required only for the influx and removal of fresh air – not actually for heating the premises. The mechanical ventilation machine is equipped with an 80% heat recovery system.

2.4 Renewable heating energy system

Geothermal energy is utilized for the building's heating and cooling requirements. In total, 60 Ruukki Construction energy piles with diameter of 115mm and of 11m in length under the floor and columns are incorporated in the foundation to use renewable energy to heat the building. The energy pile system is based on steel foundation piles, Uponor double U-heat-collecting pipes (ϕ25mm) installed in the piles, connecting pipes via manifolds to the heat pump, and heat-transfer liquid. Figure 6 shows the heat collector pipes installed. Furthermore, two conventional heat wells of 200 m in length were installed for heating and free cooling of the building. The heat pump capacity is 32 kW. The performance of the steel energy pile system in Nordic conditions has been studied in several studies, for example by Nyholm (2011), Cervera (2013), Hassani (2014) and Döring et al (2015). According to these studies it have been showed that recharging of the energy pile field during the summertime is essential in order to guarantee the long-term behaviour of the system.

Figure 6: Heat collector pipes installed in the floor slab piles

A total of $24m^2$ of Ruukki Classic solar collectors are installed on the roof of the building's technical area. The Classic solar system integrates fully with the roof, as shown in Figure 7. Solar collectors accumulate thermal energy from the sun and transfer it to the soil through the energy piles. The soil is charged whenever there is heating potential available – even in January, thanks to the very low temperature level in the ground.

Figure 7: Roof-integrated solar heat collectors

The soil acts as a seasonal thermal reserve, much like a battery. Beneath the building, a clay layer extends to a depth of 11 metres. Clay has a greater thermal storage capacity than, for example, gravel. During the summer, the energy pile loop is closed from the heat pump, and is charged by the solar collectors. In the winter, the piles transfer energy from the soil to heat the building with help of heat pump. Cooling of the building is via the deep heat wells by free cooling utilizing the low temperature of the ground rock. The principle of the system is shown in Figure 8.

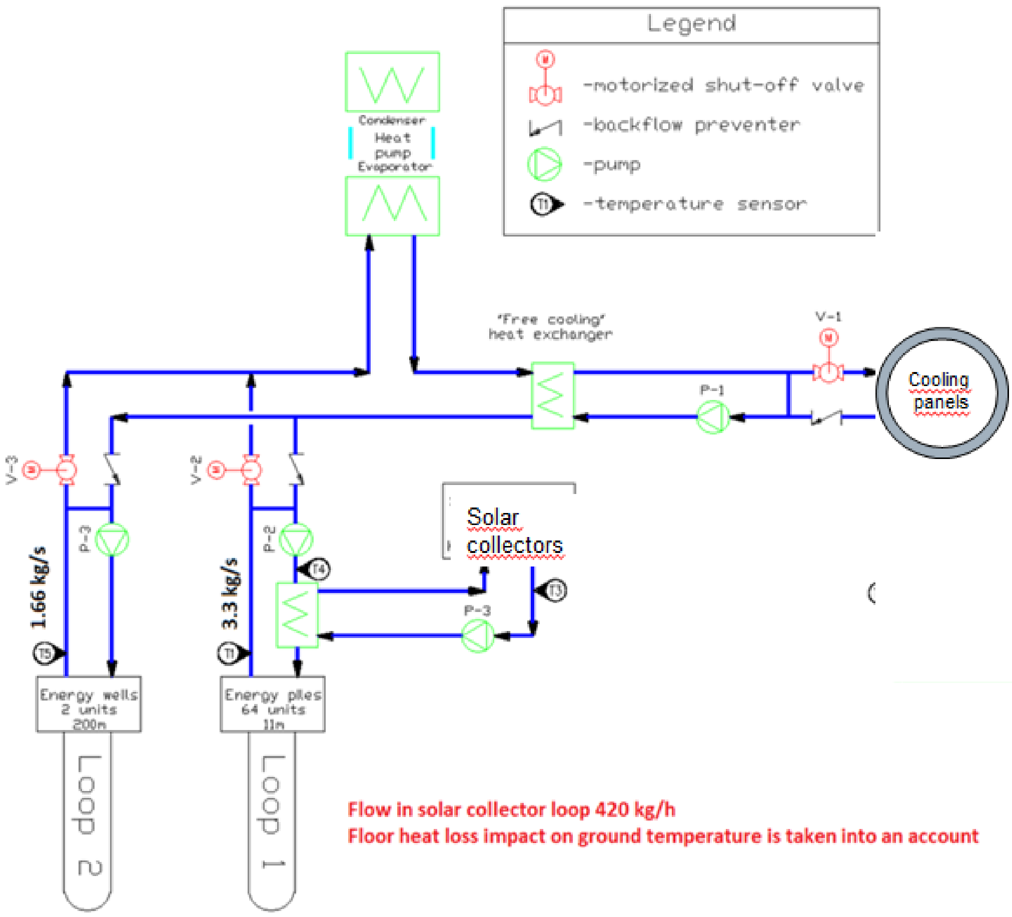

Figure 8: Ground energy system

2.5 Building Integrated Solar Energy Solution

Solar power is also used in the outer walls of the building. Ruukki Construction's on-wall solar panels, which generate electricity from the light of the sun for the building's network, are installed on its southern façade. A total of 61 m^2 PV (Photovoltaic) panels with total peak power of 10 kW are incorporated in the wall (see Figure 9). The optimum amount of solar PV-panels is based on buildings own electricity, because it's not economical to feed extra electricity into the public electrical network. Total electricity production of the system is about 7 MWh/year. In Finnish latitude the on-wall system is relatively effective, because of low angle of the sun.

Figure. 9: Building-integrated solar PV panels installed on the southern facade

2.6 Monitoring of the building

The building is equipped with a large number of energy meters and other measuring devices to ensure extensive monitoring and ascertain the real energy performance of the building. In particular, the energy pile and solar heat systems are monitored carefully to study the soil behaviour in the long run. Some building elements are also equipped with thermal-moisture sensors in order to monitor their condition throughout their life-cycle. Furthermore, the amount of snow on the roof is also monitored with a Ruukki Smart Roof application based on strain gauge measuring of the metal roof structure.

3 Building simulations

The energy efficiency of the reference building and the nZEB were determined by energy simulations with the IDA ICE 4.5 program (Equa Simulations 2014). The simulations were performed by Ruukki and Tallinn Technical University. The reference building represents the current normal, already very energy-efficient, construction custom. A simulation model included a model of the building with the structures and technical systems as well as the energy piles and heat wells. The initial data for the reference case and the nearly zero-energy case are given in Table 1. Many different alternatives were studied in order to find optimum solutions to the whole building. Special attention was paid to design and model the energy pile system carefully to guarantee long-term performance of the system. One important observation of the simulation was that further to recharging the soil with solar energy, heat losses though floor structures also help to keep energy pile field well balanced.

The final results for the energy demand and the delivered energy are shown in Tables 2 and 3. A comparison of delivered energies of the cases is given in Figure 10. The results show that it is possible to over than halve the total energy use of a building with smart design and solutions.

Table 1: Initial data for simulated cases

	Reference	nZEB
Wall, U-value	0.17 W/m2K	0.16 W/m2K
Roof, U-value	0.09 W/m2K	0.12 W/m2K
Window, U-value (avg)	1.0 W/m2K	0.87 W/m2K
Floor	EPS 150mm, ʎ=0.034	EPS 150mm, ʎ=0.034
Infiltration q50	4 m^3/ m^2 h	0.76 m^3/ m^2 h
AHU Heat Recovery	50%	80%
Lights	15 W/ m2	9 W/ m2 (LED)*
Domestic Hot Water	68 l/ m2 a	68 l/ m2 a
People	30	30
Fresh air (SFP=2.0)	1.5(2**) l/sm2	1.5 l/sm2
Temp. set points	18°C /25°C	18°C /25°C
Heating system	Air-heating	Radiant heating
Energy source	District heating	Ground heat pump***
Cooling SEER	2.5	free cooling
Schedule	8–17 weekdays	8–17 weekdays

*day-lighting control in 2/3 part of the building based on lighting level of 300 LUX
**overall rate with air-circulation in air-heating case
***SCOP 2,7 (including circulation pumps and heat distribution losses)

Table 2: Energy demand and delivered energy of the reference case

	Energy demand		Delivered energy	
	kWh	kWh/m2	kWh	kWh/m2
Heating	88272	59.0	88272	59.0
Domestic Hot Water	5918	4.0	5918	4.0
Cooling	8502	5.7	3401	2.3
Fans electricity (SFP=2.0)	18498	12.4	18498	12.4
Pumps electricity	79	0.1	79	0.1
Lighting	51178	34.2	51178	34.2
	Total distr. heat:		**94190**	**63,0**
	Total electricity:		**73156**	**49,0**

Table 3: Energy requirements and energy inputs of the nZEB case

	Energy demand		Delivered energy	
	kWh	kWh/m2	kWh	kWh/m2
Heating energy	65619	43,8		
-Heat pump			13490	9.0
-Top-up heating			4340	2.9
Domestic Hot Water	5918	4.0	3694	2.5
Cooling	3353	2.2	0	0
Fans electricity (SFP=2.0)	14302	9.6	14302	9.6
Pumps electricity	6254	4.2	6254	4.2
Lighting	19498	13.0	19498	13.0
	Total electricity:		**61578**	**41,2**

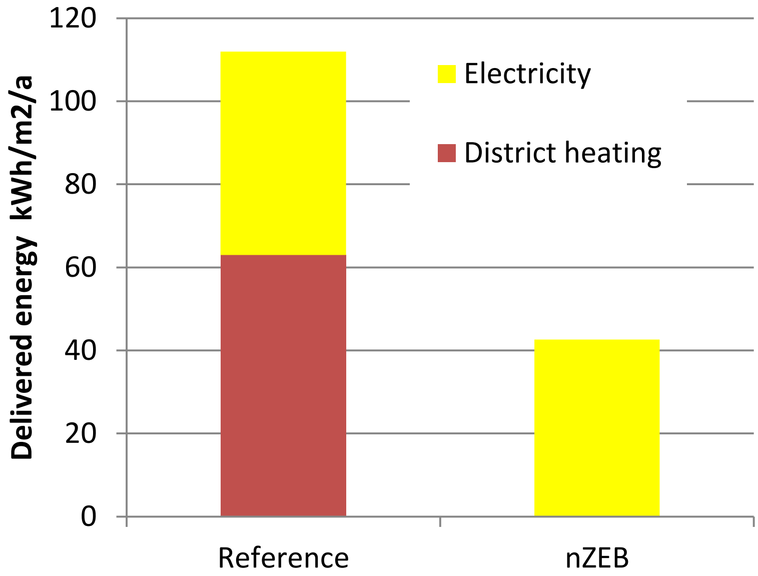

Figure 10: Comparison of deliverd energies of the reference case and nZEB case

Furthermore, the annual yield of the building-integrated solar PV panels is approximately 7000 kWh/a. Thus the need for delivered energy decreases further by approximately 5 kWh/m^2, corresponding to a decrease in a primary energy use over 10%.

As yet there are no official requirements for nearly zero-energy levels in Finland, but the proposals made in the national “FInZEB” project (FInZEB 2015) indicate that this building would clearly meet future targets.

4 Economic feasibility studies

Economic feasibility studies and comparisons between the two cases were carried out. The economic calculations took into consideration all investment costs that differed in the two cases as well as future energy savings due to improved energy efficiency. The net present values of the future savings were determined based on a 6% interest rate and a 4% increase in the energy price. The initial price of electricity was 85 €/MWh and 65 €/MWh for district heating. All prices are excluding VAT. The results are shown in Figure 11. As Figure 11 shows, the nearly zero-energy solution is economically reasonable, with a payback period of around 9 years. Also, it should be noted that the real extra investments of the nZEB solution are only about 2% of the total construction costs. Solar PV installations are not included in the studies, because they were not included into the original design and their impact is easy to separate from the overall building energy performance. The separately calculated payback for solar PV installations is approximately 15 to 20 years.

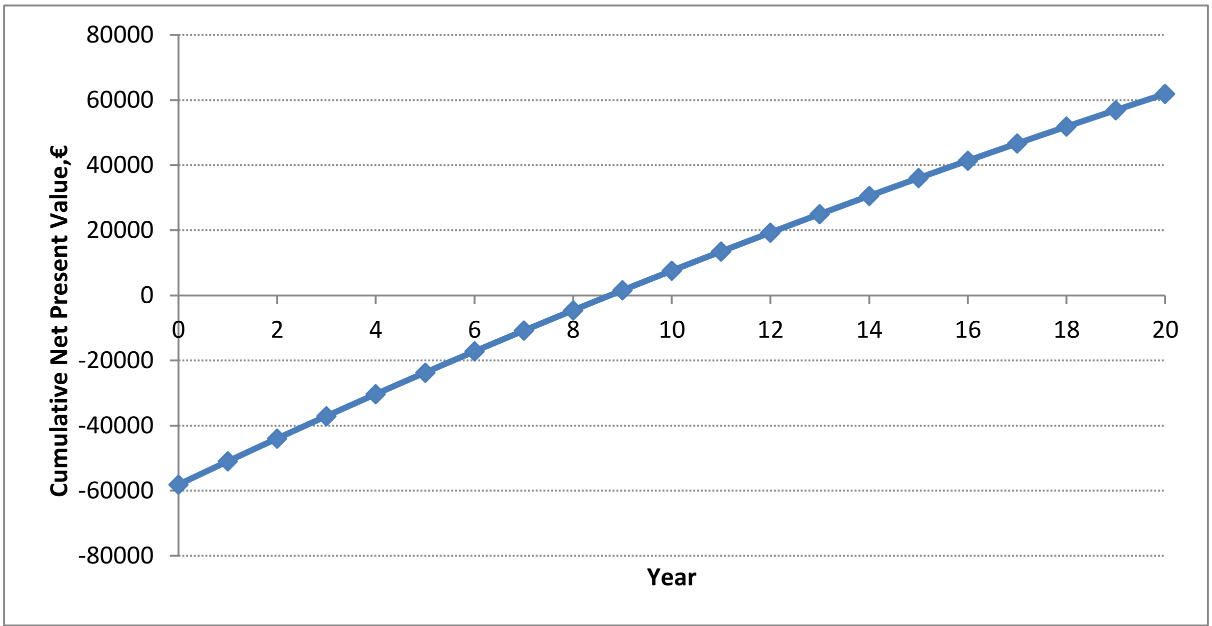

Figure 11: Net present values for the nearly zero-energy building compared to the reference building

5 Conclusions

The project showed that the nearly zero-energy building is technically feasible if the energy demand of the building is reduced and renewable energy sources are utilized in a smart way. Energy simulation tools came in handy in the early design phase of the project. Air-tightness of the building proved to be one of the most important factor in the reduction of energy demand. Lighting simulations showed that there is also lot of potential in utilization of daylighting in this kind of buildings. Solar collector boosted energy pile system proved to work well to produce heating energy to the near-zero energy building. The project also showed that the nearly zero-energy buildings can be constructed in a Nordic climate in a cost-efficient way. The extra costs of energy efficiency may be very low if the building is optimized as a whole – not via sub-optimizing.

Notation

AHU	Air Handling Unit
EPS	Expanded Polystyrene
SCOP	Seasonal Coefficient of Performance
DHW	Domestic Hot Water
nZEB	Near Zero Energy Building
SEER	Seasonal Energy Efficiency Ratio
HR	Heat Recovery of the ventilation system
q_{50}	Air-tightness of the entire building [$m^3/(h \cdot m^2)$]
PIR	Polyisocyanurate insulation
SFP	Seasonal Factor of Performance
U-value	Heat conductivity [$W/(m^2 \cdot K)$]
VT	Visual Light Transmission

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A Study on Life-cycle Environmental Management of Civil Transportation Airport

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Abstract

In recent years, many new, enlarging and rebuilding civil transportation airports are under construction along with economic development. But the problems of environmental damage of civil transportation airports which have caught more and more attention in public are becoming the barrier to the civil aviation development. Based on the theory of environmental sociology, sustainable development and green airport, this paper have summarized the environmental management measures of international civil transportation airports and the laws related airport environmental of different countries. Then the life-cycle environmental management system framework of civil transportation airport is put forward, which points out that environmental management require integrated management through three dimensions, namely environmental management contents dimension, life cycle dimension and environmental management technology dimension. At last, in order to offer a new possible method for airport environmental management in operating period, the early warning system of civil transportation airport based on gray system theory is established and proved feasible through a simple case. The results of this paper can be the theoretical basis for the life cycle environmental management of civil transportation airport and contribute to solve the existing problems of environmental management of civil transportation airport.

Keywords: civil transportation airport, environmental management, life-cycle, environment early warming, grey system theory

1. Introduction

The amount of civil transportation airports is continuously increasing as the development of economy and the improvement of people's demand. However, the development of civil aviation industry has brought serious environmental pollution (Chen, Z., Li, H., & Hong, J., 2004) which causing that people living near the airport put up protests against airport pollution more frequently in recent years. For example, the Heathrow Airport (UK) expansion project has been protested because of environment pollution (BBC news, 2015) and Frankfurt airport has been protested by nearby residents for more than 10 years because of night flight noise pollution (Ta Kung Pao Hong Kong, 2012). Civil transportation airports projects have a great impact on the environment in construction period and operating period, so the environmental pollution problems will be a main barrier to the development of civil transportation airports in both the present and the future.

FAA (Federal Aviation Administration, 2012) pointed out that the environmental problems of airport are the most important in the design and operation of a new airport. At present, the developed countries usually publish various laws and regulations related airport environmental to regulate the construction and management of airport. International airports have their own methods of environmental management, including recycling, low-carbon and intelligent measures. We have sort out some environmental management measures of airports, as show in Table 1.

Table 1 Environmental Management Measures of Airports

Airport Name	Environmental Management Measures
Manchester Airport (UK)	Integrate environmental management into the business operation.
Oakland International Airport (American)	Implement the strategy of sustainable development including includes three parts: environmental responsibility, economic vitality, social equity; draw up rules of plane landing and taking off at night; build the noise isolation area near the airport.
Heathrow airport (UK), Hamburg airport (Germany), Frankfurt airport (Germany), De Gaulle airport (France) and Narita airport (Japan)	Charge relevant fees according to the noise DB level.
Phoenix Sky Harbor International Airport (American)	Through well design in the construction, every energy consuming equipment of the airport is intelligent which is able to be automatic power off when is not required
Athens International Airport (Greek)	Provide 422000 m^3 reuse water for agricultural irrigation
Guangzhou-Baiyun International Airport (China)	Put the idea 'land conservation, energy conservation water conservation, material conservation' into planning and design
Beijing Capital International Airport (China)	Reduce energy consumption of air conditioning and lighting by using advanced technology and materials

In 2007, the Civil Aviation Administration of China brought up the concept of green airport for the new Kunming International Airport, then the concept of green airport begin to be prevalent in the Chinese civil aviation industry. The new Kunming International Airport demand all design units reflects green airport in the general planning, engineering design, etc. However, most of the policies and measures of environmental management of airport in China are limited in solving environmental problems after pollution. It has not established the life cycle environmental management system framework of civil transportation airport projects in China. Based on the successful experience of civil transportation airports of China, this paper will put forward the life-cycle environmental management system framework of civil transportation airport is put forward.

2. Literature Review

There are also many researchers researched several related studies of airport environmental management. Kılkış (2014) simulated Istanbul Airport to forecast the position of the airports and point out the importance of environmental influence analysis as well. He got more knowledge of the influence of the terminal energy consumption and which elements played a decisive role in carbon emission by analyzing the energy of terminal. Bartels, Muller and Vogt (2013) interviewed residents around Cologne Bonn Airport about the satisfaction of the airport by phone survey, and the results showed that residents around the airport hold the trust that administrators will improve the living environment by taking some measures. Bartels, Márki and Müller (2015) pointed out that the noise figure of planes was not only considered about outdoor sound pressure level, the number of planes was also concerned. And this conclusion had a certain referential significance of how to reduce the noises. Duinkerken, Selderbeek and Lodewijks (2013) revealed that single engine glide, operation pulling and electro-motor putting on aircraft wheels can all reduce the carbon emission of airport. Electro-motor method got the most obvious effect on saving the plane launch cost and carbon emission. Zheng, R. H., et al(2008) analyzed the features of airport environment influence factors to build an evaluation index system of airport environmental impact, meanwhile he also built a comprehensive evaluation matter-element model with multiple index and layers of the airport environmental impact based on matter element analysis theory. Shen Y. (1999) proposed four ways: airport management measures, airport engineering measures, plane measures and airport auxiliary measures to solve the airport noise problem, she then suggested the airport administrative department to build professional management organization and also bring in legislative regulation. Tang X.Y. (2008) put forward that Green Airport idea should be throughout every steps during the airport construction and operation process, and airport garbage harmless treatment as well as resource comprehensive utilization project were suggested to be put into effect. Li Longhai(2008) focused on power saving goal, used passive energy conservation design method to plan the airport site in an overall point of view combined with the airport energy consumption analysis, and then the airport adapted to the site environment to achieve the energy saving. He did energy-saving design to the airport terminal in every building design, and stated that there are two aspects in the concept of Green Airport: conservation and environmental protection.

3. Research method

This paper mainly involves the theory of environmental sociology, sustainable development theory, and green airport. Environmental sociology focus on research interactive relationship between environment and human society (Hong D.Y., 2009), so environmental management of civil transportation airport is one of the important researches of environmental sociology. Sustainable development theory was becoming a hot topic in the environmental field which required the span of environmental management extended to life cycle from the early stage to the operating period (Blewitt, J., 2014). The theory of green airport demand that comprehensive measure should be taken for keeping a harmonious coexistence of human being with the environment (The headquarter of Shanghai airport construction, 2010).

Based on the theory of green airport, environmental sociology and sustainable development theory, this paper have studied airport environmental regulations made by international civil aviation organizations and understood the airport legislation situations aiming to solve environmental pollution in countries around the world. We used the method of induction and extracted current situations to find effective practices which have been examined by applications in the past, combined with the regulations and practices of airports around the world, then they will be introduced into the effective environmental management system of civil transportation airport. Afterwards, the paper will put forward the life cycle environmental management system framework of civil transportation airport based on the practical experience of China large airport construction. This system can comprehensively and effectively improve the civil transportation airport environmental management status quo.

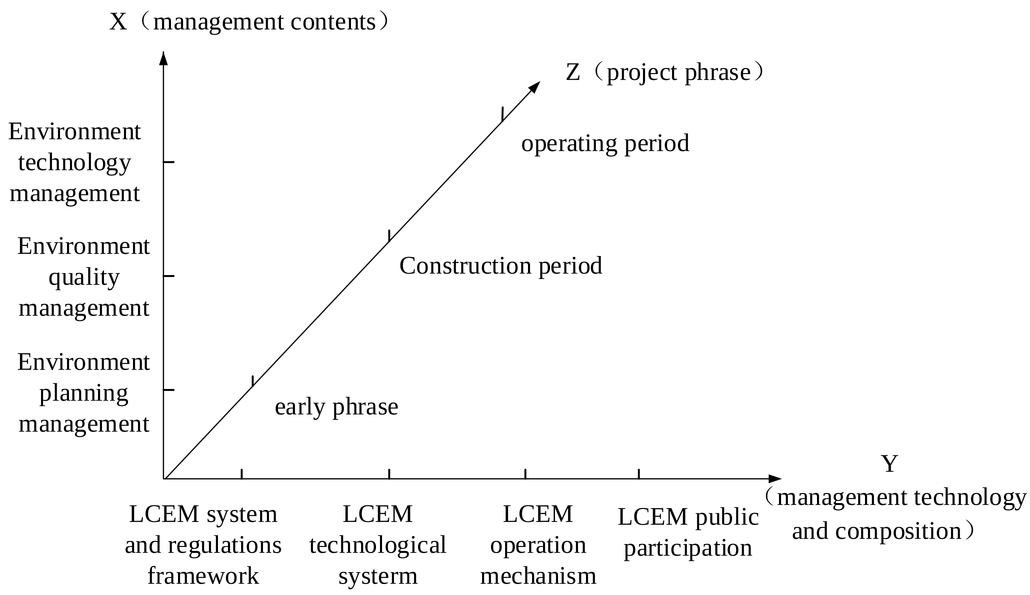

Fig. 1 The framework of the LCEM system of civil transportation airport

4. Life cycle environmental management framework of civil transportation airport

4.1 The part of life cycle environmental management framework of civil transportation airport

The life cycle environmental management (LCEM) system of civil transportation airport project includes three-dimensional space composed of X, Y, Z axis, as shown in Figure 1. The X axis shows three main environmental management contents of life cycle environmental management in the graph, the Y axis shows four management technology parts of environmental management in civil transportation airport construction project, and the Z axis represents three phrases of civil transportation airport project.

4.2 The introduction of life cycle environmental management framework of civil transportation airport

4.2.1 Project phase of life-cycle of civil aviation airport

The Z axis of the framework is divided into early phase of construction, construction phase and operation phase according to the whole life cycle. The national regulations and policies related to environment are mainly for regulating various behaviors in the life-cycle of civil transportation airport and limiting the activities which can cause damage to the environment quality, and then to achieve sustainable development of civil transportation airports. Because of the different pollution sources in three stages, the management of each stage is different. The pollution sources of each phase is shown in Table 2.

Table 2 Pollution sources in project phase of life cycle

Life-cycle of civil transportation construction	pollution sources	influence
Early phase	Environmental impact on the operation: determine airport location, traffic planning, airport design and planning, afforestation level	The planning and design phase does not produce pollution, but the results will affect the environmental management of construction and operation period.
Construction phase	(1) construction noise; (2) dust; (3) water pollution; (4) air pollution; (5) construction waste	Strengthen the relevant measures to control;
Operation phase	(1) great energy consumption; (2) low utilization of energy; (3) high maintenance costs; (4)great pollution;	Bring about main impact to the environment, which phrase the environmental management focus on.

4.2.2 Life cycle environmental management technology of civil transportation airport

The Y axis of the framework shows that the life cycle of civil transportation airport is classified by management technology and composition. The life cycle environmental management system of civil transportation airport construction project can provide comprehensive support and guarantee for protection work. The main contents of the whole life cycle environmental management system of civil transportation airport construction projects is shown in Table 3.

Table 3 Environmental management system of the whole life cycle of civil transportation airport

<table>
<tr><th>Phrase / Composition</th><th>Early phrase</th><th>Construction period</th><th>Operation period</th></tr>
<tr><td rowspan="2">Institutions system and regulations frame</td><td>Environmental impact assessment System</td><td>Environmental supervision system;
"Three simultaneous" system;
Environmental protection completion acceptance system</td><td>Environmental post-assessment institutions</td></tr>
<tr><td colspan="3">Public participation system</td></tr>
<tr><td>technical method system</td><td>Environmental assessment for planning;
Project environmental assessment;
Environmental design;</td><td>Environmental protection design for construction organization;
Environmental supervision;
Environmental protection acceptance</td><td>Environmental post-assessment</td></tr>
<tr><td rowspan="2">Management operation mechanism</td><td>Environmental policy formulation;
Environmental planning</td><td>Implementation and operation;
Inspection and corrective actions</td><td>Management review</td></tr>
<tr><td colspan="3">Preventive mechanisms (professional management, supervision and inspection management, integrated coordination management), the punishment mechanism</td></tr>
<tr><td>Public participation</td><td>Public consultation</td><td>1.media publicity and supervision;
2.set up public representatives
3.hotline telephone consultation
4.public reception day</td><td>public opinion survey</td></tr>
</table>

Life cycle environmental management institution system and regulations framework of civil a transportation airport is a collection consists of environmental management systems, as shown in figure 2. It mainly include: the environmental impact assessment system in project planning phase and feasibility study phase; "three simultaneous" system, which mainly aims to put forward the requirements and regulations for hardware construction of environmental protection facilities; environmental protection acceptance system, aiming to implement the inspection and evaluation the environmental protection measures in whole processes (Deng T.J., 2009). Moreover, it also include three system which are studying and trying in China, name Environmental supervision system, aiming to manage the environmental behavior of whole construction process; Post environmental assessment system, mainly for the environment management of operation phrase, checking and review the environmental protection work before operation phrase; Public participation system, it means environmental protection needs the public participation in whole life cycle of the project so as to monitor the environmental management of all aspects and improve environmental management work.

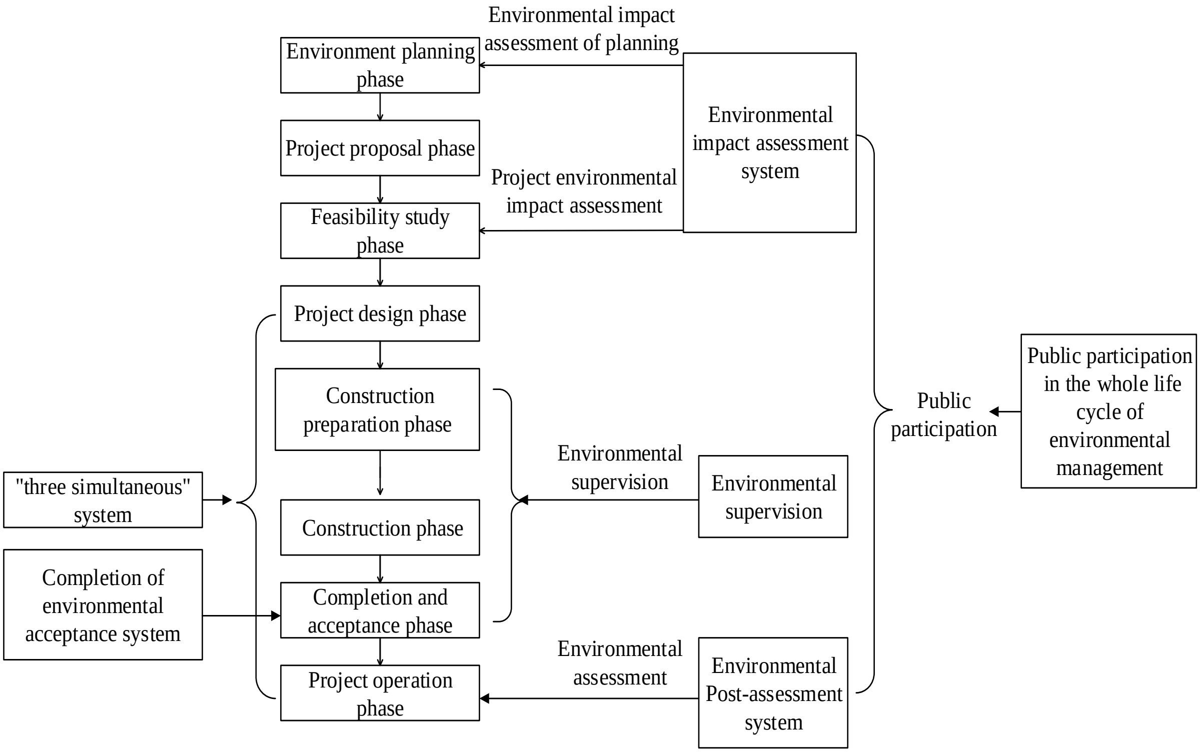

Fig. 2 Environmental management system of life cycle construction project

The establishment of life cycle environmental management technology and method system of civil transportation airport construction project is from the perspective of technical approach. In order to improve the existing environmental management techniques and methods of the civil transportation airport construction projects, such as the planning assessment, environmental assessment, environmental design and environmental protection acceptance and improve efficiency, we analyze the different environmental impact and management requirements. The effective use of the life cycle of environmental management techniques is conducive to the implementation of environmental protection measures.

Building the life cycle environmental management operation mechanism, mainly based on the ISO14000 environmental management system and ISO9000 quality standard management system, is an important component of the life cycle environmental management of civil transportation airport. This operation mechanism will cover the process from environmental policy formulation, environmental planning to operation, check and evaluation which can complete the environmental management process systematically accompanied with overall process prevention and punishment mechanism. Carrying out the life cycle environmental management operation mechanism in overall civil transportation airport construction project helps to build an international widely recognized, standardized, systematic environmental management paradigm.

Public participation method is another basic method of environmental management. Building the public participation mechanism and approach of raising the participation is the basic of this method. This method is an important institutional guarantee for reducing environmental decision-making errors, and perfected the content of life cycle environmental management system of civil transportation airport construction project.

4.2.3 The contents of life cycle civil transportation airport management

The X axis of the framework is classified by the management contents. The contents of life cycle environment management of civil transportation airport can provide the comprehensive content formulation and guidance for the environmental protection which promoted the comprehensive, perfection and validity of the environmental management. And the contents are reliable technical supports for the life cycle environmental management. The contents of life cycle environmental management of civil transportation airport was shown in Table 4.

Table 4 The contents of life cycle environmental management of civil transportation airport

Phrase / Contents	Early phrase	Construction period	Operating period
Environmental Technology Management	1. Reasonable site selection 2. Reasonable layout 3. Choose environmental friendly equipment and materials 4. Technology and system upgrade 5. Formulate rules for technology execution	Pollution prevention and technology control of construction	Pollution Abatement Technology (noise, air, land surface, solid waste, etc.)
Environmental Quality Management (QM)	1. Establish the quality index system 2. Environmental facility design 3. Develop environmental management system	1. QM of construction environmental factors (water, noise, air) 2. QM of construction environmental facilities (greening, health facilities, municipal facilities) 3. QM of construction environmental management	1. QM of operation environmental factors (water, noise, air) 2. QM of operation environmental facilities (greening, health facilities, municipal facilities) 3. QM of operation environmental management
Environmental Plan Management	Develop environmental policies and standards	1.Technical comparison and economic comparison 2.Cost optimization	1. Assessment and acceptance of results 2.Technology promotion

Environmental technology management study the method and system of technology management of the construction life cycle of civil transportation airport from the perspective of technology. The technology management is integrated management of technology and technological base of the environment protection. Effective environmental management of technology can improve the usage of environment technology and environment protection in the life cycle of civil transportation airport construction project.

Environmental quality management can be divided into quality management of environmental factors, quality management of environmental facilities and quality management of environmental management. Institutions and index system development are emphasized in the early stage of construction, and specific management quality evaluation is emphasized in construction stage and operation stage. Environmental quality management can improve the quality of the practice of environmental management, and can also contribute to the implementation of life cycle environmental management measures of civil transportation airport construction project.

Environmental plan management aim to improve the environmental management level on the experience and method aspects. Through developing policies to prevent in advance, optimizing in the process and post evaluation, environmental plan management provided experience accumulation and technical promotion at present and in the future for environmental management. It is also an important guarantee for reducing waste in the process of environmental management. And it can improve and perfect the existing environment management content.

5. Study on environment early warning of operating period of civil transportation airport based on gray system theory

The study on environment early warning of operating period of civil transportation airport can provide useful information for environmental management and improve environmental management level of civil transportation airport. Grey system theory is a kind of deepening and development of system thought. Grey forecasting model is a kind of short-term forecast tool, it can forecast the objects with raw data, and has higher prediction accuracy (Deng J.L., 2002). Modeling is based on the past and present known or unknown information, establish a GM model from the past to the future, to determine the trend of the future development of the system, to provide a basis for planning and decision-making. In this paper, the early warning of air pollution in civil airports, to a certain extent, shows regularity with the time change, and its index data has the character - small sample and poor information, so it is suitable to use gray system theory for early warning.

5.1 Selecting early warning factors

The environmental problems of civil transportation airport commonly include noise pollution, air pollution, water pollution, solid waste pollution and land use problems. The purpose of early warning is to provide support for decision-maker to develop solutions of environmental pollution. Typically, different environmental problem have different solution and different early warning system of environmental problem has similarity. So this section will only establish one warning system for one of the environmental problems. And the main purpose of this section is to discuss the feasibility of using the gray system theory in the environmental early warning of civil transportation airport, so in order to simplify study process, we select the concentration of NO_2 which is easily getting as the only early warning factors.

5.2 Defining the early warning standard

According to Chinese ambient air quality standards, we develop the ambient air quality standards and early warning standards, as shown in Table 5.

Table 5 Ambient Air Quality Standards

Pollutants	level	concentration limit mg/m^3 (standard state)			air quality	Warming level
		annual average	daily average	hourly average		
NO_2	grade I	<0.04	<0.08	<0.12	Good	-
	grade II	>0.04	>0.08	>0.12	Moderate	blue
	grade III	>0.08	>0.12	>0.24	lightly polluted	yellow

5.3 Establishing early warning model based on gray system theory

(1) The NO_2 concentration of 5 consecutive days of Shanghai Pudong International Airport is shown in Table 6. (If you want to predict for longer period, you can choose the three day or week average value of NO_2 concentration as basic date.)

Table 6 The NO_2 concentration of Shanghai Pudong International Airport

Date(Year 2010)	June 13	June 14	June 15	June 16	June 17
NO_2 concentration	0.103	0.109	0.117	0.116	0.121

(2) Building matrix based on gray system theory

According to grey prediction *GM (1, 1)* model,

$$B = \begin{pmatrix} -\frac{1}{2}[x_1(1) + x_1(2) & 1 \\ -\frac{1}{2}[x_1(2) + x_1(3) & 1 \\ \cdots & \cdots \\ -\frac{1}{2}[x_1(n-1) + x_1(n) & 1 \end{pmatrix} = \begin{pmatrix} -0.106 & 1 \\ -0.1645 & 1 \\ -0.2225 & 1 \\ -0.283 & 1 \end{pmatrix},$$

$$Y_n = [x_0(2), x_0(3), \cdots x_0(n)]^T = [0.109, 0.117, 0.116, 0.121]^T.$$

Then according to the formula "$\hat{a} = [a, u] = (B^T B)^{-1} B^T Y_n$", we can get the value of a and u and establish the early warning model.

(3) Calculating

Due to the complexity of the calculation, we use the computer software 'math tool' to carry out the calculation. Sort out the calculation results to form and calculate absolute error and relative error, as shown in Table 7.

Table 7 relative error and the average of relative error

date	actual value	predictive value	absolute error (residual error)	relative error
June 13	*0.103*	*0.103*	*0*	*0*
June 14	*0.109*	*0.1106*	*-0.0016*	*-0.01468*
June 15	*0.117*	*0.1139*	*0.0031*	*0.026496*
June 16	*0.116*	*0.1174*	*-0.0014*	*-0.01207*
June 17	*0.121*	*0.121*	*0*	*0*
average	-	-	-	*0.011*

5.4 Model precision verification and prediction results analysis

According to the relative error of residual error, we can easily figure out the posterior error C = 0.0021. According to the precision requirement of the grey system theory, the established early warning model is qualified when the posterior error C is less than 0.5. So the early warning model can objectively reflect the dynamic changes of air quality. In other word, the model can be used to predict the value of air quality index.

We can predict the NO_2 concentration of June 18 to June 20 through the early warning model. The prediction results are shown in Table 8.

Table 8 Prediction results

Date	June 18	June 19	June 20
NO_2 concentration	0.1247	0.1285	0.1324

Through the prediction results in Table 6, we can know that the NO_2 concentration is greater than 0.012 and less than 0.024 from June 18 to June 20. So the air quality is moderate according to the Table 3, and the warming level is blue. And the prediction results proved that using the gray system theory in the environmental early warning of civil transportation airport is feasible.

6. Conclusions

According to the problems of environmental management in the development of civil transportation airport, this paper puts forward the life cycle environmental management system from the perspective of practice and specifies the system need to include environmental management content dimension, life cycle dimension and management technology dimension. And then the early warning system of operating period of civil transportation airport based on gray system theory is established and proved feasible through a simple case. The results of this paper can provide the theoretical basis for the life cycle environmental management of civil transportation airport and contribute to solve the existing problems of environmental management of civil transportation airport. The study in this paper has a great significance for the development of civil transportation airport in the environmental protection.

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SECTION

6

Building information modelling (BIM)

BIM tools and modelling guidelines proposed by a Brazilian public bank

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Abstract

The Brazilian public bank described herein, Caixa Econômica Federal, is essentially a financial institution, which has also historically maintained a technical department comprising more than two thousand civil engineers and architects. These professionals perform technical feasibility analyses of infrastructure and housing projects that apply for public financing. Due to this peculiarity, this public bank is one of the most important stakeholders in the Brazilian Architecture, Engineering, Construction and Operations (AECO) industry. Currently, the project analysis process is manual, paper-based, time and labour consuming. Facing this situation, the institution has established tasks likely to be automated through BIM (Building Information Modelling), and is now pursuing its adoption. Since there are not official modelling standards in Brazil, establishing them was deemed necessary to enable a BIM-based project analysis in a near future. The aim of this paper is to analyse the proposed innovation through a discussion group that has experimented modelling with the guidelines and tools proposed by the bank. The purpose is to determine whether the proposition is viable and if future users will be willing to adopt it. Although the evaluation of the tools and project template proposed were positive, the results showed a broader issue of segregation between the disciplines of design and cost estimation. Those results may influence not only the acceptance of the technological innovation proposed by Caixa, but BIM adoption in Brazil in general.

Keywords: BIM, Feasibility analysis, Standardization, Modelling Guidelines

1. Introduction

Caixa Econômica Federal (Caixa for short hereafter) is a Brazilian public bank leader in financing construction and in transferring federal resources for public infrastructure and social housing. It holds a 67.7% share of the Brazilian housing financing market, which reached US$ 127.81 billion[1] in 2014. The public infrastructure portfolio, which enables investments in the fields of urban mobility, energy, logistics, sanitation and others, presented a total balance of US$ 21.33 billion

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[1] The conversion rate applied was US$ 1.00 = R$ 2.6587 (current exchange rate in December 2014).

in 2014, an increase of 52.8% compared to the previous year, and a total volume of new contracts of US$ 12.52 billion (Caixa Econômica Federal, 2014).

The institution currently has 97,900 employees, and over 2,000 of them are engineers and architects, working in 74 regions in the country. Since there is a significant deficiency in construction and building regulation control in Brazil, the institution has been playing an important role performing technical feasibility analysis and verifying projects' suitability. Caixa is a notable improvement driver in the Brazilian civil construction industry through its requirements for project financing. An example is the demand that all low-income and social housing construction companies must be certified by the Brazilian Program for Housing Quality and Productivity (PBQP-H) (Ministério das Cidades, 1998).

The main objective of the technical department is to analyse the operations to ensure that the resources are correctly applied. Therefore, the work is dictated by a strict set of rules that are based on laws, public procurement regulation and demands by federal investments funds. A technical analysis of proposals verifies their compliance with the funding program guidelines, the suitability of the design to the intervention site, its functionality and technical feasibility, all combined with a verification of cost and schedule.

Currently, the analysis process is manual, paper-based, time and labour consuming. All documents are provided on paper, in an extremely bureaucratic process. The design is manually checked, and the most time-consuming task is the quantity take-off for comparison with the proposed budget. Facing up to this situation, the bank has established tasks likely to be automated through BIM (Building Information Modelling), and is now pursuing its adoption (Ferrari and Melhado, 2015). Automated design checking and cost checking are the two most critical activities and the latter was chosen to start the adoption of BIM by the institution.

Since BIM adoption rate in Brazil is low (McGraw Hill Construction, 2014), and there is not a national guide or reference for BIM-based design in Brazil, the institution believes that it is essential to provide modelling guidelines and tools in order to obtain project files adequate for analysis.

The aim of this paper is to analyse the proposal being developed for modelling guidelines and tools, considering that, if approved, it has the potential to become a national standard. The research method applied is the proposition of a structured exercise using the suggested Revit project template and two plug-ins, followed by a discussion group and a questionnaire. The purpose is to determine whether the proposition is viable and if future users will be willing to adopt it.

2. Research Context

2.1 Caixa Econômica Federal as a Policy Maker

In 2013, McGraw Hill Construction (2014) conducted a research that pointed out that 55% of the Brazilian contractors declared to have low BIM engagement, 70% claimed to have been using BIM for no more than two years, and 75% stated that less than 30% of their projects are in BIM. These data indicate that Brazil was still at an initial level of BIM adoption.

Referring to Succar's BIM Capability Stages (Succar, 2010), the Brazilian Architecture, Engineering, Construction and Operations (AECO for short hereafter) Industry is pursuing BIM Stage 1, which is object-based modelling. Caixa Econômica Federal is considered in this paper as a *Policy Maker* (Succar and Kassem, 2015) due to its potential to disseminate standards, regulations, guidelines and best practices throughout the AECO Industry, therefore playing an important role in the diffusion of this new technology.

Although this Brazilian public bank has the prerogative to be a coercive and normative stakeholder, pressuring a top-down diffusion (Succar and Kassem, 2015), it has first adopted a passive approach, which consists, as Succar and Kassem point out, in making others stakeholders aware, encouraging and observing BIM adoption.

The institution acknowledged that the absence of modelling standards, guidelines and regulations would be a major barrier for any technological innovation in this area. Therefore, the efforts are towards providing tools and guidelines to the AECO Industry to allow a BIM-based project analysis, in a near future.

2.2 Guidelines and tools proposed

The proposal analysed herein was developed by a consulting company initially to solve an internal problem caused by restructuring in the National System of Costs Survey and Indexes of Construction (SINAPI for short hereafter), which is maintained by the institution and adopted by the government for public works budgets. Cost components were recently revised to consider more accurate rates of productivity (Oliveira et al., 2014), resulting in greater difficulty in choosing the correct cost component for each budget item. For example, a masonry wall that was previously associated with just one cost component now has its costs subordinated to the length of the wall, the existence of openings and to the type of mortar mix (mechanical or manual).

A project template and two plug-ins were developed in order to assist the cost estimator in choosing the right budget component for each design object, by filtering the options based on modelled characteristics or imputed information to the design. Revit was chosen due to its large diffusion in the Brazilian AECO Industry.

Firstly, to ensure standardization, a project template was conceived including loaded families and defined settings in order to provide a starting point for new projects (Autodesk, 2015). Thus, it is guaranteed that the data used in the model have the characteristics necessary for the proper functioning of plug-ins.

Secondly, two plug-ins were developed for Revit. One of them helps creating wall coverings as separated walls, so the designer is able to easily define different characteristics for each (wall plug-in hereafter). Through this application, the user chooses a room to establish settings and select from a list of coating materials (pre-determined in the template) defining its height and thickness. The plug-in automatically creates a separate wall element for each coating layer attributed, which subsequently facilitates its handling and quantification.

Finally, another Revit plug-in (SINAPI plug-in hereafter) was developed to assist the specification of materials and components for each element modelled, relating them to a SINAPI cost element. As shown in Figure 1, in each room it is possible to select materials filtering possibilities according to the characteristics of the modelled object and enabling to export data to finalize the budgeting process.

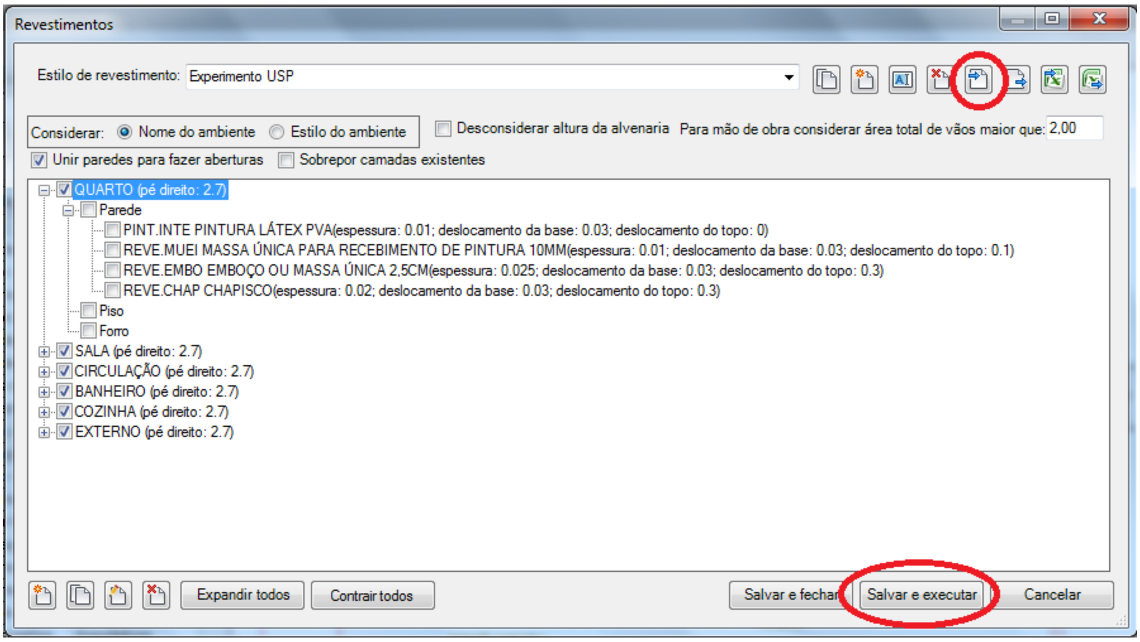

Figure 1: SINAPI plug-in

3. Methodology

The benefits of BIM utilization are not yet established clearly and empirically; thus the decision of adoption is often based on speculated benefits (Barlish and Sullivan, 2012). Consequently, verifying the user's behavioural intentions towards the proposed technological innovation was considered important.

The research method applied was a group discussion in which a modelling exercise was proposed, followed by a structured and supervised discussion among the participants, and finally, at the end of the oral discussion, the participants answered a small questionnaire. The purpose was to encourage a widespread debate among research participants, thus verifying the real applicability of the proposed tools and project template.

The modelling exercise was developed so that the proposed project template and plug-ins would be employed in a real situation. The exercise consists in modelling a small house, applying its components and materials, and lastly creating a construction budget by choosing a cost component from SINAPI for each element of the model (Figure 2).

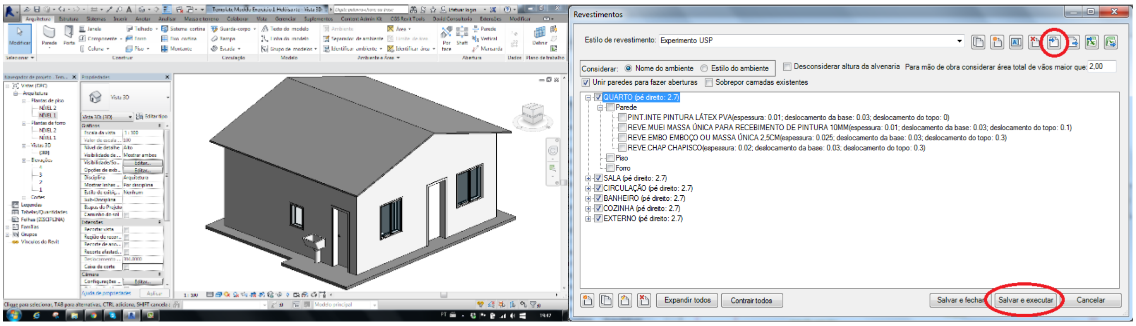

Figure 2: Screen capture of the exercise

To make sure that they would employ the tools correctly, a specialist guided the participants throughout the exercise. All the notes and questions were recorded along with their comments during the guided discussion.

Ten AECO professionals attended the workshop and they had a diversified profile, as seen in Table 1:

Table 1: Workshop participants profile

Participant #	***Educational Background***	***Occupation***	***Company***	***BIM Experience (Projects)***
1	*Architecture*	*Coordinator of the BIM Modelling Group*	*Company 1*	*More than 10*
2	*Civil Engineering*	*Civil Engineer*	*Company 1*	*More than 10*
3	*Undergraduate*	*Draftsman*	*Company 2*	*More than 10*
4	*Civil Engineering*	*Construction Manager*	*Self-employed*	*1-3*
5	*Architecture*	*Revit Instructor and Consultant*	*Self-employed*	*More than 10*
6	*Architecture*	*BIM Manager*	*Company 3*	*1-3*
7	*Architecture*	*Architect*	*Company 3*	*1-3*
8	*Architecture*	*Architect*	*Company 3*	*1-3*
9	*Electrical engineering*	*Electrical System Designer*	*Self-employed*	*None*
10	*Civil Engineering*	*PhD Candidate*	*Academic*	*None*

The workshop had an open invitation, and there were no fees collected. Having some experience with BIM was preferred but not mandatory to the participants. Their miscellaneous background enriched the discussion in which various points of view were available (Figure 3).

Figure 3: Workshop presentation (photo by the authors)

Besides spontaneous comments during the presentation and the exercise, the researchers proposed an open discussion about the points listed below.

- While modelling, what were your impressions regarding:
    - Difficulty and time to build the model?
    - Model visualization?
    - Differences from your own modelling practices?

- While using the wall plug-in and the SINAPI plug-in, what were your impressions regarding:
    - Operation of the plug-in?
    - Benefits of the plug-in?
    - Plug-in applicability in your daily practices?

The results shown herein are a compilation of the registration forms and questionnaire answers, in addition to a careful analysis of the discussion and questions from participants, recorded by the researchers.

3.1 Limitations

Even though the research method was satisfactory to investigate the main purpose of this article and to promote a broad discussion of the proposed object, it imposed a limited number of participants. There was an effort towards gathering a diverse group, but the possible influence of subjective views from the participants was taken into consideration in the final analysis.

4. Research Data

4.1 Participants profile

According to the information extracted from the registration forms and questionnaire, Architects and Civil Engineers were the majority in a young and well-educated group where at least half of the participants were postgraduates and under 30 years old (Figure 4).

The most popular BIM uses among the participants is for design coordination, visualization and presentation, quantity take-off and construction planning. Although most of them have some professional experience with construction cost planning, only three of the participants have already used a BIM software for this purpose, and they declare to be using Revit.

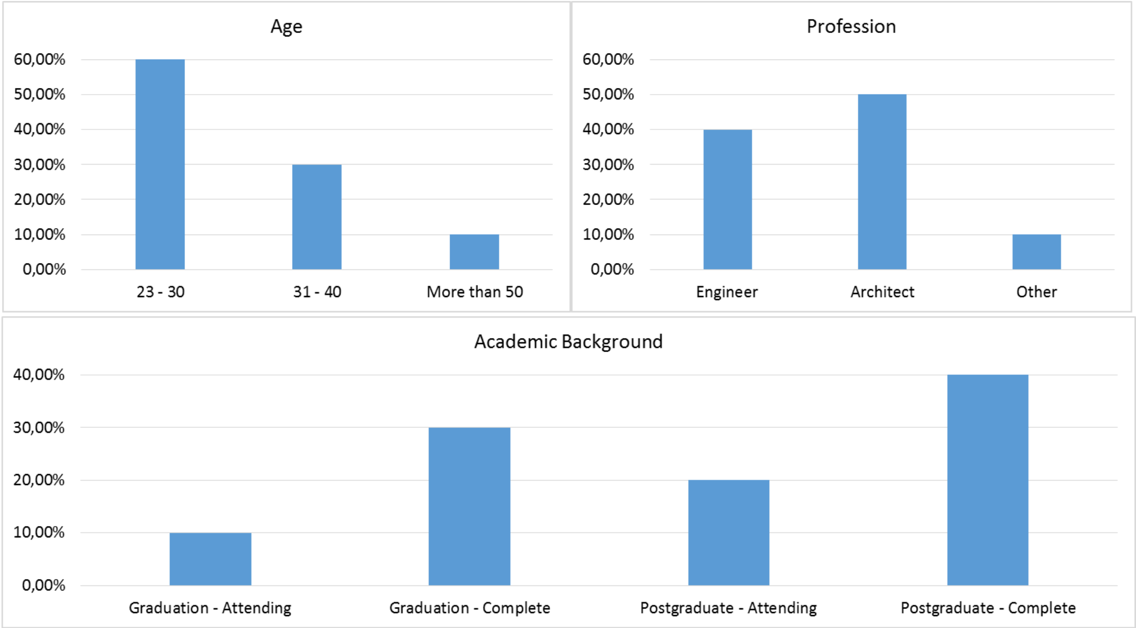

Figure 4: Participants profile

4.2 Motivations

The motivations for employing a BIM software for cost estimation noticed during the discussion were essentially related to innovation in design practices and for reducing cost estimating complexity. The changes in designer's responsibilities with the adoption of a BIM-based design process were found to be a major concern, since some decisions related to construction planning, cost estimation and construction processes must be taken earlier in the project.

Some participants admit to neglect cost planning in the design process, and they recognize that there is a lack of integration between design and cost estimating.

When asked, all the participants agreed that if Caixa established a modelling standard, they would adopt it.

4.3 Benefits

The questionnaire results showed that most participants (88 to 100%) agreed that, compared to their current practice, it was easier, faster and more accurate to model, to extract quantities and to estimate project costs in the exercise (Figure).

There were also positive responses to the questions regarding the intention of use, suitability and perception of usefulness to their professional practices (Figure 6). During the discussion, it was pointed out that the wall plug-in would be very applicable to buildings with repetitive elements such as hotels, for example. In addition, most participants declared that it was easy to accomplish the exercise.

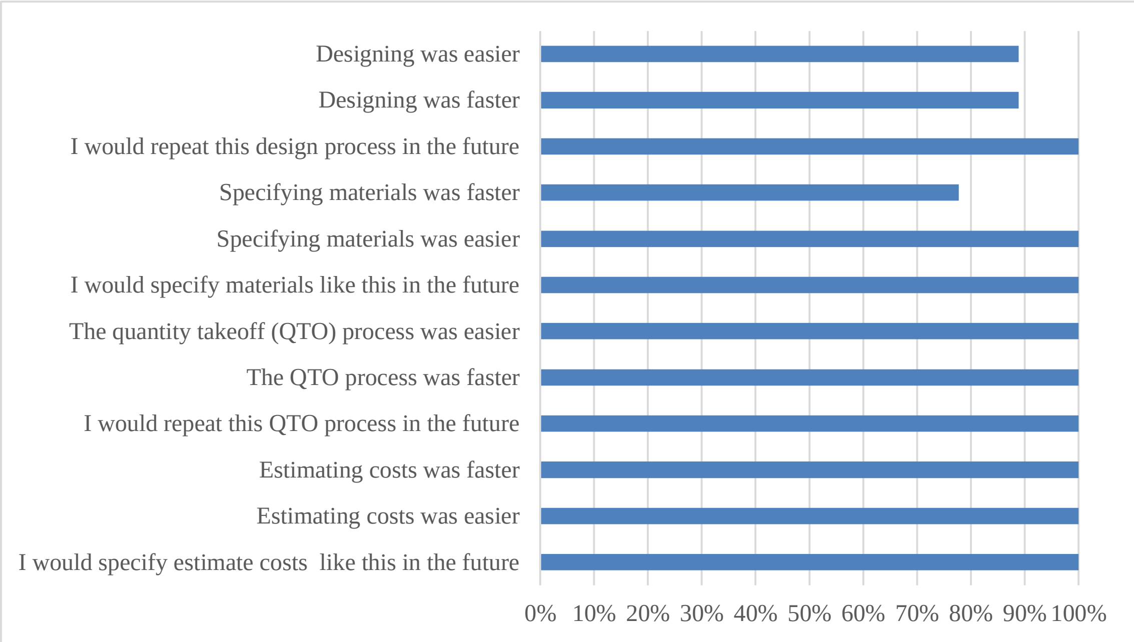

Figure 5: Results in scale from 0 to 100% for agreement with statements about the design and cost-estimating process using the tools and guidelines proposed

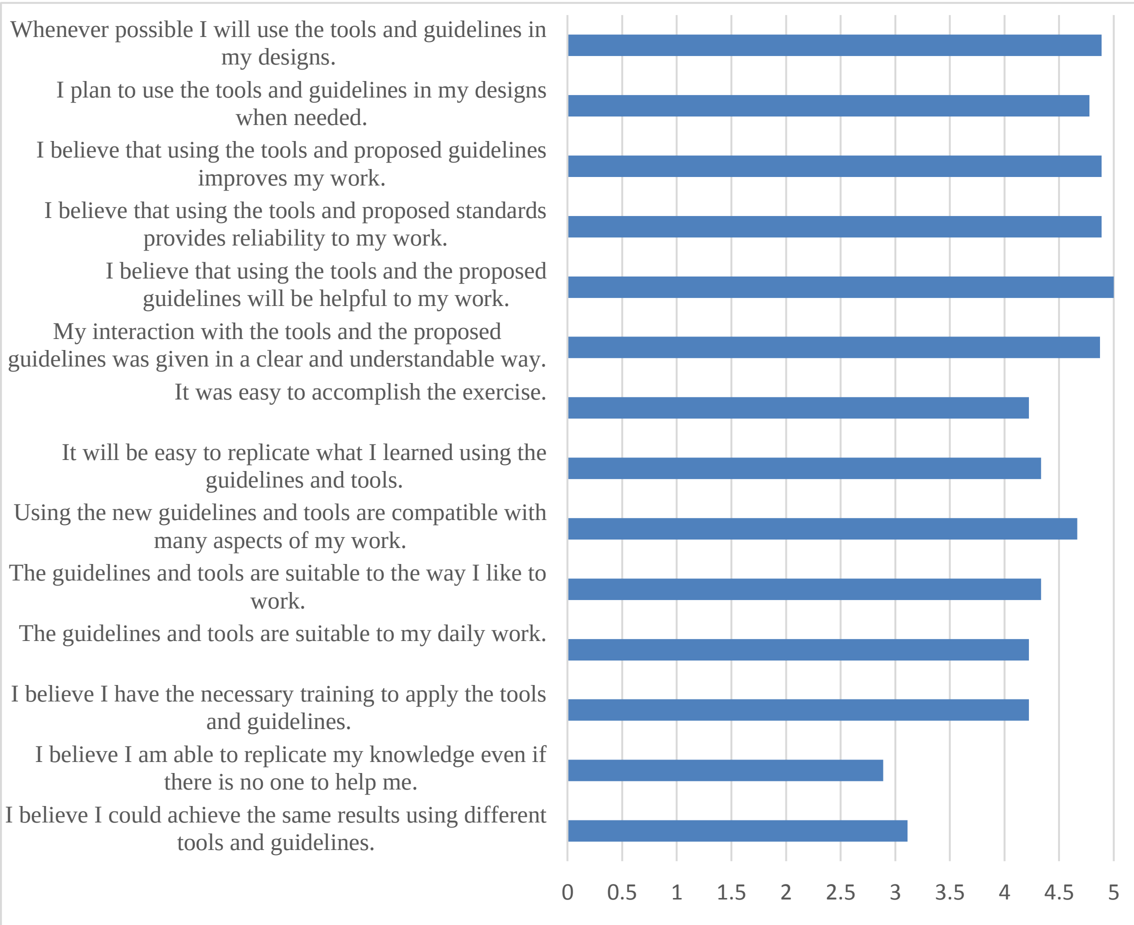

Figure 6: Results in scale from 0 to 5 for agreement with statements about use of tools and guidelines

4.4 Difficulties

The main barrier acknowledged by the researchers was perceived during the exercise explanation, evidenced by the questions the participants were asking. Their inquiries reflected their unfamiliarity with construction processes, which lead to great difficulty in estimating costs. Furthermore, the participants appeared uninformed about SINAPI’s structure and guidelines, asking elementary questions about it.

About the plug-ins and project template proposed, some participants reported difficulties in designating objects specification with the SINAPI plug-in due to the various options it presents, making it evident that the filtering process of materials and components available should be more accurate. They also expressed some concerns about exporting the data to other cost-estimating software.

Ultimately, although the participants approved their training, they declared they would have some difficulty in reproducing what they had learned without any help.

5. Analysis

The modelling guidelines and plug-ins proposed can be considered approved, almost unanimously, with minor suggestions for improvement. The TAM (Technology acceptance model) postulates that a user's behavioural intention to use technology is related to the usefulness and ease of use perceived (Son et al., 2015), and the results indicate that the participants pointed out these qualities in the proposal.

However, it should be taken into consideration that most participants are comparing the proposed practices with non-BIM traditional methods. This fact can partially explain why some participants believe that they could achieve the same results using different tools and modelling guidelines: it is due to their interest in a BIM-based practice rather than a specific tool. The lack of modelling experience can also explain why they believe they could not reapply the exercise without help.

The results also called attention to the fact that design and cost estimating are segregated disciplines, and the professional responsible for the design is not always aware of the entire construction process, including the specification of materials and cost components. That is a major barrier, not only to the acceptance of the proposed tools and guidelines presented in this paper, but essentially to a BIM-based design and cost estimation practice (Gu and London, 2010).

6. Conclusions

Even though Caixa is a financial institution, it is also an important stakeholder in the Brazilian AECO industry and can be considered a policy maker due to its potential to disseminate standards, regulations, guidelines and best practices. Therefore, its efforts towards establishing modelling standards should be closely monitored because of their likelihood of becoming Brazilian national standards.

The aim of this study is to analyze the tools (plug-ins) and project template in development, which are based on modelling guidelines proposed by the institution. For this purpose, a modelling exercise was proposed followed by a group discussion and a questionnaire to identify users' behavioural intentions towards the proposed technological innovation.

In spite of the focused purpose of the research, and the positive assessment of the plug-ins and project template, the results revealed a broader issue of segregation between the disciplines of design and cost estimation, evidenced in the difficulty demonstrated by the participants during the exercise. That may influence not only the acceptance of the technological innovation proposed by Caixa, but BIM adoption in Brazil in general.

Further studies should address this issue in terms of desirable professional qualification, responsibilities definition and impacts to the design process.

The continuity of this study will focus in the technical department of Caixa and the impacts of this technological innovation. Thus, analysing the organizational environment and the attitude of the employees in relation to the acceptance of change and innovation proposition.

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A Framework of an Image-based Integrated Approach to Create As-Is Building Information Models for Existing Buildings

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Abstract

Building Information Modelling (BIM) provides an intelligent and parametric digital platform to support activities throughout the life cycle of a building and has been widely used for new building construction projects. However, most existing buildings today often do not have completed as-is information documents, nor existed meaningful BIM models. Despite the growing use of BIM models for relatively new buildings and the improvement in as-is records, incomplete or even incorrect information is still one of the main reasons for the low-level efficiency in facilities management. Furthermore, as-is BIM modelling for existing buildings is considered to be a time-consuming and expensive process, which requires great effort, time and skilled workers. Hence, developing an efficient way to create an as-is BIM model would be essentially the foremost step for effective operations and maintenance of existing buildings in their life cycle using cutting-edge BIM tools. We aim at developing a framework to establish a high efficient as-is BIM modelling system that integrates diverse building data in different formats (e.g., photo images, drawings, text data) with low cost, in order to improve efficiency and effectiveness of operations and maintenance, and furthermore possibly support refurbishment of a building. With this ultimate goal, this paper focuses on analysing state-of-the-art object recognition and reconstruction methods applicable for creating as-is BIM models, and summarises merits and limitations of these existing techniques and methods. Then, a framework is established with the most suitable methods on the basis of applying image sources and existing documents of the target building. The framework mainly includes a mechanism that supports automated creation of as-is objects with their meanings and information, and an assisting information library for the target building. The mechanism will use intelligent reasoning algorithms as appropriate such as the hybrid neuro-fuzzy algorithm in order to take into account possibilities of information shortage. The information library will mainly consist of four functional modules and four information modules (i.e., surface information, geometric representation, extracted information, and features information). Furthermore, key challenges and current progress are also addressed in this paper.

Keywords: as-is BIM model, hybrid neuro-fuzzy algorithm, information library, operations and maintenance

1. Introduction

On January 29, 2010, building collapse accident suddenly happened in Ma Tau Wai road, Hong Kong. An old six-story walk-up building suddenly crumbled at about 1:30PM. Four people died. Reasons for those accidents were often related to inefficient operations and maintenance (O&M) of facilities using traditional methods. With the increasing complexity of buildings in recent years, facilities management need a wide range of activities and building information associated to perform the activities. Hence, efficiently accessing to up-to-date information required for operating and maintaining a facility is essential and vital. Consequently maintaining the information up-to-date throughout the lifecycle of the facility is thus one of the most important tasks in O&M phase. The current situation, however, is that most existing buildings have only 2D drawings and text documents in a hard-copy format and/or in an electronic CAD format. These documents may not keep updated in time in the O&M phase. Thus, missing or incorrect building information would lead to inefficient decision making processes, which could cause significant delays in responding occupants' daily requests and emergencies. There is an urgent need of effective ways to manage all the information in the O&M phase.

Building Information Model (BIM) has been proved to be an intelligent and parametric digital platform and could support activities throughout the life cycle of a building, including facilitating design, construction, and operations and maintenance of facilities. According to the McGraw hill Construction's investigation of BIM in more than 10 countries, including North America, Europe, South Korea etc., the percentage of projects implemented with BIM increases sharply from an average of 39% to over 69% from 2013 to 2015 (McGraw Hill Construction 2014). It is proved that BIM has been widely used for new building construction projects, such as design authoring, existing conditions modelling, maintenance scheduling, and disasters planning (Kreider et al. 2010).

However, although the concept of BIM as a "database that stores, links, extracts and exchanges information", presents a promising BIM use for operations and maintenance of facilities, the lack of effective methods to reconstruct BIM for an existing building has prevented stakeholders' interest in using BIM data to support the O&M phase. They cannot fully utilize BIM technologies and get the most benefits. Furthermore, current methods and technologies of constructing as-is BIM models mainly depend on human effort. It is considered to be a time-consuming and costly process, and even sometimes reconstructing the as-is BIM model may be treated as a meaningless task and counteract benefits for civil infrastructure projects (Forns-Samso 2011; Lee and Akin 2009).

Nowadays, considering the extra effort and time of the reconstructing process, focuses have been mainly on developing effective and automatic/semi-automatic methods to address these problems. However, it is still a long way to achieve automated and highly efficient creation of as-is building information model for existing buildings. To reach this objective, we reviewed previous efforts in details, and merits and limitations of these existing techniques and methods are summarized (Chapter 2). Then, a novel framework of reconstructing as-is BIM models is established with the most suitable methods on the basis of applying image sources and existing documents of the target building (Chapter 3). Furthermore, our research progress and feasibility analysis of this framework is presented and discussed in this paper.

2. Literature Review

2.1 Overview of Fundamental Image Processing Methods and Image-based Building Reconstruction Approaches

Beginning with the Moravec (1981) corner detector, researchers began to keep an eye on image processing and make effort on matching up the geometric primitives (e.g., corners, edges) of the 2D images. Since then, researchers has tried to extract information from images and keep developing more reliable and stable functions as shown in Table 1. Inspired by local image descriptors, Lowe (2004) presented the Scale Invariant Feature Transform (SIFT) in 1999. This SIFT descriptor translated and detected image local features into scale-invariant coordinates for image processing. After that, Mikolajczyk and Schmid (2005) introduced an extended descriptor based on SIFT, which was the gradient location and orientation histogram (GLOH). This robust image descriptor improved the SIFT by changing the location grid and replying on principal component analysis (PCA) to reduce the size of images. This descriptor could outperform both SIFT and PCA-STFT, but it was relatively expensive from a computational perspective. An approach introduced by Bay et al. (2008) could be treated as a detector and descriptor for image matching. They developed Speeded-Up Robust Features (SURF) for object recognition and 3D reconstruction. This novel detector-descriptor scheme was inspired by the leading existing detectors and took advantages of them. It was proved to be an effective tool in feature extraction (Bay et al. 2008). The aforementioned methods review the fundamental methods. As shown in Table 1, researchers have applied these methods in image processing, interest point detection, object recognition, image matching etc. These methods (e.g., SIFT/SURF) are always set as the basic step of an image-based recognition and reconstruction system.

Referring to Table 1, image-based building reconstruction approaches are divided into feature representation-based approaches, wide baseline matching-based approaches, dimensionality reduction-based methods, clustering-based algorithms and others (reconstruction of image-based 3D point cloud model). The first approach mainly focuses on the process of feature extraction. The second approach relies on matching corresponding feature points between the query image and a reference image. The third approach eliminates features and enhances the efficiency by reducing the feature into a much lower dimensional subspace, and the fourth approach tries to group those image structures into different clusters by researching on their different relationships. Typical examples representing each approach are listed in Table 1. In addition, there is another image-based technology commonly used in the computer vision community. It can be used for creating 3D point clouds of the target building from a collection of overlapping images. Hence, it provides the possibility of 3D point cloud reconstruction from a set of images instead of laser scanners. One of the methods that are most commonly used in various industries is the Structure from Motion (SfM) (Wu 2013).

Table 1: A brief summary of the typical fundamental image processing methods and image-based building reconstruction approaches

	Classifications	*Different algorithms*	*Equation / literal expression*
Fundamental image processing methods	*Corner detection*	*The Moravec corner detection algorithm*	*The earliest algorithm, which measured each pixel in the image, relied on similarity to decide each corner.*
		The Harris&Stephens / Plessey / Shi–Tomasi corner detection algorithm	*This algorithm improved the Moravec corner detector by implementing the differential of the corner and the local auto-correlation function.*
		The Förstner corner detector	*This detector provided an approximate solution, which intended to find the point (x_0) closest to all the tangent lines of the corner.*
		The curve curvature corner detection algorithm	*This algorithm is suitable for an image edge existing large curvature.*
		An affine invariant interest point detector	*It was based on the multi-scale Harris detector and used the second moment descriptor with non-uniform Gaussian kernels.*
	Key-Point extraction /Feature descriptor	*The Scale Invariant Feature Transform (SIFT)*	*The SIFT descriptor will depend on character of the target image aiming at deciding a group of images as references. And then, in the light of the Euclidean distance of feature vectors, the target image would confirm the exact one from these entire candidates.*
		The gradient location and orientation histogram (GLOH)	*The GLOH is a SIFT-like descriptor, which considers spatial regions for the histograms and uses PCA to reduce higher dimensionality.*
		Principal Component Analysis (PCA)–SIFT	*Steps of the PCA-SIFT descriptor follow: (1) compute the local patch eigenspace for expressing the gradient images; (2) compute its local image gradient; (3) derive the compact feature vector for image matching.*
		Speeded-Up Robust Features (SURF)	*This SURF is achieved by relying on integral images for image convolutions and using the Hessian matrix-based measure and a distribution-based descriptor.*
	Line extraction	*The steps of processing: Edge detection; Edge thinning; Edge linking; Line fitting; Unsuccessful line segments cleaning; Corners connection.*	• *Edge detection (Sobel operator);* • *Edge thinning (Skeleton line extraction, Morphologic operators, Canny methods);* • *Line fitting to edges (Polyline composition or decomposition algorithm, Tolerance based algorithm, Hop-Along algorithm);*
Image-based building reconstruction approaches	*Feature representation-based algorithms*	*Examples: 1). The hyper-polyhedron with adaptive threshold (HPAT); 2). The steerable filter-based building recognition (SFBR); 3). The SIFT/SURF based approach;*	
	Wide baseline matching-based methods	*Examples: 1). The fast wide baseline matching algorithm; 2). The augmented reality-based navigation systems;*	
	Dimensionality reduction-based methods	*Examples: 1). The linear subspace methods (LSMs) (such as: principal component analysis (PCA) and linear discriminant analysis (LDA)); 2). The manifold learning algorithms (such as: locally linear embedding (LLE), isometric feature mapping (Isomap), Laplacian Eigenmap (LE));*	
	Clustering-based algorithms	*Examples: 1). Hierarchical building recognition (HBR) based on vanishing point detection and localized color histograms; 2). The sketch-based representation method; 3). Clustering-based landmark recognition method;*	
	Others	*Examples: 1). Reconstruction of image-based point cloud model: the range image-based reconstruction method based on the Structure from Motion (SfM);*	

** Chung et al. 2009; Goedemé et al. 2004; Harris and Stephens 1988; Kim et al. 2006; Li and Allinson 2013; Li et al. 2014; Lowe 2004; Mikolajczyk et al. 2002; Shao et al. 2003; Suleiman et al. 2011; Wu 2013;Lu and Lee 2015.*

Based on their contributions in image analysis, information mining and 3D geometry model reconstruction, many building recognition and reconstruction approaches have been further improved and tried to achieve fully-automated/semi-automated 3D reconstruction geometry models according to image sources. Furthermore, they are often treated as an essential step to create as-is BIM models for existing buildings.

2.2 Overview of Semi-automatic or Automatic Methods of Creating As-is BIM Models for Existing Buildings

As shown in Fig. 1, creating an as-is BIM model using different technologies can be divided into four main steps: 1) data capturing step in which various building surveying technologies can be chosen and raw data sets are collected; 2) data pre-processing step in which image processing methods are implemented and information is extracted; 3) object recognition step in which objects are classified into different groups and complemented by semantic information; 4) the as-is BIM models creation step in which each object's relationships with others are identified and the primary partial information model becomes a semantically rich BIM model. Semi-automatic or fully-automatic Creation of as-is BIM models requires to streamline the process, starting collecting initial inputs (e.g., images) and ending up with constructing an as-is BIM model, while the whole intermediate processes apply semi-automated or automated techniques. In order to optimize this process, a reliable, high efficient, low-cost and automated method for representing BIM models accurately is imperative nowadays. Many researchers have focused on this field (Brilakis et al. 2010; Díaz-Vilariño et al. 2014; Dimitrov and Golparvar-Fard 2014; Murphy et al. 2013; Nagel et al. 2009). For example, in order to simplify the overall process and to increase the flexibility and operability, a two-step BIM model construction process has been developed by Nagel et al. (2009). The creation process focuses on generating as-is BIM models from 3D geometry models. The intermediate layer uses CityGML building models. Furthermore, IFC (Industry Foundation Classes) building models also need to be created from CityGML. Since there are considerable gaps between the pure 3D geometry model and the as-is BIM model, it is difficult to achieve a fully automated creation process directly using this method. In addition, there are other limitations as well. For instance, the optimal and suitable data interpretation is still the essential concern (Nagel et al. 2009).

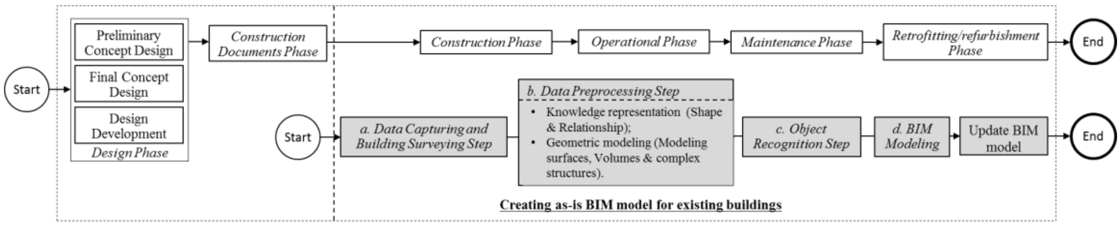

Figure 1: The as-is BIM model creating process for existing buildings in life cycle

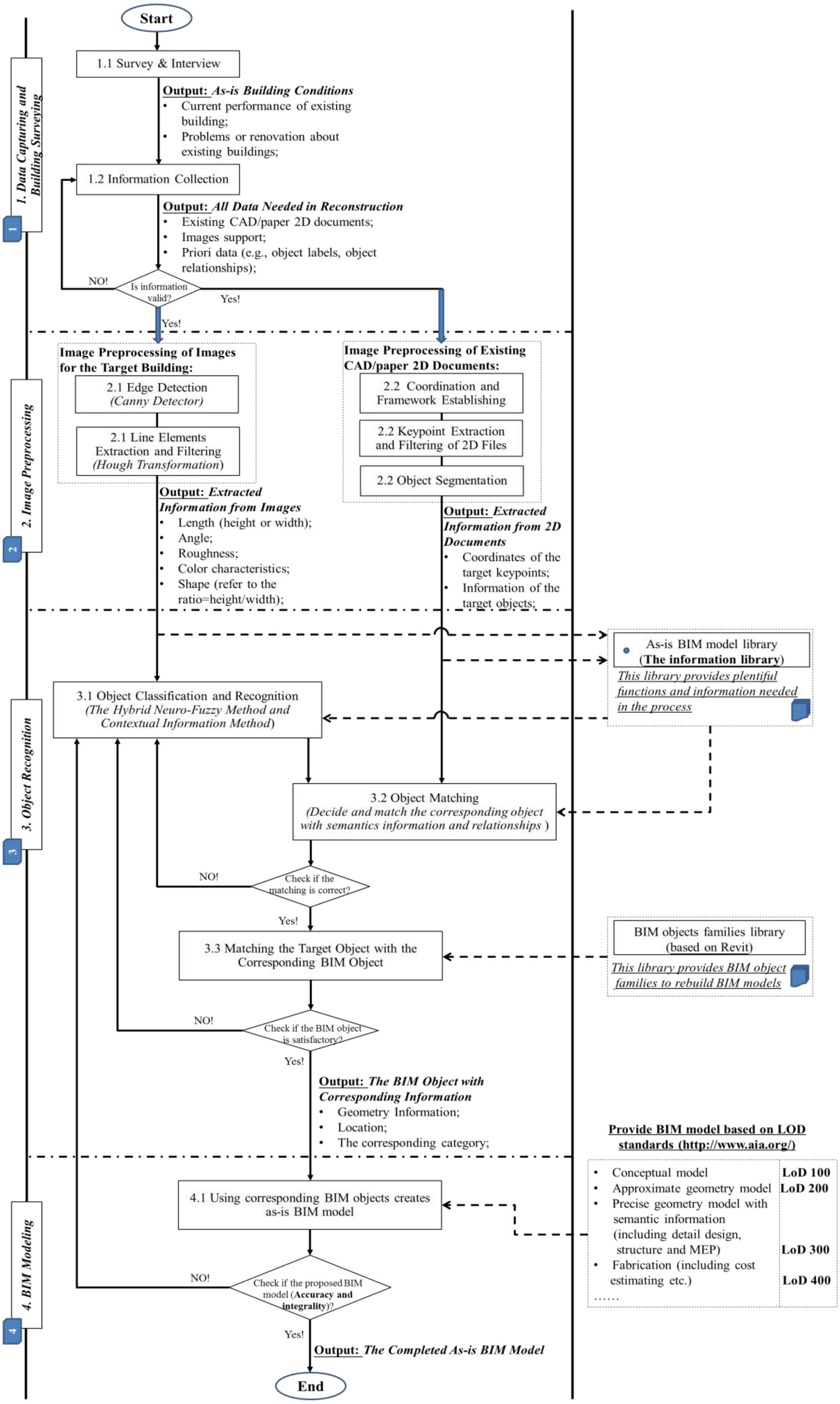

Figure 2: Framework of reconstructing as-is BIM model

3. Framework Description

We develop an innovative framework that aims to address the limitations of existing methods and to provide a high-efficient and low cost approach to create as-is BIM models for existing buildings, which does not require skilled workers. The framework chooses the image-based approach and implements corresponding computing technologies for existing buildings, as shown in Fig. 2. The framework includes four stages: data capturing and building surveying, data pre-processing, object recognition, and constructing as-is BIM models. The specific tasks to achieve each stage are stated as follows:

Stage 1: Data capturing and building surveying step.

This stage mainly focuses on collecting raw building data. The building data should cover all necessary existing documents (e.g., existing CAD documents, paper works and maintenance information) and images taken from the target building. Images captured in this stage should follow two requirements: a) One single image should cover at least one completed object (e.g., a completed column); and b) Images should be taken from different views and try to contain enough information for one target object. Furthermore, a series of survey and interview with O&M personnel who is in charge of data repositories are suggest to perform to collect data on current situations and problems of as-is building conditions.

Stage 2: Data pre-processing step.

Based on the summary of image processing methods and image-based reconstruction approaches in Chapter 2, various image processing methods could be chosen in this stage. Pieces of building information (including surface information, geometric representation, extracted information, and features information) are extracted from images. In this framework, Hough transform is applied to detect line elements and confirm building information.

All these extracted information is saved in an information library (Fig. 3). This library provides building information and image data sources of target objects for whole reconstruction process. In the context of this information library, the geometry of a target region, the image intensities of a target region, the properties of a target region etc. are considered as measured information that is provided to aid the recognition of objects.

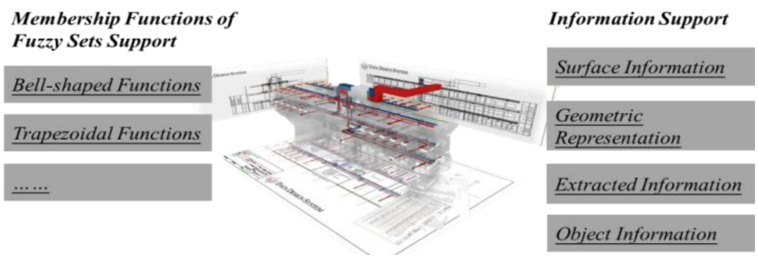

Figure 3 Modules for creating the information library

<u>Stage 3</u>: Object recognition step.

This stage uses intelligent reasoning algorithms to support object recognition and information matching. In particular, in order to take into account possibilities of information shortage and inaccuracy in the data in the forms of images and documents, fuzzy logic systems that can reason with imprecise information can be considered to adopt. From the preliminary studies on different intelligent algorithms, the hybrid neuro-fuzzy system is one of the most suitable algorithms for this framework. Fuzzy logic methods can make decisions even with incomplete or uncertain information. However, individual fuzzy logic methods cannot automatically acquire the rules used to make those decisions and has its own limitations. While, neural network is quite useful to deal with cases that relationships between inputs and outputs are complex. The hybrid neuro-fuzzy system combines fuzzy algorithms with neural network systems in order to overcome the limitations of each individual technique. Interpretability and accuracy, which are main strengths of the hybrid neuro-fuzzy method, are the key criteria of choosing algorithms (Chen and Pham, 2000; Robert 2001; Sumer and Turker, 2013).

According to building information stored in the information library, object recognition and information matching is implemented adapting the hybrid neuro-fuzzy algorithm (referring to Fig. 4). The recognized object with its related building information and the existing documents of the target building is developed to be the reference for constructing the BIM object. Then, descriptors are created to assist deciding and recognizing properties of the target object. The descriptors have two main functions: a) to bridge between the recognized object and the information library; b) to guide and connect the primarily recognized object to a matching BIM element type to construct a BIM object. Standard data models such as Industry Foundation Classes (IFC) can be embedded in the information library or BIM libraries in BIM authoring tools such as Families in Revit can be linked to the information library as the reference BIM element types in this process.

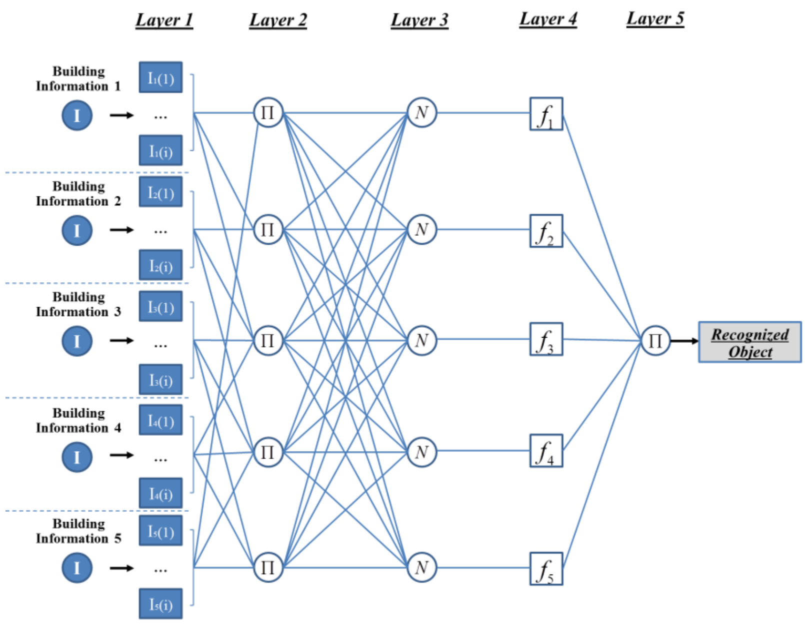

Figure 4 Process of object recognition by adapting the hybrid neuro-fuzzy algorithm

Stage 4: The as-is BIM model constructing step.

Referring to the images and existing CAD documents in the 3rd step, the exact BIM elements have been constructed. Since the as-is BIM model is not just a simple 3D geometry model, each independent BIM objects require specific classification, location information and relationships with other elements. This step organizes the individual BIM elements identified, and generates a complete an as-is BIM model, which based on LOD requirements and its functions. A further model check and validation is also necessary in the last step based on all the collected information.

4. Research Progress

Our research progress is at the 2nd stage now, which is the information extraction from collected images. Different image processing methods has been analysed in Matlab (shown in Fig. 5 left side). The Harris method and SIFT method are used to detect keypoints, and the Robert and fuzzy logic methods are used to detect edges. Image in the middle of Fig. 5 is collected by our research team using a digital camera (camera type: Nikon D7100) and it is a column of the parking place in one of the campus office buildings. We developed an application to detect necessary information (e.g., color and angle) from the collected images, as shown in the middle part of Fig. 5. It follows the route 2.1 in Fig. 2. Meanwhile, we also developed another application based on the Petzold Media3D library provided by Wu, X.S. (2009) to process CAD drawings in dwg and pdf file formats in order to confirm the location of each component (See the right part of Fig. 5). It is the route 2.2 in Fig. 2.

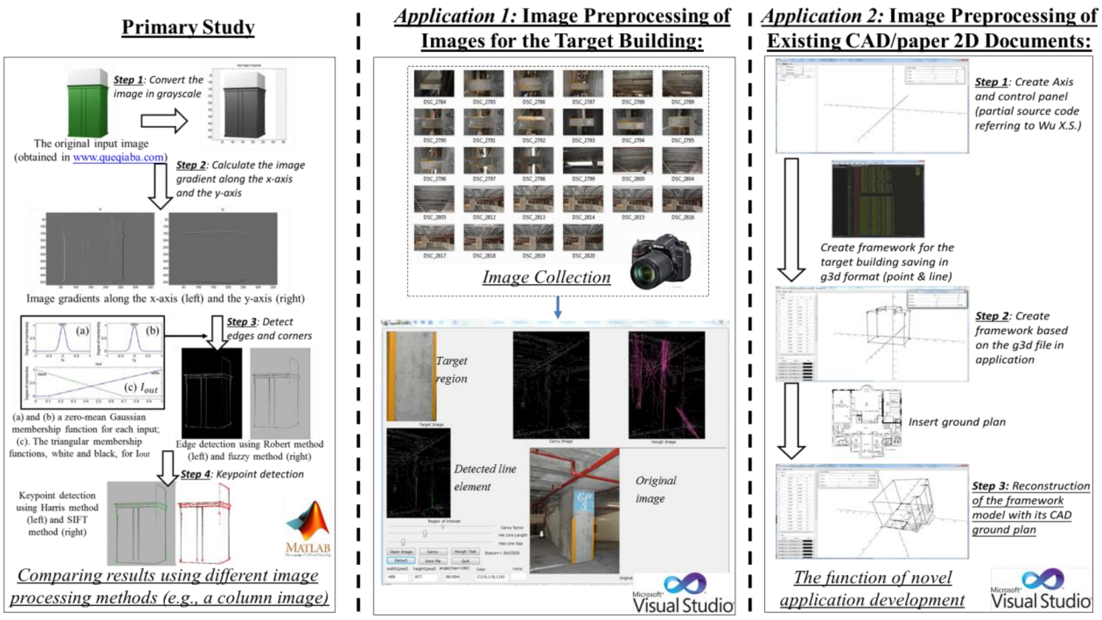

Figure 5 Research progress of information extraction

5. Discussions

The construction of an as-is BIM model focuses on surveying the geometry and surface of an existing building, improving this collected information into a primary semantically rich model and finally achieving a building information representation referring to the level of details (LoD). However, there exist various uncertainties and difficulties in this construction process, including:

- From modelling aspect: How to classify different building components in a high-efficient way? It is not easy to distinguish the target column from surrounding environments because of extra noises such as their decoration.
- From information aspect: How to collect the building information in a low cost way? It is usually expensive and requires skilled workers in building survey stage.

The framework presented in this paper aims at developing an automatic image-based approach to address these problems. It is expected that this framework of constructing as-is BIM has following merits:

- Images collected by using common digital cameras can be used as an input data, which is at relative low cost.
- The mechanism used and developed to implement the framework such as the hybrid neuro-fuzzy algorithm is suitable to recognize building elements from images, especially taken from environments that require uncertain or approximate reasoning. For instance, it is expected that the mechanism can extract building information by processing images taken from different angles of the target building, which could reduce the possibilities of producing recognition errors.

6. Conclusions

In order to achieve sustainable development throughout the lifecycle of a building, especially the O&M phases, it is urgent to adopt BIM in facilitate operations and maintenance of an existing building. Consequently, it is important and necessary to construct as-is BIM models for existing buildings. However, current methods and technologies of creating as-is BIM models mainly depend on extensive human effort and time. Although data may be collected automatically from diverse sources and methods (e.g., camera), managing useful data, recognizing building objects and conducting building logical relationships are all performed in manual or semi-automatic ways. In order to systematically automate the process of constructing as-is BIM models from images, CAD drawings and possibly other data sources, this paper gave a brief summary of fundamental image processing method, image-based building reconstruction approaches and existing systems to construct as-is BIM models. Then, we built a framework of an integrated approach to achieve the goal. The framework consists of four steps: data capturing and building surveying, data pre-processing, object recognition and BIM model creation. This framework aims to provide a foundation and guide to develop a system to construct as-is BIM with rich building information, without the requirements of extra high cost and skilled workers. We are at the 2^{nd} stage of implementing the framework. We have developed modules to process column images and tested the modules using images taken from typical office buildings. Our future works include implementing the 3rd and 4th stages and test the framework with different sets of office buildings in Hong Kong.

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Diffusing BIM – knowledge integration mechanisms and their effects

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Abstract

Building Information Modelling (BIM) has for a number of years been seen as a systemic inter-organizational innovation that will have great impact on the efficiency of the construction process as a whole. In this study both successful and unsuccessful attempts to diffuse a BIM-service in the construction sector by a building material manufacturer has been studied through multiple data collection methods. Of special interest has been in what ways knowledge has been integrated, i.e. what mechanisms has been used in the case, since it is a key area for diffusion, and this is described and discussed. Furthermore, the contextual characteristics of the construction sector have been highlighted as influential on diffusion, especially when it comes to areas such as learning, flow of knowledge and feedback loops. Therefore, the context of the different cases and in what ways this affects the knowledge integration process is also described and discussed.

Keywords: Building Information Modelling, Diffusion, Systemic Innovations, Knowledge Integration Mechanisms

1. Introduction

BIM, Building Information Modelling or Management has in many ways been seen as an innovation that will result in drastic changes for the construction process at large (see for instance (Succar, 2009, Elmualim and Gilder, 2013). Eastman et al. (2011) describes BIM as the change of moving from paper-based modes of communication, i e using drawings on paper through the construction process to a process based on using electronic information and tools. This change has taken place and been developed through the use of ICT with web-pages, 3D CAD tools etc, avoiding some of the problems connected to the traditional process. The implementation and diffusion of BIM also generates a number of difficulties (see for instance (Succar et al., 2012). This can in many ways, among others, be related to the general problems related to diffusion of inter-organizational innovations, also called systemic innovations. Systemic innovations are holistic and relational to their nature (Colvin et al., 2014), require change of processes in a coordinated fashion by multiple firms (Taylor and Levitt, 2005, Taylor and Levitt, 2007) and cover multiple relationships (Powell, 1998). Systemic innovations can be a number of innovations that together perform new functions, the relationship in-between the innovations are explicit, but most often there will be effects on other components or systems as well (Slaughter, 1998). Manufacturers and suppliers who are unaware of the changes required to implement their innovations, either in the links to other components, processes, or systems or in the product itself are likely to meet resistance in the spread of their products (Slaughter, 2000).

ICT development focus has for long, maybe too long, been on technical issues, and not on the diffusion perspective (Peansupap and Walker, 2006). BIM is in its nature inter-organizational with its focus on managing information throughout the construction process, and for construction, diffusing inter-organizational innovations poses many challenges. The characteristics of construction can be described by: the physical nature of the products and the structure of sector, the production of single/unique structures, the different types of clients (Briscoe, 1988), the importance of maintenance (Manser, 1994), iterant process, and the derived nature of demand (Bon, 1998). Production in construction is project-based and encompasses a large number of actors from different industrial sectors (Salter and Torbett, 2003).

Attempts at systemic innovation may prove to be problematic. Taylor (2006) has highlighted a number of constructs that influence diffusion of systemic innovations. These relate to the magnitude of the innovation and the level of change it has on affected parties and processes; the amount of "new" involved actors in each project, I e the *organizational variety*; the *interdependence between tasks*; *the boundary strength* or rigidity between trades; *span*, I e the number of affected professions and finally the alignment of the innovation with the work allocation in the network. A key issue related to these constructs it that they influence the ability for inter-organizational knowledge to flow. Knowledge creation and exchange is a key issue in the innovation process and its inherent diffusion (OECD, 2005). According to Rundquist et al. (2013) an ineffective flow of knowledge and limited knowledge integration constitutes a barrier for innovation. An additional complicating factor for construction is that in construction projects different types of professionals come together to work for a limited time; architects, engineers, project managers, craftsmen etc. These professionals have different knowledge types that needs to be managed through knowledge integration, i e combining new and previous knowledge (Wijnhoven, 1999, Rundquist, 2012). Knowledge integration can be done through different types of mechanisms that depend on different amounts of social interaction (Van De Ven et al., 1976, Grant, 1996). Due to these factors, choosing the most efficient mechanisms is central and following this, *the aim of this research is to investigate what mechanisms has been used in one case when diffusing BIM, since it is a key area for diffusion, and this is described and discussed. Furthermore, the context of different cases is described and its effects on knowledge integration are discussed.*

2. Knowledge integration, mechanisms and knowledge types

Knowledge is at the centre of the research presented in this paper. Knowledge is viewed as information, technology, skills and know-how in line with Grant (1996), with a view on objective information as codified knowledge (Grant, 1996, Nonaka and Takeuchi, 1995). Codified knowledge is of special importance since it facilitates the transfer of knowledge (Prencipe and Tell, 2001). Finding ways to use codified knowledge for knowledge management is of interest for construction (Styhre and Gluch, 2010), although construction research has shown that construction is hesitant to codify and formalise knowledge (Styhre, 2008, Bresnen et al., 2005, Scarbrough et al., 2004). Senaratne and Sexton (2008) mean that codification could increase, but an important factor is that it should be done in balance with soft personalization strategies.

In research on knowledge management in general many different sub-concepts are used, and construction is no exception. Examples in construction are knowledge management (Robinson et al., 2004), sharing of knowledge (Styhre and Gluch, 2010, Styhre, 2008), and knowledge sharing and creation (Bresnen et al., 2005). In a comprehensive review on the concept of knowledge integration and concepts with similarities, Rundquist (2009) treats the concepts knowledge transfer, knowledge sharing and knowledge application. A main point in the review is that knowledge integration is a broader concept that covers the other concepts. This view is shared in this research. In Rundquist (2012), knowledge integration is defined as a process of combining new and previous knowledge. A similar definition is made by Wijnhoven (1999) saying that knowledge integration refers to the process of acquiring, sharing, and making use of knowledge by incorporating new knowledge into an existing knowledge base. Although both authors mean the same thing, Wijnhoven (1999) is a bit more explicit and forms a basis for this paper.

An objective for mechanisms is to integrate knowledge as efficiently as possible and mechanisms can be classified on a scale ranging from low interaction to high interaction. According to Johnson (1992) technological change requires more social interaction like dialogue and conversation and the more advanced innovations, scientifically and technically, the more complicated communication processes are required. Another implicating factor according to Van De Ven et al. (1976) is insecurity, i e difficulty and variability in the conducted work also affects what mechanism to use. This means that it is not just the level per se that sets affects what mechanism to use, but also how the work is perceived is influential. More insecurity requires more personal mechanisms. Another useful way of classifying mechanisms used in construction research relates to explicit and tacit knowledge, and a division of mechanisms into tools and techniques. Tools rely on the use of IT to share explicit knowledge. Techniques use a more human-centered approach to transferring mainly tacit knowledge (Carrillo et al., 2006, Carrillo, 2004).

Our main focus here is to have the level of interaction as a point of departure. We use four types of mechanisms defined by Grant (1996) as a point of departure that range from a scale of low to high interaction for integration of specialized knowledge; *Rules and directives* are un-personal methods such as plans, schedules, forecasts, rules, policies and communication systems; *Sequencing* treats organizing production activities in sequence to enable every specialist to do what he or she should; *Routines* are performed automatically and can be conducted simultaneously when the person conducting them are well acquainted with them and sees them as natural activities that we do without giving them much thought. The first three can be seen as a way of avoiding costs for learning and communication, and the last mechanism *Group problem solving and decision making* is as the title shows a mechanism with communication and interaction. The need for this mechanism increases with the growing complexity and insecurity in the activities that should be conducted as stated by Grant (1996).

3. Method

The study presented in this research focuses on a reinforcement company, the construction process of which the company is a part and their development and diffusion of BIM and BIM-related solutions and services. The study consists of data collection in two steps. The first step of data collection was initially used to map the situation of the case company through a broad approach focusing on the development of the company and its context. The initial mapping focused on content (what has changed), process (how has it changed), why has it changed (context) which is an important interplay for understanding changes (see (Pettigrew and Whipp, 1991, Carlsson, 2000). The collection of data in step one lasted for about 6 months and comprised analysis of company documents, websites and 24 semi-structured interviews with company (internal) and external respondents. The semi-structured interviews provides a structure for meaningful interviews and discussions but also flexibility (Andersen, 1994, Merriam, 1994). The questions addressed the business situation of the company, including its development, objectives and challenges. The character and context of the construction industry, its development and IT related issues were also included. Development aspects are considered interesting from a diffusion point of view since they provide a picture of what ideas, solutions, products and services that are spread (diffused) and not. The interviews lasted from 30 minutes to two hours and were recorded. After the interview the whole interview was listened through and transcribed, although not transcribed in detail. Time-positions was written into the transcripts if sections of the recording were needed to listen to again. The material was summarized in a company report and the extraction has been done from this material and the transcripts, with a focus on the purpose of this paper and *on BIM as the change of moving from paper-based modes of communication, i e using drawings on paper through the construction process to a process based on using electronic information and tools.* The broad collection of data provided useful understanding for the findings.

Based on the extraction of data a new round of semi-structured interviews was conducted with four company internal actors; the technical manager, a sales representative working towards manufacturers of prefabricated elements, one team leader for the BIM/reinforcement engineers and one BIM/reinforcement engineer. These actors are working with diffusion related activities and the new round enabled an update of the situation from the first round and questions regarding the purpose for this paper were raised. The highlighted definition above was communicated in the interviews and the additional questions this time regarded what type of BIM and BIM-related solutions and services that has been diffused, to whom, why and under what circumstances. The compilation of data from the first round served as a support material and also enabled specific questions about the development of specific services. Company information about BIM and BIM-related solutions and services was also overviewed. The time between the two steps of empirical collection was afterwards considered useful to provide a view on development is progressing. The material was overviewed, summarized and analyzed a number of times to find themes and categories that relate to the aim of the study. This was made from the collected data and the section *Results from and analysis of the study* show the final compilation of the collected data.

4. Results from and analysis of the study

The case study company is an international supplier of reinforcement and the Swedish affiliation was studied. The Swedish company has undergone development in line with the steel industry at large, with closures, mergers driven by a focus on economies of scale. This has led to increased competitive pressure not least from low cost countries. Due to the development and the extremely low development potential in the material, reinforcement, the company has put a lot of efforts on developing complementary services to strengthen the company´s competitive position. Among these are electronic solutions or solutions that build on such. The company has worked extensively with 3D-models with included information and 3D-visualisation, and on managing transfer of information back and forth from different systems. By using company solutions, information can be transferred between different systems and much can be automatized, for instance electronically generated specifications lists, visual planning is enabled, print-outs from different views and documentation. The company has introduced a new software in which reinforcement is specified, and it has many add-ons enabling electronic transfer between systems especially with the CAD-software. The company had a predecessor to the software, with many users, and by stopping development of that software, they have forced users in to the new version. Other services that are offered are assembly instructions and a service called color sorting and labelling. In short, this means that reinforcement comes sorted and labelled for simplified assembly. A result from the company´s development is that the company has created their own niche as a technically competent player with BIM and BIM-related solutions and services affecting customer’s processes and approaches.

4.1 Contextual factors

In the study it is evident that contextual factors affect the diffusion of BIM and knowledge integration regarding BIM, which are presented in the following text.

Project stress, short term view and a divided chain: Especially in the first round of interviews these factors were highlighted as affecting development and diffusion in general and thereby also BIM. An effect was that actors use the same solutions as they always, for instance to reduce insecurity and risks. By moving from one project to another without a proper evaluation and use of experiences this is not facilitating diffusion of new solutions such as BIM. It was also stated that different parts of the chain work with their part, not interacting to the extent needed. Subcontractors, like the case company often also come in to late in the RFP-process eliminating room for improvement and possibilities to come up with ideas and solutions.

Organizational width and rules: For starters a key issue is that individuals and organizations need to see benefits with the solutions and has an overall process focus. In the study, actors in the end of the construction chain were not considered pushing development further to a large extent. One approach enabling diffusion was that some of the large construction companies have decided that some projects should be defined as BIM-projects. This is of course of help for diffusion. A highlighted barrier from the external interviews was also that development needs investment that in turn needs to be paid, which many small companies cannot afford, so much development must be driven by larger companies. Since BIM spans many actors, organizations and process steps, the interviewed actors in step 2 all mean that organizations covering many steps of the chain and has a broad business are highlighted as most interesting and also pushes development forward in a way that others don´t. It might be that by working with BIM, activities in the chain are moved and changed. There might be additional work for one part of the chain but with a benefit for the overall efficiency. A possible explanation highlighted is that they can see overall effects of different solutions. However, it was also highlighted that rules within the companies, which can be rigid in larger companies, could be a barrier for implementation, for instance when installing software, support is needed from an IT-department and there could be rules regarding what software that is allowed to install. One mentioned example was also that turnkey contractors have other possibilities to develop solutions from their overall perspective and can be of great importance to move development forward. Another slight point was also that commitment and push from top management was evident in the more forward moving companies.

Personal characteristics and maturity: One of the key factors highlighted in the study is the impact of “IT-ability” among people as having impact on the diffusion of BIM. Many interviewees also thought that construction was lagging behind other sectors when it comes to IT-usage, especially interviewees with experience from other sectors. One of the external companies also had a clear strategy of NOT being first in the development of ICT-solutions, but instead implement solutions when it is clearly shown that they work. Overall, an opinion was that IT-usage should improve as the amount of young people increase, since they are more used to using ICT in their everyday life. Cloud-services, integrated services etc are common in much social media that is used today. The main factor that was enabling diffusion was however individual characteristics. People who are interested and use ICT-solutions enable diffusion.

Implementation in real projects and ease to implement: One of the key factors for diffusion highlighted in the study is to present and implement solutions in real projects. When showing the solutions in real projects, the company has been able to immediately use the solutions and show their immediate effects. An additional key factor has of course also been that the solutions are easily learnt and installed and not requiring too much additional efforts. The coloring services for instance, although not having to do with BIM, was considered easy to implement since they required no additional efforts by customers. 3D-visualisation as a discussion tool was for instance greatly helped by an adobe-application in which 3D-objects could be opened and rotated. It was also highlighted in both rounds that knowledge about IT-implementation has improvement potential especially in the area of supporting IT-implementation on construction sites, for instance to accomplish knowledge integration between developers and operative personnel in understanding user needs and prerequisites and to educate on site. An additional point is also that when the company got external users in their solutions, this created an interest for the company´s other solutions.

Product type, usage and usefulness: Since a main part in BIM is 3D-models, this was specifically discussed and also led to highlighting other factors. It was concluded that 3D-models/visualization was useful to create an understanding for what a product or a specific object looked like, how it could be handled, and what problems that could arise and enabled lowered differences in interpreting the product. However, it was also stated as important not to overuse visualization since they were most useful for complicated objects. In the first round it was also evident that interviewees thought that it was most important to focus on increasing effectivity in relation to everyday operations, instead of having focus on the more visionary aspects. As the technical manager pointed out, everything is expected to go fast and simple.

4.2 Used mechanisms and their effects

The contextual factors presented above are important for the used mechanisms to become successful. Diffusion has been done through various types of mechanisms from high to low interaction with varying results, such as information letters, brochures, sales presentations, information meetings etc. The diffusion of the services has internally been considered moving slow, but the interest for the solutions has increased heavily. The company has presented solutions at various occasions. At first they were seeking interest from customers to implement the solutions and a first modest strategy was to get the solutions "out". The company used a push-strategy to diffuse solutions in real projects with consideration to the contextual factors presented (these factors are also results from failed implementation and diffusion). Implementing the solutions in real projects has been done in several ways. Often instructions were sent out to users and a YouTube video has been used as a mechanism. Often when the company has made follow-up calls they have referred to this video and new users have been able to start up solutions by themselves. Company representatives have also been present at start-up meetings having time to help new users set up their solutions and they have also provided support for users not just by answering questions, but also by being pro-active and making follow-up to get users going. An indication from this is that more interaction intensive mechanisms are needed at the start but then users work easily by themselves.

One of the regional managers also stated the importance of being present and show oneself physically at the customers. This is important to create trust and it is also a method that sells products and services. This emphasizes construction as sector with face to face contact. An example of the usefulness of being present and work in projects is that the company has visited projects with 3D-visualizations of real project objects. By using this push strategy, people in projects have been "forced" to work with the solution and many have also stated that they really could see the benefits. Anyhow, according to the interviewees, customers seldom ask for 3D-models and the demand was actually stated as larger in-house for complicated, welded products, since the 3D-models visualized what the product should look like (which of course is a benefit to the customer since the product is correct). An important part as stated by the technical manager is also that when the company launches new solutions, it is important for them to educate and create a demand for the services. This in itself highlights the need for more interaction intensive mechanisms for starters and when the need is established, other mechanisms can be used.

4.3 Summary of findings

To summarize the findings, the study shows that there are a number of contextual factors that influence diffusion and the knowledge integration that is needed for diffusion of BIM and BIM-related services and solutions. Thereby, the contextual factors also influence the choice of knowledge integration mechanisms. More interaction mechanisms are most likely needed in the start of a diffusion process and a key determinant for the choice of mechanism(s) is the knowledge base of the target groups.

5. Discussion

Speaking in metaphors, BIM can in many ways be the same as changing language. This metaphor is useful to create an understanding of the sometimes large magnitude of change that the entrance of electronic solutions constitutes in relation the former use of printed drawings and other paper-based methods in construction. Once again it is evident that contextual factors of construction complicate diffusion. *Project stress, short term view and a divided chain* has been mentioned many times in previous research and it also becomes evident that these characteristics form a basis for the rest of the contextual factors. A point regarding the divided chain is that by not interacting, knowledge integration is efficient from the perspective of “getting the job done”, but from a knowledge development perspective, potential new knowledge useful for the overall effectiveness of the chain is not being integrated.

For a systemic innovation like BIM, inter-organizational to its nature, diffusion in construction seems to require customers with control over several parts of the construction process. Both in the study and in previous research it has been shown that controlling the chain is of importance, either as having the overarching responsibility/control as emphasized here and in for instance Hjort et al. (2014) or by ownership of resources as highlighted in Taylor (2006). In the same manor, this can also be a barrier for diffusion, with actors having the prerequisites not using their power to implement and diffuse new ideas. What´s interesting in the case however, is that a supplier has the possibility to push the development forward and affect customers also, by taking contextual characteristics into account. As noted in the case and by Taylor (2006), it can also be concluded that the amount of adaptation in the process affects diffusion.

Another interesting point in the study is that construction seems to have a lot of potential in developing their change management and implementation skills. A key topic seems to be to make different actors of the construction chain meet and thereby start a knowledge integration process. In a way, knowledge integration is efficiently managed by different parts working autonomously together as emphasized by Grant (1996), but for knowledge development to take place it is necessary to incorporate new knowledge into an existing knowledge base as in the definition used in this paper (see Wijnhoven (1999)). As the in the study, the reinforcement company seems to take their point of departure in the existing knowledge base and also seems to have accepted the current situation in construction. Based on the point that young people have another knowledge base regarding IT, a potential impact is that it will probably be easier to diffuse BIM in the coming years as there is a shift in active generations. The overall maturity regarding IT should therefore increase, but this is of course also dependent on solutions becoming easier to install and implement. Older generations have most likely created a habit on how to do things based on their experience and for many this is based in an era where IT was not as visible as today. Besides taking the knowledge base into account, the study also points out the need to solve day-to-day issues besides working with visionary aspects to start the change process. By solving “easy” problems, I e bringing forth solutions that solve problems with little or less effort from customers AND showing the potential in real projects, an interest for other solutions from the company becomes interesting.

When it comes to mechanisms the study does not contradict the preferred use of soft-personal modes in construction and the combination of mechanisms as pointed out by Senaratne and Sexton (2008) . If the existing knowledge base does not deviate to a significant amount in relation to the “new”, personal contact can be said to be preferred in the start-up phase, but then codified knowledge can be used, i e more interaction intensive mechanisms starts the diffusion process and then codified knowledge can be used. Traditional codified knowledge, i e information in written form, seems also in this study less useful in construction. On the bright side, it is indicated that a useful mechanism to diffuse codified knowledge are instruction films (You Tube). This points out the potential of spreading codified knowledge using other mediums and in line with Senaratne and Sexton (2008) it advocates codification in balance with soft personalization strategies, i e highlights *combination of mechanisms* as useful. However, it´s not just about choosing the right mechanism to diffuse a solution, it´s also about having future adopters in focus, support these in the best way and make set-ups and systems simple.

It can be noted by the results that more interaction is needed along the chain with a more overarching focus which points in the same direction as pointed out by Taylor (2006) when comparing BIM implementation in Finland and USA. One of the key differences was differences in viewing the chain, where the US had a short term view and divided approach in the construction chain and Finland had a more long term view and a more cooperative process. A conclusion was that BIM-implementation was more favorable in Finland due to a more integrative view on the construction process.

6. Conclusions

Based on previous research and this study it is evident that *Project stress, short term view and a divided chain* affects knowledge integration necessary to diffuse BIM and BIM-related solutions. Due to this and the decentralized work-model, it is of significance to create a demand from the projects to use BIM and BIM-related solutions. A push-strategy has been found useful as a phase one strategy in order to create a need for BIM-solutions and thereby creating a pull from the “market” i e the projects. The influence from the organizational width and its set up of rules is also visible, where an organization with a wider set-up of businesses along the construction chain is more likely to successfully implement BIM due to the ability to control the construction process. At the same time, the study shows that a small niche player also can affect the diffusion of BIM and its customers if contextual characteristics are taken into consideration in the implementation process.

With BIM and the transformation into an electronically managed information chain, different parts connect and become more dependent on each other. In addition, a key issue in the study is that adaptation to the existing knowledge base is of central importance for the diffusion of BIM. It is indicated that a major problem for the diffusion of BIM is the level of general knowledge about IT in construction. A higher knowledge level regarding IT seems to facilitate diffusion and as younger generations come into the sector the diffusion of BIM will most likely become smoother and faster. This is further enabled by the development of solutions that are easy to implement and understand. The study validates soft-personal modes as most useful and frequent in construction and validates the combination of different mechanisms as useful for efficient diffusion. The study furthermore indicates that new media can improve the diffusion of codified knowledge. Finally, an important aspect highlighted for the mechanisms is the necessity to introduce solutions in real projects, to show immediate advantages and discuss actual problems.

A final indication from the study is the need to develop change management and implementation knowledge to implement and diffuse solutions. Of interest for further studies is therefore to study approaches of implementation and change management in construction and evaluate what approaches that are specifically useful in construction research. Since the study also highlights that general knowledge regarding IT is of help for the diffusion of BIM, it can be of interest to study how knowledge in general or from other sectors can be used and implemented in the construction context and also what barriers that exist. In addition, the study has treated the aim in general and to validate the results further it could be interesting to go in more in detail in specific cases to get a picture of the diffusion from both inside the company and outside the company.

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Level 3 BIM for Standardised Design Delivery, Refinement and Optimisation: Is it a real option in the UK?

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Abstract

Building Information Modelling has been hailed as a panacea which will overcome the endemic fragmentation and collaboration issues in the UK Construction Industry. The Government's target to make BIM mandatory for all public projects from April 2016, and its roadmap to Level 3 BIM are extensively discussed in the literature. It is now clear that a number of large main contracting companies such as the Kier Group, Laing O'Rourke have been positioning themselves as the market leaders in the delivery of projects using BIM. Despite such developments, the Government's push and the general desire within the industry to make collaboration happen through BIM, industrial experience points to a number of important issues which can only be resolved by changing the way building projects are developed and delivered; and the way facilities are managed. Such changes would help close the performance gap by establishing feedback loops between operations, construction and design stages.

This paper reports on the findings of an Innovate UK-funded research project which aims to bring about these fundamental changes in the delivery, refinement and optimisation of standardised school designs. It sets the background by describing the context of this joint-venture between a major UK contractor and a local authority owned specialist offering national procurement frameworks. The multi-method approach to collecting, analysing and making sense of the case study data is explained. The key issues in achieving and using Level 3 BIM, e.g. competing processes and systems within the main contracting company, different levels and extents of use amongst the design and delivery teams, are then identified through one aspect of this case study. This discussion paves the way to establishing when, where, why and how Level 3 BIM should be utilised. The paper thus makes a novel contribution to the existing literature on BIM as it illustrates that BIM is not necessarily one size that fits all in terms of collaboration.

Keywords: BIM, collaboration, UK, standardised designs

1. Introduction

There have been a plethora of initiatives and discussions on the implementation of BIM in the construction industries across the World. It is commonly argued that the implementation of BIM will help these industries overcome their endemic reluctance to collaborate and thus achieve cost and time savings, and improved quality. Industry professionals, especially those who have had the experiential knowledge of using both CAD and contemporary BIM tools, will support claims that the capabilities and advantages inherent in the latter surpass the former. An extensive literature directed towards demonstrating the benefits of BIM either through implementation studies (Becerik-Gerber and Rice, 2010; Migilinskas et al., 2013; Li et al., 2014; Poirier et al., 2015) or some form of conceptual extension of the scope of different applications (Schlueter and Thesseling, 2009; Azhar et al., 2011; Wong and Kuan, 2014; Oti and Tizani, 2015) support these views. This literature, however, tends to rely on the perceptions of professionals of the benefits of BIM or of academics who theorise on how these benefits can be quantified in projects. Moreover, the uptake and diffusion of BIM appears to be slow across the industry. Certain studies (Azhar, 2011) have attempted to capture the reasons for such slow rate of diffusion. Despite this, there are indications that an evaluation of the current levels of BIM adoption is necessary to judge whether the desired Level 3 maturity is realistic in the UK. This paper aims to make a contribution to providing this evaluation through a ‘real-life’ BIM implementation case study.

It is divided into six sections. The second section outlines the case study context. The third section describes the methodological approach. An extensive literature review is then provided as evidence that there is a gap in the literature in terms of ‘real-life’ cases evaluating the implementation of BIM. A description of the design review meeting and the following user feedback session, which is the core of this paper, follows. The findings and observations are also discussed. Conclusions are drawn at the end of the paper.

2. The case study context

The case study that is presented in this paper is undertaken as part of an Innovate UK-funded research project, which is led by a British Main Contractor. The case study context is the delivery of standardised school designs as turnkey projects using a national framework agreement, which is set up by a public sector owned built environment specialist. Standardisation is particularly important for this project delivery approach as there is a clear advantage of using knowledge from one phase of the project life cycle to improve other phases. For instance, feedback from the operations phase can help to achieve continuous improvement of the standardised designs for potential future clients.

The Main Contractor aims to develop and adopt strategies to utilise the power of BIM in delivering, refining and optimising the standardised design as a ‘product’. This research project focusses on the integration of project data from construction and operation stages in a BIM environment and the capacity of BIM to facilitate collaboration between the main contractor, their consultants and supply partners. These ideas are tested as part of the continuous improvement of the 'product'. Thus, the opportunity for evaluating a 'real-life' BIM implementation approach to delivering projects is exploited. This paper reports on one aspect of this approach, namely the use of BIM in a collaborative design review meeting.

One of the first key deliverables of this research project was to develop a 3D federated model using the architectural, structural and M&E design models, locating the BIM implementation at the border between Level 1 and Level 2 BIM (Figure 2). The aim of the research project was to move this initiative to Level 3 by establishing and utilising feedback loops from the construction and operations phases of the building life-cycle. One aspect of this plan was to use Autodesk BIM 360 Field and Glue during the construction phase in order to integrate the project reporting and snagging information into the integrated model. This plan could not be implemented for three main reasons. First, 360 Glue/Field applications did not support the Main Contractor's sophisticated H&S reporting processes in an automated manner. Secondly, there were issues around the amount of training that the site team would require and whether it could be accommodated within a very tight and relatively short construction phase. Third, the Main Contractor started to use Priority 1 to report snagging while these discussions were taking place. Priority 1 was considered to be a more suitable platform than integrating the H&S reporting process into 360 Field/Glue. Fourth, the standardised design and its delivery processes were set up such that the lessons-learnt from the construction stage and the associated requests for design change would be incorporated into the Design Review meetings. Hence, it was decided that the regular Design Review Meetings between the Main Contactor, their design consultants and Supply Chain Partners would be a more appropriate venue to evaluate whether the integrated BIM could enhance collaboration between partners.

3. The methodological approach

The rationale behind using a Design Review meeting as a 'test-bed' for the use of BIM for collaboration purposes was explained in the previous section. This section describes only the methodological approach utilised in order to collect data during a design review meeting, and to subsequently analyse it. The overall methodological approach adapted in the whole project is out of the scope of this paper.

A predominantly qualitative approach was the obvious choice for understanding how the use of BIM influenced collaboration within the design team, which included supply-chain partners, and the closure of the feedback loop from operations and construction stages to the design stage. The lack of existing research in this area and the opportunity to study the complex phenomena of collaboration and learning from experience in its natural setting were the fundamental reasons behind this choice. The design review meeting was set up to provide an occasion for real-time observations, and to gather feedback from the participants at the end of the meeting.

The key supply chain partners were challenged to come up with ideas on reducing the time it takes to weather-tighten the envelope. The architectural design consultants, roof contractors, aluminium systems and insulation suppliers, and representatives from the main contracting company, were represented at the meeting. Researchers attended the meeting as impartial observers to collect data on the means and tools of collaboration that participants used. They also ran a real-time survey and a short focus group.

The participants were asked to complete a short questionnaire at the beginning of the meeting. This questionnaire was designed to collect demographic data and to establish each individual's BIM readiness. This data was used in making sense of individual's responses to the survey and the focus group discussions. The survey and the focus group aimed at gathering feedback from the participants on whether and how they thought the use of BIM influenced real-time collaboration. TurningPoint was used to collect survey data anonymously, and to display the results in real-time. As a result, it was possible to identify the key issues, i.e. those on which there was consensus or divergence of opinion, and thus to concentrate the focus group discussion on these issues. The focus group discussion was recorded. Key findings emerged from the content analysis of the focus group discussion.

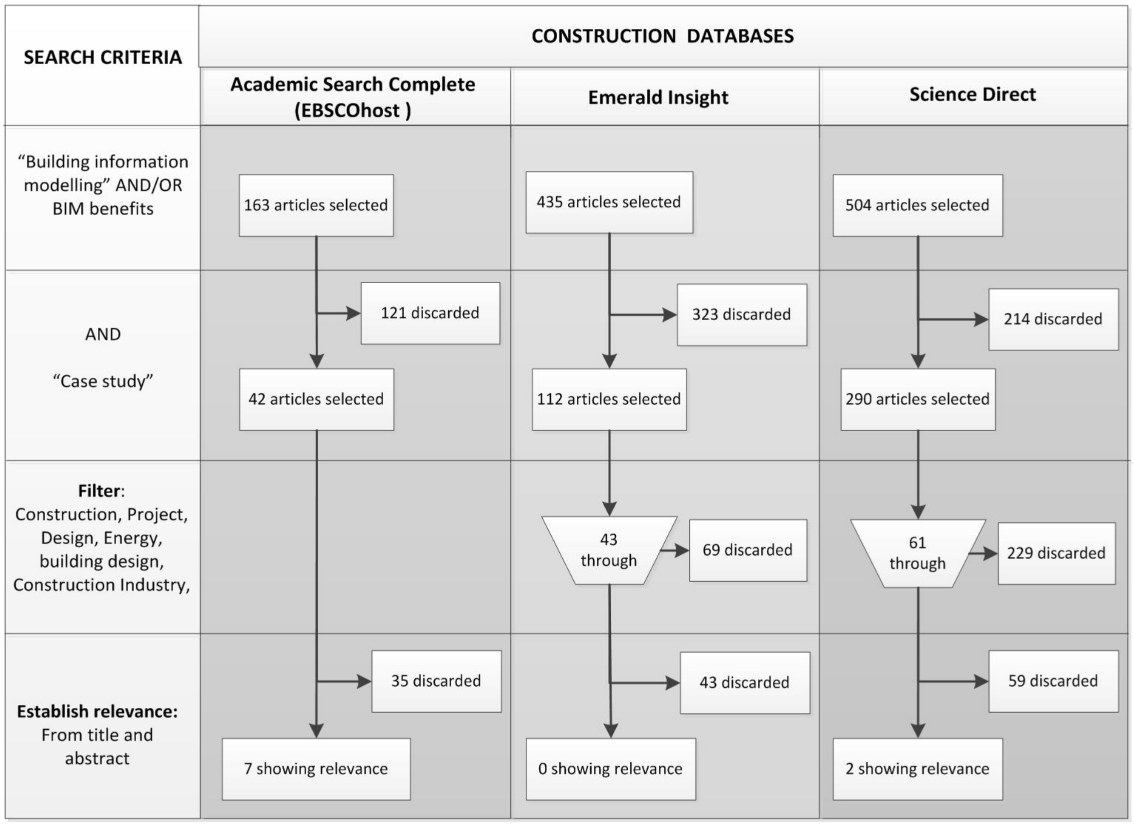

Figure 1: Literature search description

This case study was complemented with an extensive literature review. The aim was to establish the extent of existing knowledge on 'real-life' BIM implementation case studies with respect to Level 3 maturity. Three scholarly, cross and multidisciplinary databases, i.e. Academic Search Complete, Emerald Insight and Science Direct were chosen as they provide access to foremost literature in the construction sector. Database searches were undertaken using these keywords: building information modelling, BIM, case study and benefits. The results were further refined by filtering them using construction, project, design, energy, and building design as additional keywords in Emerald Insight and Science Direct. The EBSCOhost interface did not allow for the search results to be refined in the same way. The results are displayed in Figure 1. This filtering yielded 41 – 61 search returns in respective databases. The authors then scanned through the titles and abstracts to establish actual relevance. The systematic review therefore focused on the nine papers summarised in Table 2, and critically reviewed in the next section.

4. Literature review

It is important to start with an overview of the current state of BIM adoption in the industry. There is evidence in the literature that the uptake of BIM has been increasing across the globe. In the UK, the National BIM Survey Report focusing on SMEs indicated that the number using BIM rose from 13% in 2010 to 54% in 2013 (NBS, 2014). Similarly, Kiviniemi et al (2008) suggests that the ratio of BIM tools to Computer-Aided Design (CAD) use among companies in Denmark, Norway, Sweden and Finland is likely to increase from about 1:3 in favour of BIM. On a global scale, there have been positive indicators from the annual studies consistently conducted since 2007 by McGraw Hill Construction to gauge impacts and uptake of BIM in leading construction markets such as Canada, France, Germany, UK, US, Brazil, Japan, Korea, Australia and New Zealand (McGraw-Hill Construction, 2014). In most of these 10 countries there have been active efforts by both the private and public sectors to encourage the uptake of BIM. For example the UK government mandated government projects to be executed using Level 2 BIM maturity (Figure 2) from April 2016 (BIM-IWG, 2011). This has resulted in chains of events ultimately geared towards catching up with the BIM implementation boom. A number of higher education institutions have introduced BIM applications into their curriculum. There are a significant number of BIM- related research projects funded by the UK Government. Also, public institutions such as the BRE run short training courses (BRE, 2015). Workshops are also being held to promote the adoption of BIM by firms in the AEC industry. Despite all these efforts, it appears the industry is still struggling to get a full grasp of Level 2 BIM maturity.

Professionals are expected to be working in their separate software environments and models with the opportunity for federation at Level 2 Maturity (Figure 2). It is argued that such federation should aid with reducing the number of clashes between the designs provided by different disciplines. When this maturity level has been fully attained, it is expected that the industry will naturally attain the Level 3 BIM maturity.

Despite these aspirations, at the moment, it is difficult to establish from the literature whether and how well Level 2 BIM maturity has been achieved by the industry. The relevant literature (Table 1) that discussed BIM implementation tend to demonstrate the benefits of BIM through surveys of practitioners' perceptions built around notions already established via BIM promotion campaigns (Gilkinson et al., 2015; Poirier et al., 2015). Others theorize how the benefits of BIM can be quantified on projects (Barlish and Sullivan, 2012; Lu et al., 2012; Pilehchian et al., 2015). However, robust empirical evidence detailing actual experiences of BIM adoption during the various phases of the project lifecycle is lacking in the literature.

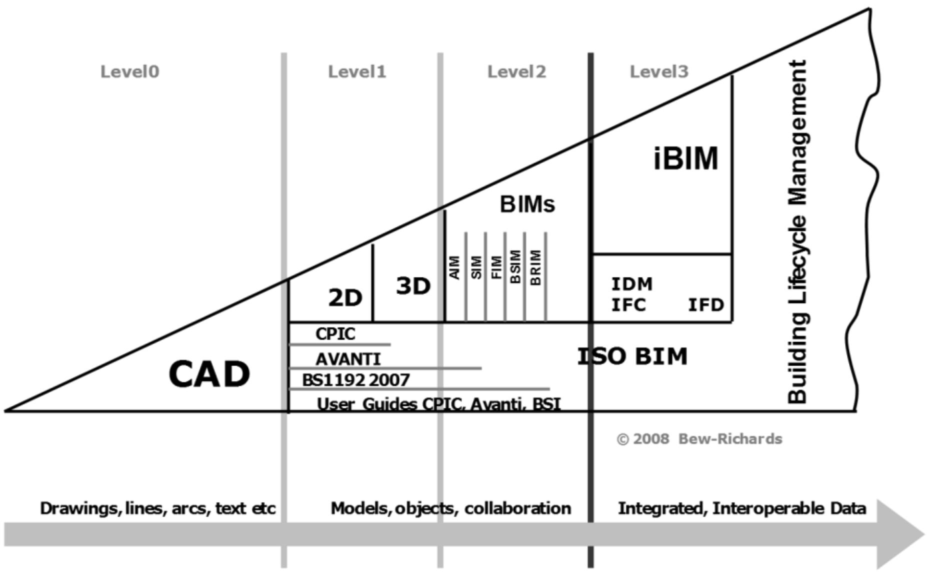

Figure 2: BIM maturity levels (BIM-IWG, 2011)

The lack of evidence becomes even starker when the literature search results of 1102 articles are filtered and the results discarded for their relevance, i.e. reporting on 'real-life' benefits of BIM implementation. Only 9 of the original 1102 report on BIM benefits are based on practical experience of implementing BIM in any stage of the project life-cycle (Table 1).

Gilkinson et al (2015) discussed the benefit realisation based on six case studies that relied on popular BIM tools such as Revit, ArchiCAD and Allplan 3D. The aspects of BIM application in these projects include the architectural design of Knowsley Schools, Royal Opera House mechanical, electrical and plumbing design services, the structural steelwork of North Lakes Police Station and the Heathrow Airport Energy Centre, the services engineering of 1 Bligh Street, Sydney – a 28 storey building, structural design of four high-rise blocks of Wood Lane studios of an academic institution and the planning/scheduling of the extension of Queensland State Archives. The authors suggest that the tide may be turning in favour of BIM following the changes in the UK government policy as contractors and their sub-contractors will have to be BIM-ready to be able to secure centrally- funded contracts from April 2016. They also advocate the move from a building information model to a building knowledge model in order to exploit all the benefits of a digital model. Migilinskas et al, (2013) featured four cases executed in Lithuania using various BIM-enabled tools (STAAD.Pro, Bentley Structural, Bentley Triforma, Allplan, Tekla Structures and CADVENT). The aspects of BIM application included planning and design, construction scheduling and facility management in these projects. Azhar (2011) provides an earlier, similar study covering planning and design, construction scheduling/documentation and sustainability analysis of three case studies in Georgia, USA, and identifies associated trends and benefits in the AEC industry.

In a rather more detailed study of ICT innovation on a large hospital project in the UK, Davies and Harty (2013) discussed the implementation of 'Site BIM' system for site workers to use mobile tablet computers to access design information, capture work quality and progress data on site. The tablet computers access coordinated 3D models developed in BIM-enabled tools hosted on site office servers equipped with document management system connected to a site database where progress reports, compliance targets, defects information and 3D viewer are logged and hosted. The authors argued that the use of Site BIM can be justified due to the large scale nature/complexity of the hospital project and the construction management procurement approach which required speed. Adjudged to be successful, the project was rolled out by a small team of construction project staff and enrolled IT personnel. Although details of BIM tools utilized were not clearly mentioned in the study, the accomplished tasks respectively appear similar to the functions of common data environment and field applications such as Buzzaw/BIMSight and Autodesk BIM 360 Field that were used in our case study.

Table 1: Literature on BIM implementation benefits

Research source	**Origin of study**	**Area/ life cycle phase**	**Main features**
(Gilkinson et al., 2015)	UK	Design, Construction	• Reports on a number of case study research projects • Identities benefits, challenges and opportunities
(Poirier et al., 2015)	Canada	Renovation construction works	• Based on action research • Measurement of labour productivity
(Lu et al., 2012)	China	Construction	• Based on the use of learning curves • Proposed measuring benefits of BIM as a learning tool on site
(Pilehchian et al., 2015)	Canada	Design	• Use of graphs and dependency matrix • Monitoring of design changes and their dependencies
(Barlish and Sullivan, 2012)	USA	Design, Construction and Post-completion	• Combined literature and case studies • Developing a holistic methodology to quantify BIM benefits
(Eadie et al., 2013)	UK	All stages of construction project	• Use of web-based questionnaire survey to gather information • Designed to gauge perception and experiences of participants in BIM implementation • BIM is more extensively used during the early stages of the project-life cycle
(Bynum et al., 2013)	USA	All stages of construction	• A survey-based analysis of BIM implementation • Application of inferential statistics on findings to establish relationship between BIM and project delivery
(Lindblad and Vass, 2015)	Sweden	Organisational management	• A literature and a case-based study to identify associated organisational change effected in steering documents and work process due to BIM implementation
(Davies and Harty, 2013)	UK	Construction	• Case study of 'Site BIM' system implementation • The use of mobile tablets to access design information, capture quality and progress of work on site

This literature review illustrates that various scales and approaches of BIM case studies exist. However, studies which evaluate the use of BIM as a collaborative tool which facilitate the closure of the feedback loops from operations and construction stages to the design stage are missing. Moreover, more focused and detailed recounting of actual experiences is required to encourage cascading of candid practical accounts through the industry. In this light, this study presents lessons from the actual experiences of BIM application in a standardized turnkey project delivery. In this project, BIM is utilized as a learning platform to close up the operation/ construction-design feedback loop.

5. The Design Review Meeting as a Collaborative Learning Platform

As stated above, the Design Review Meeting focused on reducing the time it takes to weather-tight the building. The participants are involved in the design and delivery of the product both at the strategic, developmental and operational levels. Each attendee has at least ten years' experience in the industry. The delegates from the architectural consultants and the Contractor's BIM Manager were the only delegates who have high levels of experience in using BIM environments. The majority of the participants (6 out of 9) had low levels of BIM-readiness.

The Product Director of the Main Contracting (MC) company chaired the meeting following an agenda that would enable collaborative envisioning of possible solutions. The BIM Manager of the MC walked the attendees through the 4D model and showed the construction simulation based on the 4D programme of one of the schools. Attendees also viewed a time-lapse video of the construction phase of the same project. An informal discussion which broadly followed the pre-determined agenda ensued. The attendees were willing to share their ideas and make suggestions for reducing the time to weather-tightness. In this context, high levels of collaboration were observed among the participants who were all driven by a desire to continuously refine the standardised design and bring about efficiencies in its delivery.

Despite all the intention of facilitating collaboration through the use of BIM, the use of the construction simulation and the federated model during the meeting was very limited. Throughout the meeting there was a preference towards using 2D information that had been drawn out of the 3D model. In one case, a 2D print out was quicker to make available than its digital version as a pdf file. The time-lapse video was preferred to the construction simulation when visualisation was required. It could have been argued that the time-lapse video is more effective in facilitating real-time collaboration than the construction simulation in this particular context. However, relying on time-lapse videos mean that the variations to the schemes are not considered as part of the Design Review Meetings. Although this business model centres around a standardised design, about 70% of the schemes are adapted for various reasons.

Perhaps the low levels of BIM exposure among the event delegates is the reason behind the little use of the construction simulation and the preference towards the time-lapse video. It also points toward the need for training but more importantly a focus on changing the way people conduct their day-to-day business, if the capacity of BIM to facilitate real-time collaboration is to be exploited. This change can only happen if every company involved in refining and delivering these standardised designs are convinced that only BIM can deliver the business performance that will render each company a leader in their field. As identified by Lindblad and Vass (2015), even a large public client, which intiated BIM implementation in their own organisation, is not yet certain how BIM should and would influence the organisation. Hence, there is a need for robust methods for evaluating the impact of BIM on a business' processes and performance.

The results of the anonymous feedback survey show that the majority of the attendees (7 out of 8) either agree or strongly agree that 4D visualisation made it *easier* for the delegates to share their ideas at the meeting, and *encouraged* them to share their ideas with others. One of the Product Managers working for the Main Contractor explains why:

> *"..when you bring the model up there, you are not trying to interpret it from a 2D drawing. It is the same as standing on site and looking at the detail and saying 'can we do that better'…"*

The Sales Director of the Aluminium Systems supplier corroborates as follows:

> *"I get involved in structural design very early on. Sometimes the Structural Engineer overdoes it for me. When I look at the 3D model, I can ask why certain elements are there. Then, they tell me that they are to receive my products and I tell them that I do not need it. Hence, early on in the process you can make an input. Very useful. Very easy to understand where the other person is coming from."*

This finding contradicts with the findings of Eadie et al. (2013) which identified that "the visualisation benefits were thought to be not as significant as the increased collaboration, reduction of waste and accuracy".

Same positive responses were also achieved when the attendees were asked whether they were more willing to contribute ideas. The reasons behind this score also centre around the ease of understanding each other as a result of having access to the model. The BIM Director of the architectural consultants explains:

> *"You do not have to explain something to somebody. You can point to it. You can say: 'look this is what I am talking about'. It is much easier than saying: 'you know the little bit under the eaves …'*

It should also be noted that some of the delegates believe that collaboration is in the nature of this group mainly because they are involved in refining a standardised design. In this context, members of this group are already willing to share their ideas with each other. The 4D model makes the communication during the meeting more effective rather than facilitating collaboration in the first place.

Only 3 out of the 8 respondents agree or strongly agree that it was easier to coordinate the meeting as a result of 4D visualisation. Nearly all respondents are neutral that 4D visualisation helped identifying programme reduction opportunities or potential conflicts in the design solutions proposed. As such, the 4D visualisation facilitated a more effective *sharing* of ideas but it has not helped with *evaluating* the implications, e.g. cost and time, of incorporating these ideas into the design. Delegates reported that this evaluation was better done in a more traditional way outside the meeting. The Product Director of the Main Contractor explains:

> *"If you are considering what could have been done differently, by its nature you have not modelled it yet. If you have not modelled it yet, you cannot look at it in the software. It is more appropriate if people went away from this meeting, modelled stuff up, and we centred our discussions at the next meeting around [the model]. I think that would be really, really, really useful. We are a couple of steps before that point. I would say BIM helped us get our bearings today but we could have had a photo instead….*
>
> *BIM is one of the tools at your disposal. Some tools are better at a certain juncture than others…. [BIM] is never going to be as intuitive as taking a felt-tip pen out and sketching it, unless your model is super-duper."*

The BIM Director of the architectural consultants further elaborates:

> *"You use a meeting like this to inform you when you go away. Everybody still works in their individual silos on their models which are then federated, obviously, and then clash detected. You could not necessarily work on your model because it is on your server and the engineer's model is on his server till you get to a Level 3 environment where they are all stored in the same place. Even then, you are trying to access them remotely. So, the reality of it is, you all get together, you go through it in Navisworks, or whatever you are using. You make your notes, you mark the model up. You post that model. You go back to the office. You download it and you look at it. You make the changes. [A model] is incredibly useful in the right place."*

This discussion illustrates that, at least in this context, a clash-detected digital model is produced following the traditional approach to integrating the architectural, structural and mechanical designs. It is clear that these professionals do not consider real-time collaboration to be an option even when Level 3 BIM is achieved. Also, the standardisation of the design and its delivery mainly using a framework contract seem to be more influential in facilitating collaboration than the BIM, which is considered to be valuable for visualisation purposes. This suggests that this team is a relatively long way away from Level 3 BIM and Gilkinson et al.'s (2015) suggestion to move to "building *knowledge* models". More importantly, the professionals imply that one needs to establishing when, where, why and how Level 3 BIM should be utilised, rather than considering it to be a panacea for the industry's collaboration issues.

6. Conclusions

The literature review demonstrated that there is a gap in the literature in terms of 'real-life' BIM implementation. One of the small number of case studies that can be found in the literature identified the scale, nature/complexity of the project and the procurement approach to be the key justifications for using BIM. User feedback from this case study points to similar situation. The standardisation of the design and the use of a framework contract for delivery play a more important role in collaboration than the use of BIM.

In this particular context, 4D visualisation is considered to help with sharing ideas and coming up with solutions to existing problems. This team considers that real-time collaboration facilitated by BIM is neither desirable nor possible in their context. Hence, BIM and other means of nD visualisation remain to be enablers rather than collaboration tools in themselves, placing this case study closer to Level 2 than Level in terms of BIM implementation.

Although it is impossible to draw general conclusions from a single case study of a very specific approach to design and delivery, the literature review and the case study point to the importance of companies considering the implications of their BIM implementation strategy in different contexts. As such, project characteristics such as type, scale, complexity, procurement method, and the ease with which internal processes such as H&S reporting can be incorporated in the use of field applications such as 360 Field and Glue, should be taken into account. The development of a BIM implementation matrix with these characteristics would enable companies determine which projects are most likely to benefit from BIM implementation. The authors have identified the development of this matrix as a future research opportunity.

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Building Information Modeling; a New Business Trend in the Construction Industry of Iran

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Abstract

Building Information Modeling (BIM) is a 3D design tool that has been widely used in the developed countries and has become a profitable business. However, this procedure in developing countries is proceeding slowly. This research looks at BIM, as a new business tool, and uses SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis (a business method) to specify and analyze internal and external motivating factors in the construction sector of Iran. It also investigates industry readiness for implementing BIM in Iran. A questionnaire survey was conducted among a number of different parties within the construction industry. The outcomes of the survey were used to determine most important strengths, weaknesses, opportunities, and threats of BIM application in the construction industry and SWOT analysis was performed. Based on the survey results, internal environment properties (strengths and weaknesses) and external environment possibilities (opportunities and threats) were prioritized from respondents' point of view. Regarding to survey results, structured interviews were conducted to formulate strategies for decision makers to introduce the new trends and encourage the construction companies to apply BIM in their projects.

Keywords: Building Information Modeling, BIM, SWOT Analysis, Construction Industry, Developing Countries

1. Introduction

"Construction is a large industry of small firms" (Fellows et al., 2002) that is divided into two major sectors: general building construction which includes residential, commercial, institutional and industrial buildings and engineering construction which includes highway construction and heavy construction (Bennett, 2003).The construction industry is a massive business with more than $3.9 trillion annual turnover and employs around 7 million directly and hundreds of thousands indirectly in the world (Jackson, 2010) it is estimated that in 2008 the construction industry in the US spent around $1.288 trillion (National Institute of Building Sciences, 2007) with 2.53 million construction companies in 2007 (Levy, 2009). Buildings consume 40% of the world's raw materials and 40% of the world's energy (65% of U.S. electrical consumption is used in building); therefore, the construction industry plays an important role in energy consumption, economics and politics. Producing 40% of carbon and 20% of waste materials of the world, the construction industry has considerable impact on the environment. Taking into account these characteristics and over $600 billion estimated waste in the U.S. construction industry (National Institute of Building Sciences, 2007), it is essential to manage the construction projects.

Project management is applicable in the construction industry regardless of the size and complexity of the projects (Chartered Institute of Building, 2002). Construction management is defined by Patrick (2003) as "planning, scheduling, evaluation, and controlling of construction tasks or activities to accomplish specific objectives by effectively allocating and utilizing appropriate labor, material, and time resources in a manner that minimizes costs and maximizes customer/owner satisfaction." Bigger and more complex construction projects require larger and more professional workforce. The project team must be effectively coordinated to achieve project goals. For this reason, 3-D modeling has been developed by technological advances to build a virtual model by computer much prior to construction phase (Levy, 2006). Manufacturing industries like the automotive industries have integrated design, production and operation phases by virtual design of their complex products. This technological approach has been applied to construction industry in the shape of BIM (Jones, 2008).

Smith (2007) defined BIM as "a digital representation of the physical and functional characteristics of a facility and shared knowledge resource for information about a facility, forming a reliable basis for decisions during its life-cycle, from the earliest conception to demolition." It is essential to consider that BIM should not be the goal, it is just a tool to help project members to achieve their goals (Kymmell, 2008). BIM caused a revolution in the construction industry (Jones, 2008). As stated by Weygant (2011) "Just as CAD (computer-aided design) improved upon hand drafting, BIM is improving upon CAD. The difference is that BIM involves so many more project participants than just the architect." However, this improvement has not been started yet or it is still in its infancy in some developing countries. In order to implement BIM in developing countries, it is essential to analyze the construction industry to discover its potential.

SWOT analysis in the construction industry has been performed in some studies. For example, Lu carried out SWOT analysis for the strategic planning in China, Ling et al. (2009) used it for A/E/C firms in Vietnam and Lee et al. (2011) conducted SWOT analysis for the strategic management in Korea. However, such an analysis has not been performed on BIM application in the construction industry in Iran. This study aims to bridge this gap.

2. Methods

A SWOT analysis has been conducted in this research. The SWOT analysis consists of three stages: identifying SWOT factors to know the internal specifications and the external elements which might affect the industry; designing SWOT matrix to provide a summary of the industry's current situation and make strategic decisions to maximize utilization of resources strengths; gain profit from opportunities, minimize significant weaknesses and eliminate threats (Thompson et al., 2009).

A questionnaire consisting of three sections was designed. The first section was general information about respondents for further use in categorizing the data. In the second section, the level of knowledge about drawing and design tools and software was evaluated by close ended questions. This section provides awareness around the current situation of the construction industry's parties and their skills. The third section contained questions about SWOT factors in the construction industry for BIM implementation. The characteristics of BIM and the construction industry in Iran had been studied through a comprehensive literature review and accordingly several alternatives for each factor were considered to determine their importance by 7 points Likert scale (zero representing not important and 6 representing most important). Based on the results of previous researches (Sanei Sistani, 2015, Sanei Sistani and Rezaei, 2012), practitioners in the consultants, design, and construction companies with basic knowledge about BIM were selected as respondents. Out of the 100 questionnaires that were distributed, 60 were responded.

Since the level of knowledge about BIM among Iranian construction industry practitioners is not so high and strategic management need broad knowledge about BIM, afterward, face to face structured interviews with 10 professors of civil engineering and architecture were performed. Based on the interviews, a SWOT matrix with two rows (opportunities and threats) and two columns (strengths and weaknesses) was prepared as a solution to overcome threats and weaknesses by managing strengths and opportunities. Considering four quarters of SWOT matrix, S-O (Strengths-Opportunities), S-T (Strengths-Threats), W-O (Weaknesses-Opportunities) and W-T (Weaknesses-Threats), analysis was carried out and strategies for decision makers were formulated.

3. Results and Discussion

SWOT factors for the construction industry in Iran were considered as a result of a detailed literature review and were validated by questionnaire survey as listed in Figure 1.

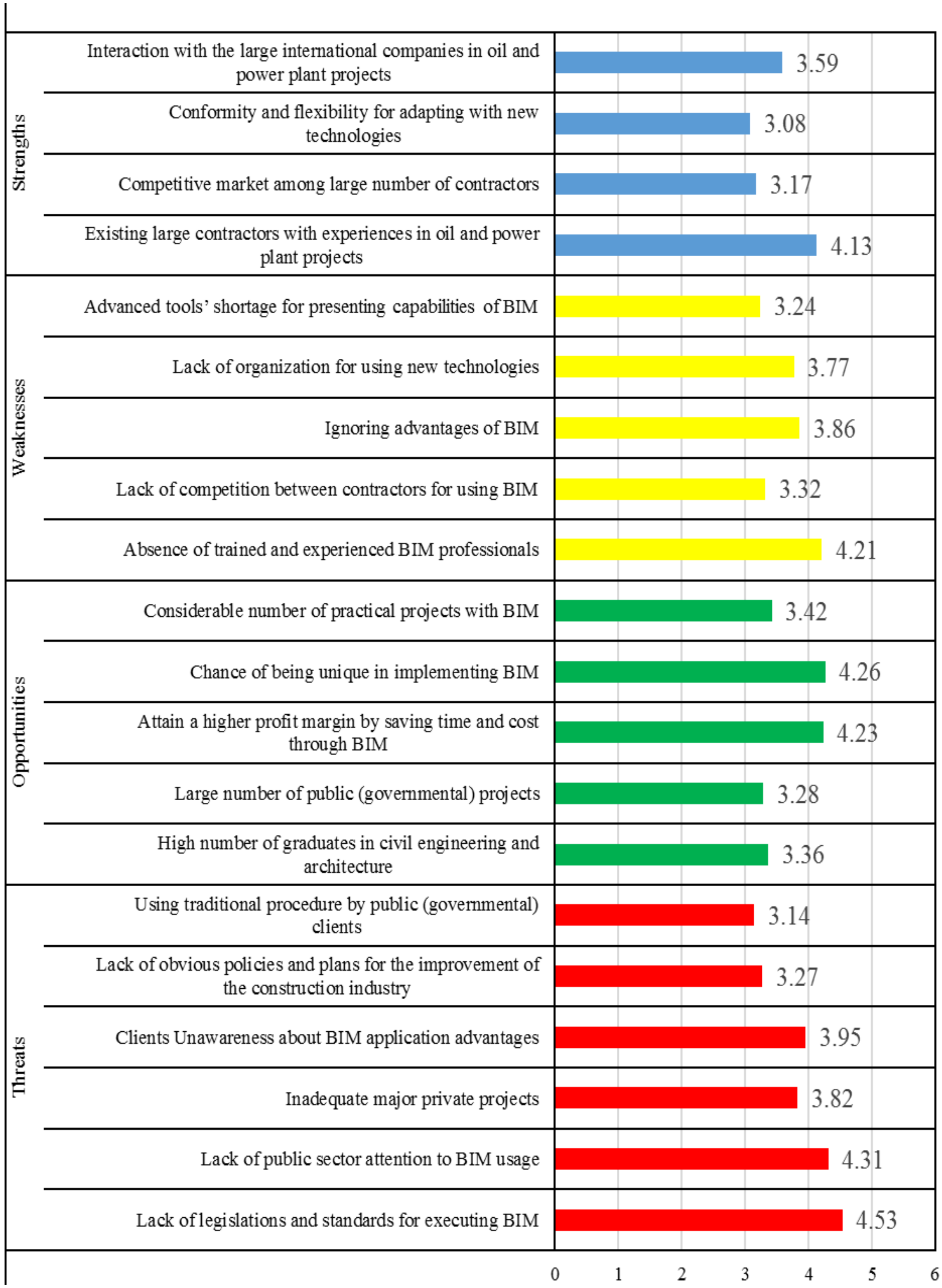

Figure 1. Weighted means of SWOT factors based on questionnaire survey

3.1 Strengths

Existing large contractors with experiences in oil and power plant projects Like other Middle Eastern countries, oil plays a vital role in Iranian economy. Due to cheap and easy access to oil, the number of power plants have been increased considerably. Petroleum and its related industries (oil platforms, oil refineries, pipelines, power plants, etc.) form some of the biggest construction projects which require serious attention in this section. Due to these needs, the domestic contractors tried to improve their capacities in executing huge projects (Faani et al., 2014b). Working on these types of industrial construction projects provides valuable experiences for the construction industry.

Competitive market among large number of contractors By increasing the number of graduates in civil engineering and architecture, the construction firms grow simultaneously. The more firms in the construction market, the more competition for winning the bids. The firms try to adapt themselves to new technologies; otherwise they will lose competitions (Sheikh Khoshkar et al., 2014).

Conformity and flexibility for adapting with new technologies The entry of a new generation of civil engineers and architects to Iran's construction industry, the industry's adaptability to new methods and technologies have been improved (Vatankhan et al., 2013). Their potential to advance makes the construction industry flexible towards the technological changes and alterations.

Interaction with the large international companies in oil and power plant projects As stated earlier, the petroleum related construction industry is one of most active fields in Iran. Working in this field requires cooperation with huge international oil companies at the highest level. This close relationship between the Iranian and the international companies has many advantages for the construction industry of Iran. For example, becoming familiar with the latest methods and tools, gaining valuable experience, getting involved in the international markets, etc (Faani et al., 2014b).

3.2 Weaknesses

Absence of trained and experienced BIM professionals Some of the Iranian universities do not even offer design and drawing as core courses in civil engineering and architecture disciplines. These courses include hand drawings or at the best cases 2D CAD drawings. In this situation, the graduate of such universities normally lack 3D modeling experience (Akbari and Safari, 2014). The few that have this skill, have learned it through self-study which in most cases is time consuming and not done in a correct way. It is obvious that without proper training, sufficient experiences would not be gained (Gu and London, 2010).

Lack of competition between contractors for using BIM The most important factor that could encourage an industry to use new tools is competition. Contractors were not motivated to use new tools unless there was a demand for using those tools; in other words, there was no demand for such tools (Vatankhan et al., 2013). The supply and demand is a cycle and it is an ancient question that "which one is the start point of this cycle?"

Ignoring advantages of BIM Since the students have not had the opportunity to learn the latest design and drawing techniques and tools other than 2-D, the awareness about BIM and its advantages is very low. Adopting BIM in the construction industry demands serious attention in education and training at the first level (Asgari and Gerami, 2014). The construction management is moving from CAD to BIM, but in Iran moving from hand drawing to CAD has not been completely achieved yet.

Lack of organization for using new technologies The Iranian construction firms work with traditional design tools. BIM is a revolution in the construction industry, not only in drawing and design but also in tendering, construction, and mainly operation and maintenance (facility management). This alteration must be done by a well-organized policy (Faani et al., 2014a). Unfortunately, this organization does not exist in the construction industry of Iran.

Advanced tools' shortage for presenting capabilities of BIM BIM is a high performance technological tool and requires to be appropriately presented to its users. BIM's primary requirements including hardware, software and equipment like 3D projection and laser cameras have an important role in introducing BIM potentials (Qing et al., 2011). Obviously, in order to replace the traditional tools with the new technologies, BIM can be used as a new tool. However, BIM has its technological requirement (Akbari and Safari, 2014).

3.3 Opportunities

High number of graduates in civil engineering and architecture The annual rate of bachelor degree graduates in Iran ranges between 280 and 300 thousand yearly (Ameri, 2011). There is a high competition between graduates to be employed in the construction companies. The demand for engineers and architects with BIM knowledge encourage the graduates to learn these skills (Ahn et al., 2015).

Large number of public (governmental) projects The government is the biggest client in Iran's construction industry. Although, this limits competition among clients, but competent organizations in this sector can be effective in persuading contractors to use BIM in different phases of the projects (Tafakor and ShaterZadeh Yazdi, 2014).

Attain a higher profit margin by saving time and cost through BIM The main advantages of BIM are time and cost reduction. BIM helps to prevent the clashes during the construction phase by creating a visual model of the project at the design stage (Ahn et al., 2015). These digital 3D models are also very useful for better understanding of project specifications, from conception to commissioning. In traditional methods, the coordination between different parties in a project mainly started at the construction phase, but by using BIM, the collaboration can be started at an early phase which helps to reduce re-works and this can lead to considerable saving in cost and time (Ebrahimi and Mahmoodabadi, 2013).

Chance of being unique in implementing BIM BIM is a very new technological tool that is still in its infancy in many countries. The novelty of BIM offers an opportunity to be one of the first enterprises that implement it (Sheikh Khoshkar et al., 2014). Although there are difficulties in using a new tool for the firt time, valuable experiences can be gained and the benefits of being a pioneer in an industry will create great opportunities for any company.

Considerable number of practicable projects with BIM BIM application might not seem to be economic for a company (according to high initial investment to start using BIM). Considering the government's construction development budget of $34 billion 2011(Council of Ministers, 2011), it is clear that BIM application in noticeable number of projects could cover its initial costs in a short period of time (Mirjalili et al., 2014).

3.4 Threats

Lack of legislations and standards for executing BIM Standardization could be the first step for using BIM. The term of 'Building Information Modeling' must be clearly defined and its usage domain must be specified (Qing et al., 2011). The designers, owners and contractor must be aware of their responsibilities and duties for using BIM in projects. Whereas construction industry is very debatable, legislation is essential for preventing and solving disputes. BIM legislation and standardization must be assigned to an independent organization body and if such an organization does not exist, it can be set up (Shakeri et al., 2014).

Lack of public sector attention to BIM usage While public (governmental) sector does not attend to new technologies like BIM, construction industry faces this threat. Lack of organization in the Iranian government regarding BIM utilization has caused delays and an increase in projects cost (Faani et al., 2014a).

Inadequate major private projects Private clients try to gain more benefits by reducing time and cost. BIM could be a very effective tool in this regard, but unfortunately due to inadequate large private projects, there is a lack of encouragement and competition in the construction industry of Iran (Tafakor and ShaterZadeh Yazdi, 2014).

Clients Unawareness about BIM application advantages The clients are not aware of BIM and its advantages in reducing time and cost. Research works in construction management are not adequate and not successful in improving the clients' knowledge about new methods in managing construction projects (Faani et al., 2014a). Without awareness about BIM and its usage, the construction industry has been slow in accepting this tool (Abubakar et al., 2014).

Lack of obvious policies and plans for the improvement of the construction industry Despite the recent activities to integrate construction related ministries and spending more than 5 percent of the government's budget for construction development, there are not clear plans to improve and update construction methods yet. Transition of the construction industry from traditional to modern methods requires effective planning and defining policies in macro scale (Asgari and Gerami, 2014).

Using traditional procedure by public (governmental) clients The traditional structures of the construction industry in Iran have caused the clients to think it is risky to use BIM without the required experiences (Shakeri et al., 2014). It is impossible to use highly technical tools in the traditional systems. To improve the efficiency of the construction industry by using BIM, the construction projects procedures must be changed.

3.5 SWOT matrix

SOWT (or TOWS) matrix (Table 1.) shows how to use environmental and internal specific positive factors in the construction industry against negative external and internal factors to gain more benefit from the strength and opportunities and to overcome the weaknesses and threats.

S-O strategies are strategies for using strengths to take advantage of opportunities by pursuing them rapidly. These are future growth strategies. W-O strategies specify how to overcome the weaknesses that prevent the industry from taking advantages of these opportunities and are known as internal fixes strategies. S-T strategies determine how to use the strengths to reduce the likelihood and impacts of threats as external fixes strategies. W-T strategies are Survival strategies to overcome the weaknesses that will make threats a reality must be placed in W-T strategies quarter of SWOT matrix.

4. Conclusion

A serious trilateral synergy between educational, industrial and governmental organizations is required to persuade the construction industry to use BIM. The first step for adopting BIM in the construction industry is to show its advantages and potentials in time and cost reduction. This goal can be achieved by organizing conferences and seminars. After providing awareness and motivation about BIM and creation of demand, the educational effort must be concentrated on educating students through courses in universities; training engineers and architects through workshops and clients through conferences and seminars.

The Government must provide appropriate legislation and environment for using BIM. These legislations could be used to prevent disputes. Appropriate standards for BIM integration implementation could also be created. On the other hand, public sector must encourage contractors to use BIM. This can be achieved by making the use of BIM in large projects mandatory. Due to traditional characteristics of construction industry in Iran, institutional efforts for finding ways for transition into technological age are required. This transition needs effective policies and long-term planning in macro scale.

Table 1. SWOT/TOWS Matrix

SWOT/TOWS MATRIX	STRENGTHS	WEAKNESSES
	Existing large contractors with experience in oil and power plant projects Interaction with the large international companies in oil and power plant projects Conformity and flexibility for adapting with new technologies Competitive market among large number of contractors	Absence of trained and experienced BIM professionals Lack of competition between contractors for using BIM Ignoring advantages of BIM Lack of organization for using new technologies Advanced tools' shortage for presenting capabilities of BIM
OPPORTUNITIES	S-O STRATEGIES	W-O STRATEGIES
High number of graduates in civil engineering and architecture Large number of public (governmental) projects Attain a higher profit margin by saving time and cost through BIM application Chance of being unique in implementing BIM Considerable number of practicable projects with BIM	Provide appropriate legislation to use BIM in large public (governmental) projects Encourage contractors through contractual requirements to reduce time and cost through using BIM Training of engineers and architects to learn how to use BIM software	Educate civil engineering and architecture students to use BIM Provide awareness workshops about BIM's advantages among contractors Demand for using BIM in public projects to encourage contractors to adopt BIM
THREATS	S-T STRATEGIES	W-T STRATEGIES
Lack of legislations and standards for executing BIM Inadequate major private projects Lack of public (governmental) sector attention to BIM usage Clients unawareness about BIM application advantages Lack of obvious policies and plans for improvement of construction industry Using traditional procedure by public (governmental) clients	Partnership with private sector in public projects organizing conferences and seminars to introduce BIM Establish or assign an institute to legislate and standardize BIM	Long-term policy to improve management in construction projects Replace traditional methods with technological alternatives Interaction with international companies for implementing BIM in large projects

The construction industry has a significant role in adopting BIM. Using BIM is a sound investment that helps each company to recover its cost once and for all and enjoy its benefits in long term. This investment can be done by training engineers and designers in BIM software application in n-D modeling. Large contractors involved in national projects can drive benefit of collaboration with the international companies and use their experiences in utilizing new technologies.

Building visual models with software at first stage of projects has become popular in the construction industry. BIM as a new technological high performance tool plays a key role in the construction industry and its advantages have helped this trend to grow rapidly. In order to enjoy the benefits of BIM, close synergy between related sections is essential for the building of the necessary infrastructures.

In this research, the characteristics of the construction industry in Iran were studies through a SWOT analysis. SWOT factors were identified based on a comprehensive literature review, structured interviews and a thorough questionnaire survey. The strategies considering the external and internal factors in three main areas were suggested. These areas are education, legislation and adoption strategies which must be pursued in parallel and without priority.

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Framework for Enabling Scan to BIM Services for Multiple Purposes – Purpose BIM

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Abstract

Technology for scanning is in rapid development. More advanced solutions are available for lower cost of scanning, and simple methods are available for everyone. Use of a building information model (BIM) for facility management is gaining interest, there is still a large number of existing buildings without BIM representation. As-built drawings are not updated or unreliable. However, establish a BIM for an existing property is often costly, and hard to utilize for new purposes. Time and cost effective methods for flexible use is therefore wanted. Integrated Design and Delivery Solutions is used as theoretical frame for this study. The analysis explores the steps in the process of scanning and modelling, collaboration between people in establishing the BIM, and further use for multiple purposes within facility management. An overview of technology presents in relation to process and people to give support for ordering commercial scanning and BIM services. A scan to BIM project of an old apartment building is used as case for demonstrating a framework for "Purpose BIM". This framework combines relevant technology, processes and personal resources for flexible and stepwise processes of ordering scan to BIM services. An outcome of this approach can be add-on services that can enable reuse previous work. This can result in extended use of BIM to multiple purposes in facility management.

Keywords: Purpose-BIM, process specification, product specification, scanning technology

1. Introduction

There is an increasing interest for integrating laser scanning as basis for establishing building information model (BIM). Laser scanning technology is in rapid development, likewise development of BIM software. Detailed scanning of heritage buildings is often presented as an example of the potential of scan to BIM, but most buildings are ordinary and need a more simple approach to maximize the cost/benefit relation. Even if there is a lot of available theology for scanning and modelling a BIM, the projects are often motivated by solving one single task, by use of one technological approach, often by one single provider. Development of technology contributes to reduced cost, but the traditional processes have limited flexibility and the cost must be covered by only one use-case, or benefit. Often will small changes in requirements to the BIM – result in repeating almost the entire scan to BIM process. The impact is limited establishment of BIM for existing facilities, despite the benefits for using BIM for multiple purposes within facility management.

There is an increased number of papers regarding integration of BIM, based on various methods for laser scanning in BIM related conferences. This can be illustrated by activity at following BIM related conferences; the BIM 2015 conference had one entire sessions about BIM and GIS integration (Breibba et al., 2015), and the CIB-W78 IT in construction conferences have included papers which cover solutions where BIM can be established based on laser scanning (Issa et al, 2014 and Beetz et al. 2015). This integrated focus has also reaches standardization, where ISO/ TC 211 about GIS and ISO/TC58/SC13 about BIM have joint workshop (Kim, 2012). The general focus of research is on issues related to technical interoperability, demonstration of laser scanning hardware and use of software for transforming point clouds into 3-D geometrical models and BIM.

The outcome of this concept paper is useful for building owner / facility manager (client) for design of specification or requirement for ordering scan and BIM services – especially when the purpose is not limited to only one purpose. Expected impact is increase return of investment. The outcome for service providers of scan and BIM services is in improved accuracy of deliverables in relation to client current and future needs. The proposed framework is called “Purpose BIM” and includes all elements from preparing of the project, capturing information by laser scanning, processing of information into BIM, and various ways of presenting results for different users and use cases.

2. Technology overview

2.1 Overview of methods and processes for scan to BIM solutions

The process from the decision to capture geometrical data describing the building to establish a BIM for solving one or more purposes consists of several steps. To be aware of these steps and the options within each steps can make it possible to order according to the principles of “purpose BIM”, see figure 1. This is possible even if purpose is unknown or multiple.

Representation of points, z,y,z	Creating a 3D volume model (mesh)	Establish building objects enriched with attributes and relations	Building information model of a building

Figure 1: Overview, main stages in the scan to BIM process

Awareness of these steps, and potential between the steps and within each step, is one of the main motivation for this study, and will be explored later on in this paper. Use of the "Purpose BIM" is presented as a framework for an improved ordering of services to enable flexible use and options for future use with positive cost/benefit of the BIM model.

2.2 Overview of capturing geometrical data

Today there is a large variety of instruments used to create a BIM for an existing building. In this paper, we will refer to this as Interoperable Technologies, with reference to IDDS (2013) presented later in this paper. The different technics are mainly:

- Use the original building drawings (both digital and paper based)
- Tape measure (ruler or handheld laser)
- Static point based laser measurement (e.g. "Flexijet" or total station)
- Static laser scanner (terrestrial laser scanner mounted on a tripod)
- Laser scanner and other instruments mounted on a moving platform

We focus on the laser-based methods. These approaches have developed dramatic in recent years and have changed the way we capture indoor data. The "static point based laser measurement" approach use the concept "less is more". This technique has a direct link into the modelling software, e.g. by use of Flexijet. The modelling and enrichment of the model is done on site. Which in many cases has a big advantage. On the other end of the scale, you find "laser scanner and other instruments mounted on a moving platform" which use a "more is less" approach. The goal is to measure as much as possible and also the same objects as often as possible. This method has taken technics from the robotics into use. The technique is called Simultaneous localization and mapping (SLAM). This is the key concept in autonomous robotics. The robot use SLAM to create a map of the surrounding and at the same time place itself in the map. This concept is now used by many manufactures of indoor measurement systems. These systems are special made to rapid create a building model. These techniques give new opportunities and new challenges. One problem with the more is less approach is that you also collect information that might be sensitive for the people living or working there. In such a situation, the data need to be handled with care. Different techniques have different accuracy capability and the performance improve rapidly with time. We have manly talked about laser scanners, but new software can put the traditional photogrammetry into new life. Examples of software are Autodesk Memento (https://memento.autodesk.com/about) and Agisoft photoscan (http://www.agisoft.com/).

2.3 Software for processing and enriching of scanned data

There are many different software, that can be used to perform the modelling work, adding attributes and relations to the building objects. Typically software is EdgeWise Building™ from ClearEdge3D (www.clearedge3d.com/), Pointsence for Revit from Faro (http://faro-3d-software.com/) and RECAP from Autodesk (http://www.autodesk.com/). It is also relevant to mention the DURAAK project (http://duraark.eu/).

To fulfil a real BIM the collected measurement of a building has to be enriched. This process is called Integrated Processes (see figure 2) in this paper (BIM-ing). To enrich the measurements different software solutions can be used. Some software are standalone solution, but most are plugins into typical architectural software like Revit from Autodesk, Archicad from Graphisoft and Microstation from Bentley. One important difference between the software solutions is the level of operator interactions, which is needed to create the BIM. This is often a time and cost consuming operations. Another difference is how the building objects are placed related to the point cloud. In most cases, the operator can select different settings, which will place the object based on Gaussian distribution, best fit or with different kind of assumption. Typical assumption is that two walls should meet perpendicular and that a wall should always be vertical.

3. Framework for scan to BIM

The dominating focus when exploring scan to BIM has been technology, which is presented in a systematic way. Other organisational issues are often very randomly explored and presented. It is therefore a need for a framework that include technology in a systematic way. In this respect is the Integrated Design and Delivery Solutions (IDDS, 2013) as theoretical framework. IDDS can be regarded as simplification of the socio-technical theory (Bostrom & Heinen, 1977) which is adapted to the AECOO construction industry. The IDDS framework is developed by the International Council for research and Innovation in Building and Construction (CIB) in order to optimize construction projects. IDDS is a powerful framework to explore and understand interactions between different imperatives. The three imperatives of the IDDS are illustrated in figure 2.

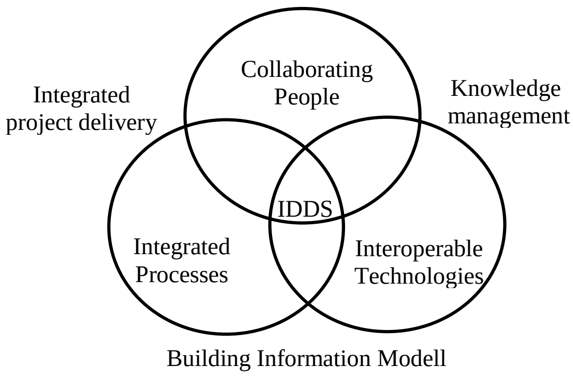

Figure 2: The three imperatives of IDDS (2013), figure simplified by the authors

In our study of the process of establishing a BIM for multiple purposes within facility management, we have used the model in figure 3 to describe the collaboration. Figure 4 illustrat the current situation in the case used in this study.

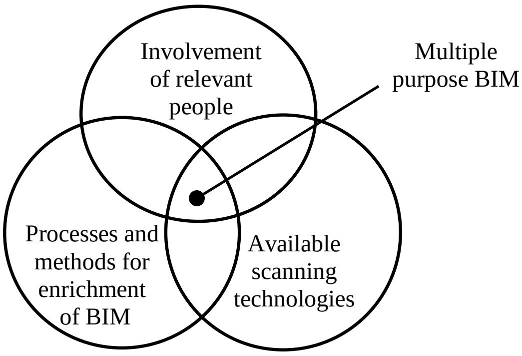

Figure 3: Identifying imperatives for multiple purpose BIM based on IDDS

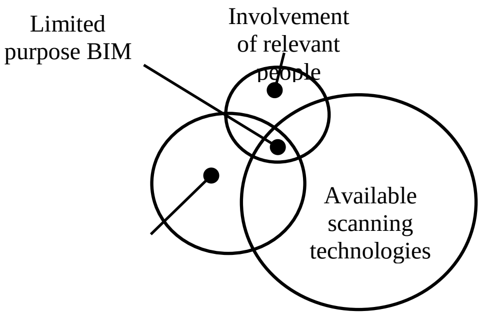

Figure 4: Example of unbalanced IDDS and limited purposes of scan to BIM

The different imperatives are in our case exemplified by the following content:

- Involvement of relevant people (Collaborating People): architects, engineers, land surveyors, BIM specialists, landlords, residents,…
- Available scanning technologies (Interoperable Technologies): drawings, tape measure, laser scanner, total station, Flexijet, rangefinder, camera,…
- Processes and methods for enrichment of BIM (Integrated Processes): Software and methods for creating BIM.

The size of each circle can be changed due to current resources, e.g. the amount of relevant and available technology or the number of collaborating people. The relative position of the circles may also change according to the interaction in between the imperatives. Examples of this are the degree of harmonization of software and hardware or the maturation of new processes in the user communities. The resulting size of the centre region can then be regarded as an indicator for the possibilities for success. Small circles with large internal distance make it difficult to succeed. An example with very good harmonization of hardware and software, but with a limited number of skilled and collaborating people is shown in figure 4. The two lower circles are highly overlapping in figure 4. The problem is that the circle representing the relevant people purpose is small. The consequence is that command area for all three circles is very limited compare to figure 2 and 3. This means that the resulting BIM has very limited purposes.

4. Framework for Purpose BIM

Our evaluation of the case study is that an ordering guide would be useful for the collaborating people. The goal of an ordering guide is to maximize the common area between collaborating people, technologies and processes. The purpose is to help the buyer to order the product, that has the potential to give the best cost benefit ratio. A spin off to this is that the provider of BIM easy can understand the customers demand and expectation. In the early days of airborne laser, the industry had a problem. The buyers of airborne laser data had a poor description of their expectations. They had very different knowledge about airborne laser data and different approaches to control the result. The consequence was that some suppliers took the benefit of this and delivered data with bad quality, knowing that the probability to be discovered was minimal. After some years, the buyers became more professional and establish detailed specification and methods to control the result. The result of the new specification was that the quality of the products became more even. Another important effect was that the different providers could compete based on the same understanding of the customers expectations.

The first step in our framework is to establish a development plan with focus on collaborating people. This will decide which persons who have interest in the project and who should have access to the result. Another aspect is who should continue to work with the BIM to ensure that it is up to date. When the BIM is up to date, it is a “Living BIM”. The second task is to get an overview of the different challenges the collaborating people have and how BIM can be used as a tool to solve their problem. Based on this the accuracy level of the data capture can be established.

Table 1: Accuracy Levels of Data Input to further proceeding BIM model

Accuracy level	**Level 1**	**Level 2**	**Level 3**
Description	Rehabilitation	Area information	Management/develop
Relative accuracy *	0.003 m	0.01 m	0.03 m
Maximum average deviation *	0.01 m	0.04 m	0.10 m
Maximum deviation between measurement and model (at 1 meter above the floor)	0.01 m	0.03 m	0.10 m
Modelling assumption	Exact modelling. The object should be placed on the average location of the point cloud	Exact modelling, but walls can be straighten up to be perpendicular to the floor or celling	Walls can be straighten up to be perpendicular to the floor, ceiling and walls

* Calculated on a 0.2 x 0.2 meters surface

The accuracy level give the BIM provider an accuracy expectation to the final product. Both data capture and the modelling work is covered. Based on the accuracy level the provider can select the most cost efficient method to capture the data. One of the important messages in Table 1 is that you do not need a level 1 scanning if you during modelling will straighten up walls, floors and ceiling to ensure that they are perpendicular. This count if your intention is to use your model in further work and not the point cloud.

Table 2: Information contend in BIM model, gives an overview of 3 different level of detail

Level of Detail (LOD)	**Class A**	**Class B**	**Class C**
Description	*Full BIM*	*Slim BIM*	*BM (overview)*
Relative content of information in BIM	Volume model, standard objects with attributes and relations	Volume model, standard objects *Defined (limited) information*	Volume model

The next step is the integrated processes. In this step, the measurements become a real BIM. Again, it is important for the buyer to have a conscious relation to the content of the BIM. A simple volume model is cheap, and this is classified as BIM class C. If you add standard objects, it is more expensive and more useful. Finally, if you add attributes and relations you get a full BIM and BIM class A.

Table 3: Framework for Purpose BIM

Accuracy level / **BIM class**	**Level 1**	**Level 2**	**Level 3**
Class A	Multiple purpose (Expensive)		Limited purpose (Moderate price)
Class B			
Class C	Limited purpose (Moderate price)		Single purpose (inexpensive)

Table 3 illustrate the relation between the cost and applicability based on the criteria accuracy level and BIM classes. The highest accuracy product is level 1. If you combine this with the BIM class A, you get the most expensive product. BIM class A gives you a BIM with standard objects with attributes and relations. On the other end of the scale, you find accuracy level 3 and BIM class C. This is the cheapest product with less accuracy and no building objects. The accuracy level 1 has the highest flexibility. With high flexibility, you have the opportunity to change your BIM from an accuracy level 1 to accuracy level 3. You also have the opportunity to change from BIM class A to C and vice versa. If you create your BIM with the accuracy level 3, you are not able to change you BIM to the accuracy level 1 without new measurement, but the BIM class can be change. This means that accuracy level 3 has a lower flexibility than accuracy level 1.

Table 4: Framework for Purpose BIM examples

Accuracy level / BIM class	Level 1	Level 2	Level 3
Class A	Rehabilitation		Facility management
Class B			
Class C	Absolute documentation of geometry		Volume sketch and planning

Table 4 illustrate which purposes, which accuracy level and BIM class are suitable for some example purposes.

5. Examples from the case study

The case study used in this paper is based on a project in Oslo, Norway. The building was built in 1890 and has a co-ownership organization with 16 different sections. A board selected by the co-owners controls the building. An important aspect was distribution of cost related to the total area of each section. The area of each section was unknown. It was disused to use the existing drawings to create the BIM. The problem was that the drawings where old and did not give a correct picture of the areal situation. Another problem was that the basement was not present in the drawings. The boarder also had maintenance tasks waiting ahead where they would like to using a BIM. The dream was to link the maintenances history, the today's status and scheduled maintenance directly to building objects in the model. Additionally they needed a fire and evacuation plan. They also had a project where they needed to control the chimneys. Based on these needs the scan to BIM project was started. The Norwegian Building Authorities was interested in the project and decided to finance the project. The company Rendra won the project after public announcement. Rendra has developed an application for interoperability in construction projects based on BIM. Sweco BIMlab consulting engineers performed the measurement and modelling of the building. The data capture and modelling was scheduled to take 5 weeks. The static point based laser measurement called Flexijet 3D 4ARCHITECTS was used for data capture. The system is directly linked to Archicad, which means that the BIM is created directly on site. The total budget for the project was 200 000 NOK (approximately 22.000 €).

The result from the project was good. The boarder got a BIM they could use for area calculation of each section, storage room in the basement and storage room in the attic. This solved an ongoing conflict in the basement. From the BIM they can extract drawings like fire and escape plans, extract volume of the walls, framework to store information about the past, present and further for each building object. The new established BIM is a good starting point to establish a maintenance plan (DIBK, 2015).

In the evaluation of the BIM one of the section owners discovered that his apartment was 10 m2 larger than the report form the latest valuer report (DIBK, 2015; chapter 4.6). It is likely that the areal in this report has been calculated with a tape measurement device, manual or digital. It is therefore likely to claim that the BIM provide the correct area calculation. The price pr. square meter in this area is higher than 50 000NOK (5400 €). This has a big influence on the value of the property.

The experience from the project shows that it is very time consuming to arrange access to all the different sections. Sweco BIMLab performed the measurement and informed that 25% of the time was used just to get access to the different sections DIBK (2015, chapter 4.7). In the evaluation of the result, the board claim that the model has a higher quality and richness than they actually needed (DIBK, 2015; chapter 4.3). There are for instance more objects present than they expected. This model is therefore a good opportunity to use the BIM for more purposes than initially intended.

We have concluded that it would have been beneficial to use a data capture method, which use less time on site and more time in the office. The main reason is that approx. 25% of the time was spent on getting access to the different sections. Flexijet scanning contain only what has been presented in the model. There is no extra data for further processing. This makes the method sensitive for missing registrations and it is difficult to document the quality of the model.

Table 5: Identification of possible purposes for the example case

Accuracy level / BIM class	Level 1	Level 2	Level 3
Class A	No Possible expansion	No Possible expansion	No Possible expansion
Class B	No Possible expansion	Case study	Possible expansion
Class C	No Possible expansion	Possible expansion	Possible expansion

The case study have an accuracy level 2 and a BIM Class B. Table 5 illustrate which direction it is possible to expand the BIM. The main reason for this limitation is the Flexijet method where you collect limited amount of data. It is not possible to enrich the model without revisit the building. If a “more is less approached” had been use it might have been possible to enriched the BIM without revisit the building. Then all BIM classes with accuracy level 2 and 3 would have been an option for expansion. If we assume the same starting point. This is illustrated in Table 6.

Table 6: Possible purposes for the example case collected with a "more is less approach"

Accuracy level / BIM class	Level 1	Level 2	Level 3
Class A	No Possible expansion	Possible expansion	Possible expansion
Class B	No Possible expansion	Case study	Possible expansion
Class C	No Possible expansion	Possible expansion	Possible expansion

6. Discussion

This concept paper is based on a literature overview of available technologies within hardware for scanning and software for processing captured data, in addition to use a real project as case. The practice of today is driven by use of technology offered by the selection of services from the scan to BIM provider. The proposed "purpose BIM" framework intent to enable an overview of applicable technology for capturing data, and by processing the data into BIMs applicable for multiple purposes. Overview of technology, process and competency (with reference to the trinity in the IDDS framework) enables the building project owner to manage the scan to BIM process by ordering or purchasing process. This study is therefore not a study of selecting the best technology, but how different technologies can be combined to enable a potential for multiple purposes in the future based on reuse of previous work (normally done at low additional cost as supplement to the primary job, e.g. a cloud scanning, when doing point scanning).

A real case was used as example for the scan to BIM process to explore how the "purpose BIM" can be applied. However, further empirical studies are needed to assess the reliability of the framework, in addition to further detailing and guidance. We have focused on accuracy level in the data collection, accuracy in modelling and the level of detail in the building objects. Especially the level of detail is general and need further detailing. In a comprehensive product specification, it will be necessary to have a full list of objects, which should be included in the model. It is also necessary to define which attributes and relation each object should have. In a complex building, this list may be long and complicated. If possible, it will be an advantage to create general rules instead of a complexed list. The comprehensive product specification is important to make sure that the model is created and enriched according to the contractor's expectation. Additionally the providers have the possibility to calculate the cost more precise. This will contribute to a more fair competition situation where the provider know precisely what to deliver.

7. Conclusions

This study has introduced the “Purpose BIM" as a framework to support flexible ordering of services to solve multiple purposes at positive cost/benefit. This framework structure the ordering processes to combinations off accuracy level from scanning related to BIM classes for processing of scanned data for defined purposes and potential purposes.

An overview of technology and services is presented and illustrates possibilities for a more flexible process. Detailing the overview by current commercial solutions is recommended before practical use. On the other side, we see that the Purpose BIM as a framework will become more relevant to enable increased numbers of solutions by combining technology and processes and personal resources. An important aspect is to break-down into small work-packages or services that can act as options for further processing and enabling of new purposes.

Development of technology will increase the possibilities to combine various technologies at low cost and enable possible multiple use. This will be a key factor to make it common to use BIM in the facility management. With lower prices and flexible processes, the purposes can be extended to purposes we have not thought about or minor tasks, which normally are taken care off in a manual way. One key aspect in this framework is to set up development and feasibility plan to ensure a multiple purpose BIM. Another key aspect is to use the purpose BIM framework to select technology and process to maximize the cost /benefit ratio.

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From BIM to CIM to Innovate Life Cycle Management of Entire Works and their Parts

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Abstract

During the last few years, many efforts have been made to promote the widespread use of Building Information Modelling (BIM) and to exploit its potentialities. Despite several important activities at international level aimed at creating standards, free tools and open languages for interoperability, the BIM approach has mainly brought enhancements to software for 3D renderings which now are able to represent complex models where information is directly associated to each object constituting the model itself. However, the exchange of information among different stakeholders has not improved significantly, most of all because real interoperability among software has not been achieved and because data sharing has to be independent of specific commercial software.

Along different life cycle stages, asset and facility management represents a very interesting field for the application of BIM strengths because it needs to store and use much information about the behaviour over time of different building materials, products and components. Moreover, because at international level (for instance, CIB W080 Commission is still working hard on this aspect) the lack of reliable tools for service life planning and data capitalisation from facility management is evident. It is then necessary to develop some methods for Service Life Planning and Management, to be easily integrated by maintenance data and used during the design of facility and maintenance activities. Therefore, only the development of specific Information and Communication Technology (ICT) tools for life cycle data use and sharing based on Industrial Foundation Classes (IFC) standards of the International Alliance for Interoperability (IAI) can actually enable exploiting BIM potentialities along the entire building process.

The paper presents a number of activities undertaken in the last few years by Politecnico di Milano in order to move from a BIM approach (where the modelling is central) to a Construction Information Management (CIM) system capable of allowing an effective integration and exploitation of building process data along the entire life cycle of construction works and their parts.

Keywords: Maintenance, facility management, Service Life, Life Cycle management systems

1. Introduction

Service life planning and data capitalisation from facility management are only the first steps for an efficient asset and maintenance management because it is necessary to develop specific ICT tools for life cycle data use and sharing [Daniotti et al. 2015]. Without an integrated information managing system, it is difficult to gain exhaustively each necessary input data and it may affect a correct maintenance planning and management. This causes a waste of money and time, but it can also decrease the effective control on the sustainability of the building process itself: for example, without the knowledge about laying procedures, in-use condition or end of life interventions for the specific construction site, the choice of sustainable products could be frustrated and Life Cycle Assessment (LCA) be incomplete.

That is why, in the last few years Politecnico di Milano has undertaken research activities in order to develop on one side an international platform for durability management, supported by reliable methods for Service Life estimation, and on the other side a national prototype of database for an efficient data exchange among different stakeholder of the construction chain. The adoption of the same object approach to the entire construction field (not only buildings, but also infrastructures, services, processes and anthropomorphic environment), together with sharing information independently from the model, allowed the creation of a Construction Information Management (CIM) system.

Hereafter the description of these two important tools, which in the future could be merged together in order to build a unique and interoperable platform to innovate life cycle management, capable to store objects with different level of complexity (from simple products to entire construction works).

2. The international platform for Service Life appraisal, data storage and sharing

As mentioned, Service Life planning is important in the design step because the set of taken choices must be influenced by the entire life cycle assessment of a building process. Moreover, the choice of the most suitable building components and materials to adopt has to consider not only their duration but also their failure rate curve over time: an effective sustainable process depends on an optimised maintenance planning and this is possible only through the knowledge of building components' durability. Consequently, the need for more accurate Service Life data is essential, compounded by the necessity of a wider availability and an easier accessibility to such information. That is why, through the analysis of the necessary data to allow designers evaluating duration and planning maintenance, CSTB (Centre Scientifique et Technique du Batiment - the French Scientific and Technical Centre for the Building Industry) and Politecnico di Milano structured the French Reference Service Life (RSL) database [Hans et al. 2008].

Such a database contained some input data necessary to ICT tools for Service Life management and, therefore, became the starting point for integrating results from past research activities and developing new research programmes to enhance and make it usable at international level [Daniotti et al. 2008].

The realisation of an international database involves the need to use a classification for building components and materials that could be valid beyond French and Italian borders and available for further implementations. A unique and efficient communication tool demands a standardised description of building objects that makes easy the communication among different subjects: in the construction field, this facilitates a faster individualisation of characteristics, a proper organisation of each set of documents and, eventually, reliable costs evaluation, time scheduling and sustainability assessment.

This classification system must have two essential characteristics in order to be proper for this purpose:

- to individualise univocally each family of objects and to allow every further piece of information to join in order to describe precisely each object;

- to be applicable to every class of objects, independently from its complexity.

Since the base of a classification system is the partition of a series of elements in classes, there are two different ways to group various elements:

- a direct grouping: elements are identified as belonging to a class, classes are organised according to a hierarchical order, so there are some main classes and, for each of them, some sub-classes and so on; for instance, the parts of a building are walls, floors, foundations, the roof, etc.; inside these groups, it is possible to identify other elements; an example of classification based on a direct grouping is MasterFormat, which is widespread in the USA and Canada;

- a combined grouping: there are different attributes for an element and this is identified by the free aggregation of these attributes; examples of this classification are the SfB and the Italian standard UNI 8290.

The first activity that was undertaken was to define the most proper classification system to adopt: therefore, it was necessary to fathom and study, first of all, existing classification systems adopted all over the world (Figure 1). This preliminary analysis showed the difficulty in classifying every construction element in an univocal way and, above all, a great fragmentation of these systems .

Consequently, it was necessary to propose and adopt another classification system that could be used at international level for the RSL database.

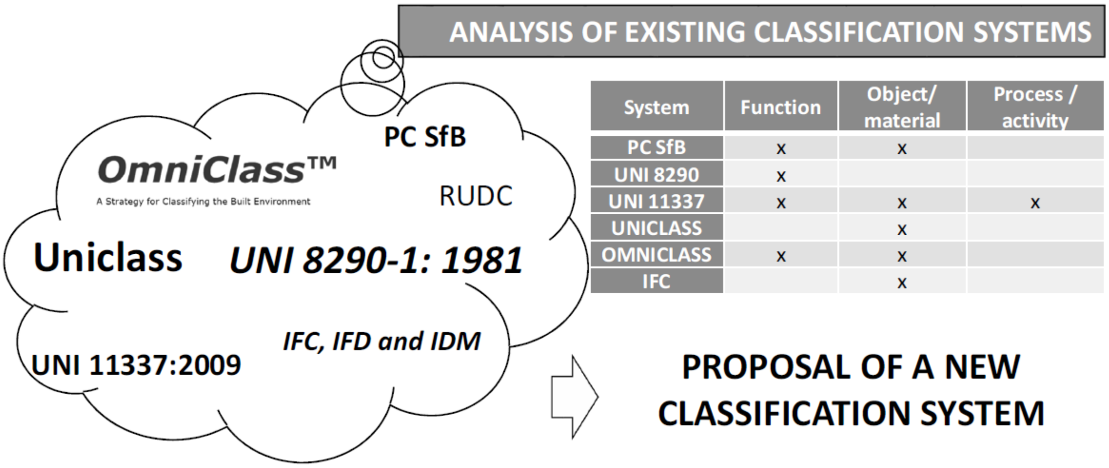

Figure 1: Comparison between existing classification systems

The SfB classification (Swedish acronym of Samarbetskommittén for Byggnadsfrägor - Cooperative Committee for Construction Issues) was born in 1956 with the objective to become an implementing classification system at international level. Realised in Sweden, it was presented in Holland in the presence of many experts from all over Europe. The first English version was translated into German and Italian. In spite of this transnational peculiarity, SfB classification has not been used on a large scale.

Another exception to local classifying systems is RUDC, part of UDC (Universal Decimal Classification) which was not directed toward the construction field, but to organise every kind of information.

The Italian standard UNI 8290 of September 1981, aimed at standardising the terminology to employ, represents an important step in supplying at national level a classificatory model, which gives, in the field of residential buildings, the classification and the articulation of technological units and of technical elements in which the technological system is divided.

The Construction Project Information Committee (CPIC) introduced the UniClass (Unified Classification for the construction industry) system in the United Kingdom in 1997 and it suggested a method for the building sector classification based on 15 tables. Each board looks at a specific information aspect and it can be used separately or linked together with other tables to express complex concepts.

MasterFormat represents the standard of communication more used in USA and Canada to organize the project contents and the relevant documents. The project, through the Construction Specification Institute (CSI) proposal, can be split into divisions and sections, with the aim of standardising a procedure to manage every type of project information.

OmniClass is a classification system that was accepted by the US building industry in 2006. It is a freely available standard based on a common language for the whole building sector and a standardised system to classify information regarding the entire building life cycle, from planning to demolition.

Eventually, the Italian standard UNI 11337:2009 introduced a new framework approach to classify contemporarily functions, objects and processes/activities. It organises a list of items according to the logic of the works carried out, in order to permit analytical evaluations (as the cost per measurement unit for each intervention required by each work) and elementary evaluations (as the cost per measurement unit of technological units).

Therefore, for the international RSL database a new classification system was adopted: it is based mainly on SfB classification, UNI 8290 and UNI 11337:2009. As the necessity was to allow a collection of RSL data for building objects, this proposal does not contain the classification of activities, vehicles, tools, human resources or environments. For example, it can be used to individualize univocally a pillar, but not an activity like daubing, a vehicle like a crane, a tool like a trowel, a person like a bricklayer or a place like a kitchen.

Politecnico di Milano contributed not only to RSL definition, but also to create some grids for the application of Factor Method [Daniotti et al. 2010], considering moreover the elaborations on statistical basis lead on the climatic agents for accelerated ageing cycle definition [Daniotti et al. 2008]. As a consequence, the database for RSL collection became necessary not only for the convergence of all the information coming from the experimental researches, but also to constitute an indispensable tool for the application of existing methods for SLP (ISO 15686-2 and UNI 11156-3) and, in particular, of the Factor Method.

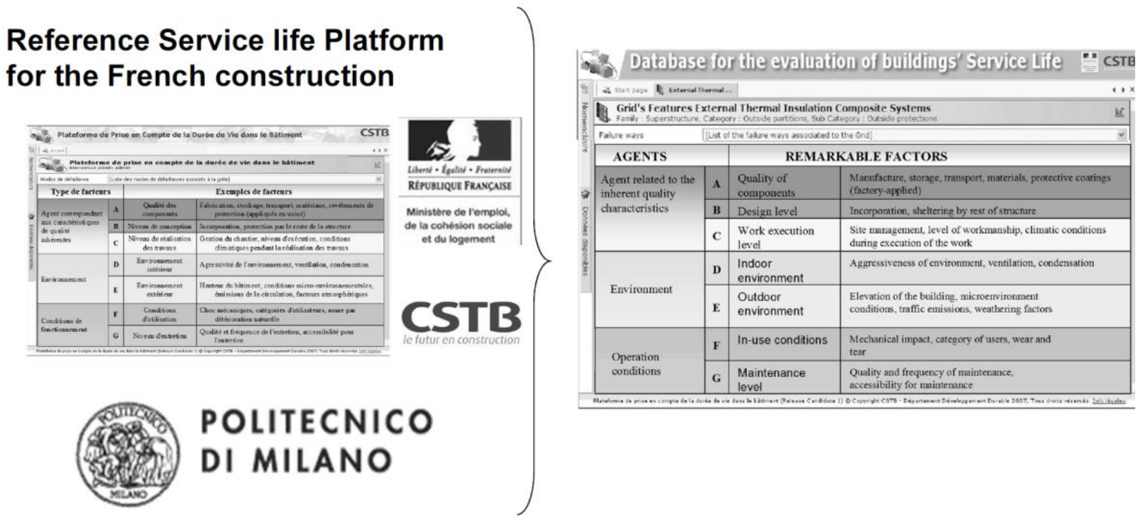

Figure 2: From the French National RSL database to the international durability platform

To do that, each single building component is associated to a specific factor grid, which translates all the variables affecting Service Life into different sub-factors belonging to the seven main factors proposed by ISO 15686 Factor Method. Thus, the construction procedure of the database consists of four main steps, namely:

1) a grid is built for a given building component by a panel of experts;

2) the grid is shared among the stakeholders of the construction sector;

3) information regarding properties and service lives is collected by the stakeholders for the comprised sub-factors;

4) data are validated by the platform administrator.

3. INNOVance, the Italian database for Construction Information Management

Another step forward in evolving the BIM approach, through Building Information Modelling and Managing (BIM&M), towards CIM was made by Politecnico di Milano together with many important partners (Figure 3) during a three-year research project called INNOVance.

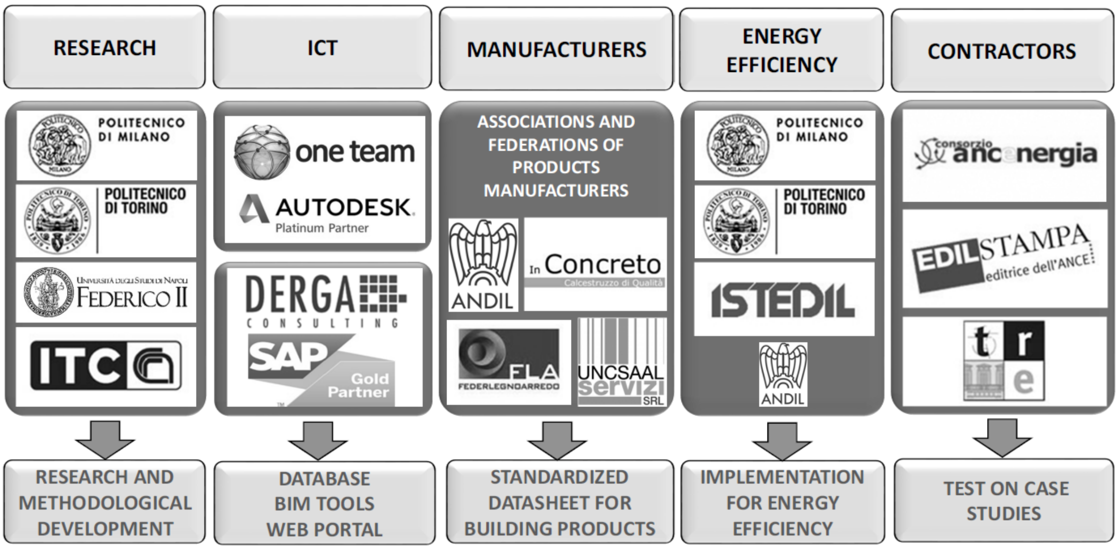

Figure 1: INNOVance partnership

This research project, funded by the Italian Ministry of Economic Development, started in July 2011 with the aim to introduce a radical innovation into the Italian construction sector by creating the first national construction database and a prototype of interoperable BIM&M platform (Pavan et. al 2014).

To overcome possible inefficiencies due to incorrect or redundant exchange of information among actors of the construction chain throughout the entire life cycle of a work, Politecnico di Milano developed a new classification, naming and coding system that allows speaking an unambiguous language where synonymies and all the different meanings of the same word are clear and already defined [Daniotti et al. 2013]. The naming and coding system developed with INNOVance takes into consideration the entire construction work as the last output of the construction industry, analysing it from five points of view (Figure 4):

- the functional-spatial logic in order to highlight environment and functional areas in which the construction work is divided (for example, commercial areas inside a building);
- the technological logic for construction in order to disassemble it in its elements, from entire components to single products;
- the technological logic for equipment in order to disassemble it in its parts, from entire systems to single products;
- the anthropomorphic logic to represent all the changes on environment and those natural aspects related to it (e.g. excavation and embankment);
- the processual logic to individualise and codify activities, vehicles, tools and human resources.

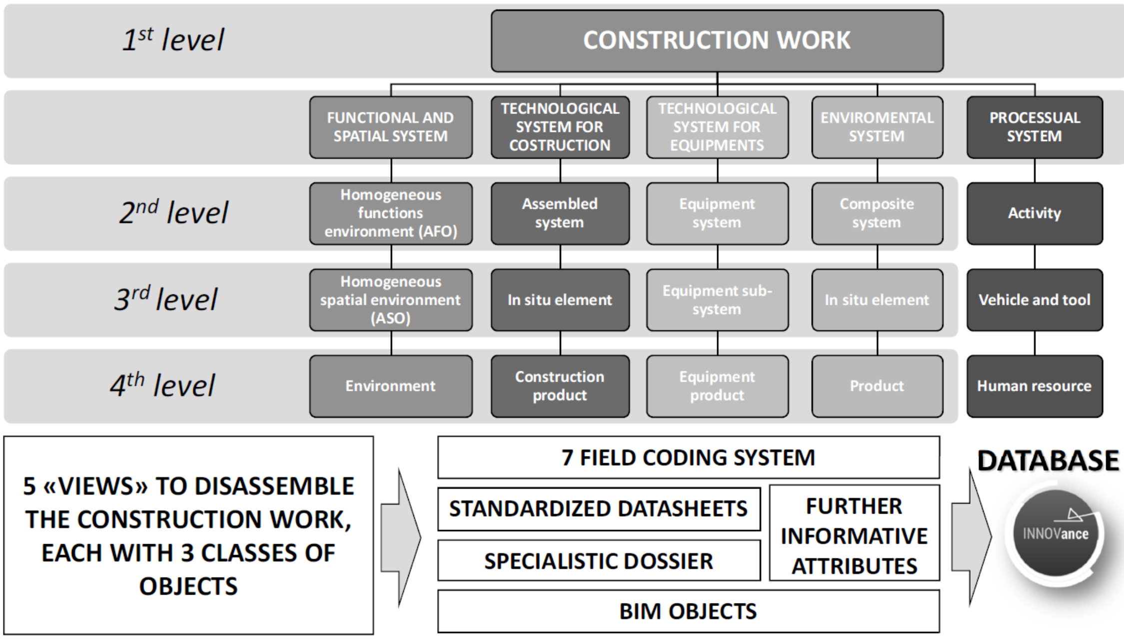

Figure 2: INNOVance hierarchical structure

Each of these logics contains three levels of objects, according to their complexity. Considering this hierarchy, the adopted coding system then defines a structure with an open compilation and seven fields, which can describe every element to be encoded, independently from the object complexity and the set system to which it belongs (Figure 5):

1. category;
2. type;
3. functional and in use characteristics or, for construction products, harmonised technical standard;
4. performance characteristics;
5. geometrical features such as geometry, shape, aesthetic and constructive traits;
6. dimensional features;
7. physical / chemical properties.

The reason for the choice of a fixed seven fields coding system is to standardize the output code and to a have a coherent individualisation of each information inside the code itself.

7 FIELDS CODE, INDEPENDENTLY FORM THE OBJECT COMPLEXITY						
Category	Type	Functional characteristics/ Harmonized technical standards	Performance characteristics	Technical characteristic		
				Geometrical features	Dimensional features	Physical/ chemical properties

Figure 3: INNOVance coding system

Talking the "same language" with a common classification and coding system allows avoiding communication errors especially during design and construction. However, this was not enough to innovate the life cycle management. The second step was, therefore, to create a tool with a standardised procedure for data sharing to avoid misunderstanding, errors, over costs and delays, mainly due to documents and drawings that are not correctly interpreted and updated.

Consequently, exploiting the unambiguous classification system for every object and the defined hierarchical structure, Politecnico di Milano, in collaboration with Derga Consulting S.r.l. (a partner of SAP, acronym for System, Applications and Products, a software company which developed some Enterprise Resource Planning and data management programs) created a unique database to store and share information. This ICT tool allows collecting, for each object individualized in the above-mentioned hierarchical structure:

- standardised datasheets and specialised dossiers, with every useful document (images, videos, drawings, etc.) that can be easily enclosed;
- further informative attributes which cannot take place in the defined datasheets and dossiers;
- BIM objects in different file formats (among which, the interoperable IFC format).

Figure 4: Web portal homepage

A SAP ERP system (SAP NetWeaver) contains all the structured data. By unequivocal names, technical datasheets, specialised dossiers, complementary data and BIM objects, all organised in the INNOVance database and accessible by a user-friendly web portal (homepage in showed in Figure 6), each user can manage his projects, since the design brief and through all the further phases.

Through this website, many operations are possible: for example, manufacturers can create, upload and modify their construction products standardised datasheets, adding BIM objects too, designers can describe the technical solutions designed and share their projects; companies can consult data sheets established by designers and manufacturers, checking the correspondence between ordering and arrival of the goods.

The web portal constitutes an exchange platform (Figure 7) with:

- a public section, open to any user, where it is possible, for example, to find a BIM Library, and where information (graphical, alphanumerical or multimedia) is embedded into Generic BIM Objects (out of a specific context);
- a private section, open only to logged users, where it is possible to store a personal library of datasheets and dossiers and where, thanks to the so called BIM&M Server, in any stage of the construction process, they can convert generic BIM object from the BIM&M library into Specific BIM Objects (in a specific context).

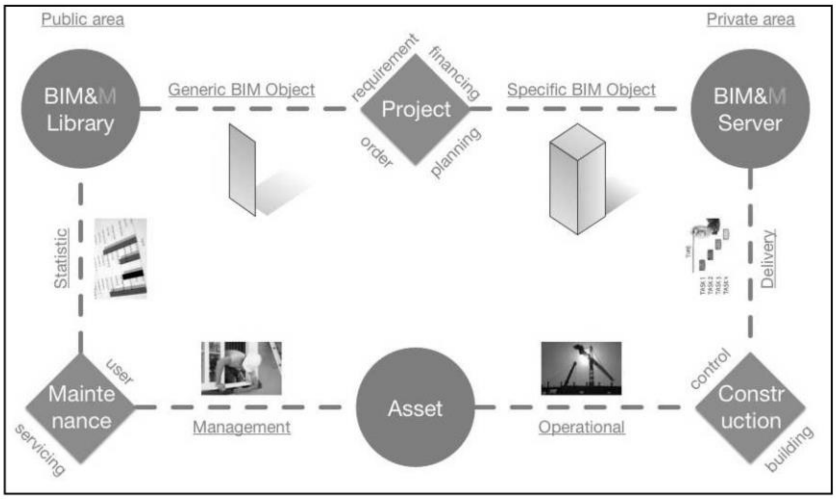

Figure 5: INNOVance system workflow [Pavan et al. 2014]

This web platform aims at becoming an interactive footbridge among different stakeholders. To do that, as the quantity of collected information will be huge, there are different views of the database according to the user's profile: this facilitates its use, filtering only useful data for the considered stakeholder, but leaving the possibility to search, visualise and, possibly, modify any other information of the database.

4. Conclusions

Asset and facility management needs to store and use much information about the behaviour over time of different building materials, products and components. Service life planning and data capitalisation from facility management are only the first steps for an efficient asset management because it is necessary to develop specific ICT tools for life cycle data use and sharing.

A strategic step toward the optimisation of both the building process and the whole construction sector is represented by a rationalisation of the information flows connecting construction process stages (planning, design, construction, use, management, maintenance, disposal or reuse) and the various actors involved (customers, users, designers, contractors, components manufacturers, etc.).

Starting from the expertise in developing the above-described international Reference Service Life database, Politecnico di Milano structured a complete Construction Information Management system: the INNOVance platform. This constitutes a unique collaborative tool, meant to store, elaborate and share every useful data along any building process and to support every actor involved in the process. Impacts on the entire construction field are evident: by its adoption and use, it is in fact possible to avoid misunderstanding in communication and redundancies in data, increasing the efficiency of building process along the entire life cycle of each construction work because the exchange of every information is associated to unique codes in a fast, interoperable and reliable way.

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A Case Study of Building Information Modelling Enabled 'Information Totem' for Operations and Maintenance Integration

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Abstract

This paper reports upon the use of a semi-automated toolkit to aid the development of as-built Building Information Model (BIM) (As-built model reflects on-site changes by the contractor to the original BIM) from inception to final construction. An observational case study of two educational 'multi-storey' facilities obtained primary data from project archives and focus group meetings with key design team members. The results demonstrate that the data requirements for both structures evolve post occupation because of stakeholder tacit knowledge accrued via building operation and usage. The semi-automated toolkit developed can readily access operations and maintenance (O&M) manuals, retrieve room specific data (such as categories of equipment or building element) within the as-built BIM and, assist in the navigation and coordination of amendments and changes throughout the construction phase. This paper provides useful practice-based information for practitioners to develop suitable BIM data structures for future information requirements throughout a building's lifecycle. The inherent value of the semi-automated toolkit resides in the facilitation of ease of handover for the Facilities Management team during the O&M stages.

Keywords: As-built model, BIM, Facilities Management, Operations and Maintenance, Maintenance management

1. Introduction

Succar (2009) defined Building Information Modelling (BIM) as a: *"procedural, technological shift within architecture, engineering, construction and operations."* This definition was expanded upon by Eastman *et al.*, (2011) who noted that BIM has shifted the way building information is managed, exchanged and transformed to enhance collaboration between project stakeholders. Garber, (2014) concurred with this view and suggested that BIM provides a platform for better design team integration and project coordination. From an operational perspective, BIM embeds key product and asset data, and a three-dimensional computer model that can be used for effective management of information throughout a project's lifecycle from earliest concept through to occupation and use (HM Gov, 2012). Consequently, BIM deployment throughout the building lifecycle is invaluable to organisations that seek to obtain value from the technology (Love *et al.,* 2013; 2014). In essence, BIM represents a collaborative way of working, underpinned by digital technologies, which unlock more efficient methods of designing, creating and maintaining assets (HM Government, 2012).

Khemlani (2011) states that every constructed facility requires a bespoke BIM model, analogous to an owner's manual, with mandates for model updates that correspond to periodic repair, or refurbishment works. In practice, BIM in the operations stage has been primarily connected to the roles and responsibilities of the Facilities Management Team (FMT) but this can create problems in other areas (Becerik-Gerber *et al.,* 2012; Volk *et al.,* 2014; Kassem *et al.,* 2015). For example, Teicholz, (2013) reported upon a litany of issues which include: inconsistent naming conventions used; a myriad of bespoke FMT information requirements; inadequate data categorization in BIM and computer aided facilities management (CAFM) systems; poor information synchronization; and lack of methodology to capture existing facilities and assets. Delivering efficient operations and maintenance (O&M) procedures for buildings is therefore problematic and exacerbated by the vast complexity and volume of data and information generated (Mohandes *et al.,* 2014).

The open access digital environment afforded by BIM provides a partial solution to this issue because it readily affords storage, sharing and integration of information for future use. Indeed, contemporary research demonstrates promising potential for integrating facilities management (FM) within a BIM environment at the post construction stage (Azhar, 2011). In aiming to characterise the hybrid BIM-FM environment, Kelly *et al.,* (2013) observed that the following advantages could be accrued, namely: augmented manual processes of information handover; accuracy of FM data; and increased efficiency of work orders execution to accessing data and locating interventions. However, the construction industry currently resides within a transition period of adopting BIM. Industry practitioners are now selecting their own paths to cope up with the new technology in this rapidly changing environment and climate of exponential technological advancement. To date there remains a considerable dearth of applied studies that develop a hybrid BIM-FM environment and/ or report upon the tangible benefits of such to practitioners. With this in mind, this paper proposes a semi-automated toolkit (also known as an *information totem*) to aid the development of as-built BIM from design to final construction. A conceptual design for the toolkit is presented and is based upon a case study of two multi-storey educational buildings augmented with pragmatic input from the building's FMT.

2. BIM Value for FM

Contemporary literature indicates that exploiting BIM's inherent value adding capability within a building's development remains questionable especially, during the transition period of adopting BIM within the project's whole lifecycle (Parn *et al.,* 2015). Despite the palpable benefits of BIM application during the design and construction stages, case-studies of its application during the management and maintenance of assets during the O&M stage of building occupancy remain scant (Kelly, 2014). Yet, Boussabaine and Kirkham (2008) reported that 80 percent of an asset's cost is spent during O&M, leaving the benefits of BIM short lived at the design and construction stages. In addition, Love *et al.,* (2015) suggests that significant challenges are presented by an ill-equipped project team who lack standardized tools and processes, specific data required for operations and, maintenance and the workflow to deliver a digital model.

As a 3D modelling tool associated with a parametric database of components, BIM offers the FMT opportunities to manipulate and utilise information contained within 3D objects (HM Government 2013). However, Liu and Issa (2014) found that during the design phase, participants in a BIM project focus on clash detections and tend to ignore future-proofing maintenance accessibility. The authors (*ibid*) highlighted potential in BIM for designers to explore the background geometry and parametric database to add functions to help the FMT anticipate and solve maintenance accessibility issues. Similarly, Meatadi *et al.,* (2010) and Motawa and Almarshad (2015) proposed additional tools to improve BIM's performance at the O&M stage by effectively engaging stakeholders. Longstreet, (2010) further added that the value of implementing BIM increases exponentially as a project lifecycle unfolds. This is because BIM value in FM stems from improvements to: current manual processes of information handover; accuracy of FM data; accessibility of FM data; and efficiency increase in work order execution (Kassem *et al.,* 2015). Consequently, FMT involvement during the BIM development process is essential because they can alert the building delivery team of any issues related to O&M of facilities. This synthesis of extant literature underpins the necessity to involve building operators/ management stakeholders in the design phase of a BIM project. Interestingly, Bosch *et al.* (2015) contradicted this position and concluded that the current added value of BIM in the operations stage was marginal due to a lack of alignment between the supply of and demand for FM related information and the context-dependent role of information. Although the antithesis of Bosch (*ibid*) is contrary to opinion within main stream literature, Kassem *et al.,* (2015) did concede that a key challenge of BIM-FM integration is a lack of methodologies that demonstrate the tangible benefits associated with this hybrid merger.

3. As-built BIM Model Structure to Aid O&M

At the O&M stage, more than 80% of a FMT's time is spent on finding relevant information because such expenses are often overlooked at the pre-construction stages by designers (Becerik-Gerber *et al.,* 2012). Consequently, a number of studies are supportive of BIM application within the O&M stages (Patacas *et al*., 2015; Motamedi *et al.,* 2013; Volk *et al.,* 2014). This is because BIM provides an information conduit and repository (containing for example, manufacturer specifications and maintenance instructions linked to building components) in support of building maintenance management activities (Sabol, 2008). Such information and functionality is important when handing-over an accurate as-built model to building owners for the purpose of asset management. At present, laser scanning represents a common methodology used to create an as-built model of the completed project (Bennett, 2009). However, this methodology is time consuming and prone to human error and hence, as built preparation is perceived to be a time consuming and costly procedure (Huber *et al.,* 2011). The Institution of Civil Engineers (ICE) (2015) state that these issues can largely be eliminated through the provision of a reliable, BIM-sourced suite of information. However, the technical expertise of the FMT represents a significant barrier to BIM and as-built model development and maintenance (Kassem *et al.,* 2015).

McArthur (2015) suggests that identification of critical information required to inform operational decisions is a critical determinant towards configuring data retrieval techniques at the post-construction stages. Despite being emphasised by a number of authors (Meatadi *et al.,* 2010; Motamedi *et al.,* 2013), the issue of identifying critical information and linking them to the as-built model for O&M phase usage remains problematic. Meatadi *et al.,* (2010) revealed that the inconsistency between demand and availability of particular information in an as-built model incur unnecessary expenditures. Thus, linking data and configuring the retrievable information within the as-built model for the project's post-construction operational phase is a key issue that must be considered during the design and development of the BIM data.

4. Problem Domain: Big Data Acquisition

When utilising BIM technology, a vast array of data (commonly referred to as *big data*) is produced and integrated into existing objects within the 3D BIM (Bentley, 2003); where big data has been defined as high volume, velocity and variety data sets which pose extreme data management and processing challenges (Laney, 2001). Data within the model requires a structured method of information and data categorisation that can be tracked, validated and extracted. Grilo *et al.,* (2010) argue that BIM should create a broader base for interoperability in order to be fully utilisable, such as standards on communication, coordination, cooperation and collaboration. The huge volume of data within an as-built model is a matter of concern in terms of extracting valuable information and knowledge from it during the O&M phase of a building, particularly for the FMT (Russom, 2013). Federated models are defined as the amalgamation of multiple models in one, namely: architectural, structural and MEP models (HM Gov, 2012). To further exacerbate this issue, not all data is contained within one federated model because the FMT often link BIM to additional relevant external databases, to create a highly integrated multi-dimensional model (Succar, 2009; Love *et al*., 2015). This mass of data creates opportunities for new thinking and/ or adopting alternative techniques for model data structuring (Bentley, 2003). Matthews *et al.,* (2015), explored adaptation of cloud-based technology with object oriented workflow for as-built BIM scheduling. In a similar vein, this research adopts an 'object-orientated workflow' for real time data capture. However, the semi-automated toolkit proposed will predominantly be used to capture changes relevant to the FM parameters embedded within *information totems*. Information totems provide an additional layer of information structuring that are fed through to the federated as-built BIM model congested with high volume of data loads.

5. Methodology

This observational case study largely relied on project archival data and focus group discussions to explain as-built BIM preparation and the development of information totems. Specifically, the research sought to observe and report upon the processes and procedures adopted during the development of the as-built BIM to facilitate ease of handover for the FMT. Two multi-storey educational buildings located in the centre of Birmingham, UK were used for this study. Building one was build first and constituted phase I of the development and building two was built second and constituted phase II. Primary qualitative data was collected using verbal interviews with key stakeholders which included representatives from the project management team (PMT) including the client's representatives (i.e. the Building's Estates Department) and design related disciplines (including the Architect, the Contractor's BIM Manager , Principle Designer for Mechanical Engineering and Plumbing and the Lead Structural Engineer). Note that the Estate's Department held three fundamental roles, namely that of: client's representative; project manager; and Estates Department and hence, covered all three major phases of the building's life cycle. Two meetings were held with the PMT over a 4 months period during 2015. Secondary data sources further complemented information obtained and consisted of project documents including contracts, bids, BIM execution plans, EIR's and BIM protocols. Additional hand written notes were taken to record impromptu meetings or telephone calls held. Largely archival records of BIM documentation and contracts provided: i) an elaborate account of contemporary practices through the exploration of stakeholder experiences and interrogation of the images themselves; and ii) sponsoring organisations with opportunities to learn from everyday experiences of design team members and the FMT. During the study, FM associated aspects of BIM implementation were observed to evolve as a consequence of a synthesis of diverse opinions emanating from the PMT.

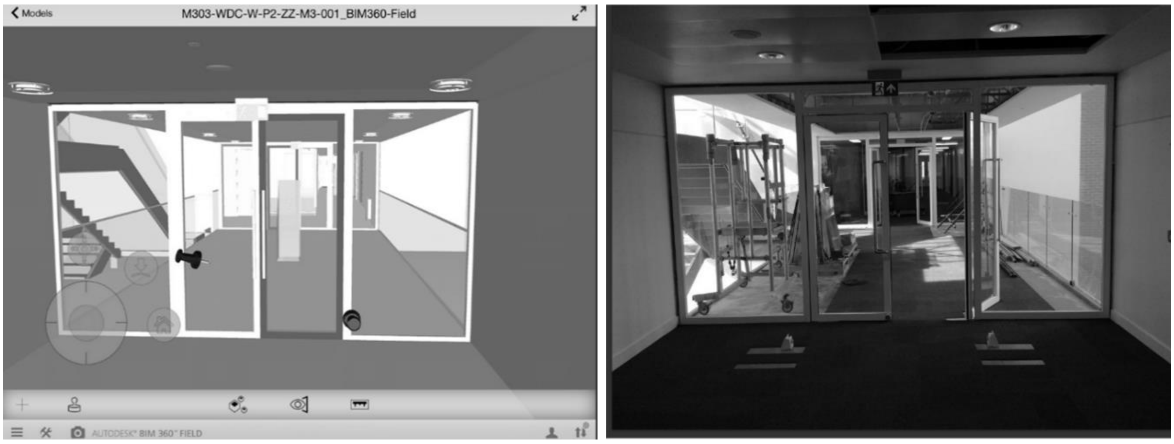
6. Case Study Discussion and Findings

Individual PMT group members claimed to have been inexperienced at utilising BIM technologies the outset of the project's development during phase I. However, at the end of phase I team confidence grew, and the idea for an information totem was conceived and proficiency/ competency gains were adopted in phase II. Information totems were described by the PMT as a placeholder for the room datasheets used during O&M stages of a development and are used for data input and retrieval. When formulating the information totem concept to ensure BIM and O&M data integration, the PMT considered various outcomes including: modelling requirements for FM; and model structure for data retrieval. The aim being to generate an information totem that would deliver interoperability and encapsulate the following attributes: i) increased of coordination; ii) facilitated ease of communication link; iii) informed decision making; iv) enabled information exchange enabler between multiple stakeholders; and v) provided ease of navigation between BIM model and construction site. Different PMT members added room specific information into each totem; contractors then retrieved asset related information for guidance during the construction stages and attach construction progress photos to each totem. Data within totems was predominantly categorised into FM parameters, were often room bound and in the instances of open plan spaces, these divisions of space were allocated by the PMT during the building's design. The totems themselves connected to multiple external data bases which are directly linked with room specific O&M manuals, maintenance frequency codes for different spaces and product fact sheets.

6.1 Asset Management at O&M stages

During the O&M phase, the client used of room barcodes (Figure 2) to aid the management of assets by allowing efficient access to data at the O&M stages. This same barcode was applied within information totems and mapped into FM software utilised at later stages of the development, including the cloud based BIM platform used for both projects.

Figure 1.Infromation totem for site navigation



(a) *(b)*

a) View of the Information Totem in yellow from the cloud based federated BIM model. b) Photograph of the same location on site as cross reference retrieved from the information totem.

Figure 2. Asset Management with room barcodes

(a) *(b)*

a) A Barcode tagged room in Phase II, barcodes are typically placed outside the rooms on doorframes. b) Individual steel barcode plates, typically an 8 Digit number bi-directionally linked with the information totem held in the federated model. These barcodes associated per room are used by facilities management team for ease of access to the digital O&M manuals and room asset data.

Table 1 displays the stakeholder disciplines and their input of information into the information totems during pre- construction, construction and post-construction stages.

Table 1. PMT use of totems

	Pre-Construction	***Construction***	***Post-Construction***
Architect	*Client room number. Room name. Target briefed area.*	*Occupancy and room data sheet added in totems, linked with snagging list.*	*Asset information data. Link to O&M manuals.*
Contractor's BIM Manager	*Not applicable.*	*Site photos on a room by room basis. Snagging list.*	*Reports and links to finished room photos.*
Real Estate Department	*Mandating the information requirements of totems.*	*Finished room photos for BIM model snagging to ensure the as-built BIM model development is accurate.*	*Floor Plans. Links to O&M documentation on a central database. Asset register information.*
Lead Structural Engineer	*Not applicable.*	*Navigation between model and construction site environment.*	*Reports. Asset information data.*
Principal MEP Designer	*MEP services information. Ventilation flow rates. Room noise rating levels.*	*Room data sheet integration.*	*MEP room data. Full services documentation. Links to O&M manuals. Asset register information.*

Snagging is an expression coined in the building industry in the UK and Ireland. Snagging is defined as the process of defect identification and resolution (Sommerville and Craig, 2006). The contractor used disciplinary BIM models from the design stages to develop the project design. Design developments were uploaded in the BIM model using the federated cloud model and the updating of consecutive information totems. This federated model was used for a number of reasons, namely to: avoid clash detections; facilitate, 4D and 5D modelling; and provide a basis for the cloud BIM data base, where information totems are linked with the federated BIM. A cloud based BIM database and information totem parameters were managed by the contractor on site but was developed by the estates team. The information totems were gradually populated throughout the construction to provide a full database reflecting the changes of the as-built development. All BIM models were updated by the contractor to reflect the building completion. So called 'BIM snags' were developed to aid the development of the as-built BIM these were helped with site photographs and commentary attached to the federated model. BIM snags follow a similar function as snagging, except they are used to inform designers of any potential changes on site that need to be reflected in the as-built BIM. Laser scanned data was used to verify the validity between model and as-built building. Other documents not directly related to the BIM, such as equipment fact sheets, O&M manuals, documentation and drawings were linked into the cloud based federated model via the information totems. Currently the estates and research team are exploring ways in which Building Management Systems data (as an external source of data) will be linked via totems into the cloud based model.

7. Discussion

During the PMT focus group discussions, four main lessons emerged regarding the use of BIM and information totems during the project, namely: i) *the creation of information totems*; ii) *limitations of a semi-automatic totem*; iii) *inflexibility of software providers*; and iv) *lack of* *software integration*. First, information totems were only adopted towards the end of phase I when the Real Estate Management Team realised that FM requirements (such as building heating and cooling loads, and building usage) could have been uploaded into the BIM at the design stage to inform the design and better meet client expectations. A MEP designer said: *"Design data, such as ventilation rates, cooling loads could have been included in the design stages already, as the M &E contractors are often playing catch up from the other design team…"* Second, it was apparent that the information totems developed were not fully automated and hence, as changes to specification occurred, manual updates were needed in the model. For example, when the contractor altered a specification provided by the Architect or MEP designer (at the construction and commissioning stages). The contractor stated: *The totems still lacked automation, what would have been good was to have a live feed of the changes in the model with the totems, as they currently did not capture all of the changes in the model, some information had to be manually added to the totems…"* Third, the BIM software designers (as external providers) were unwilling to implement bespoke modifications and amendments to their software. For example, information could not be exported into other file formats for usage in room data sheets or for snagging lists post construction. A BIM Manager said: *"We were unable to export the totem information directly out of the software into a PDF, which could then be used as a room data sheet…"* Fourth, the BIM model had a distinct lack of software integration capability and therefore, when clicking on the information totem, room elevational views could not be seen and these had to be extracted from other databases within the BIM model. A Project Manager said: *"What would be useful is if we could have direct views of reflected ceiling plans, room elevations and floorplans just by clicking the totems faces, makes it easier to then share the model with subcontractors…"*

However, these aforementioned issues apart, a largely inexperienced PMT valued the input guidance and advice from the client's representative throughout the design and construction phase. This allowed the PMT to mature as a collaborative and collegiate partnership that allowed both phases of the development to be constructed and commissioned to all parties' satisfaction and with minimal disputes arising. Efficiency gains were also made by individual PMT members who acquired new knowledge of BIM that allowed them to streamline their management of the project and ultimately cut costs without adversely impacting upon quality, For example, the Architect who employed ten people during phase I, reduced this to five people in phase II. In summing up the project's success, a representative from the Contractor said: "*Phase II has been one of most successful BIM project in our business, it has really pushed BIM all the way through the process right through to FM, and we haven't actually done this on any other project to date"*.

8. Conclusion

Extant literature illustrates that BIM-FM integration presents an ideal opportunity to produce accurate design data extended throughout a building's lifecycle for retrieval during the O&M stages. This case study has revealed that an effective means of creating model infrastructure to manage data is essential at the hand over stages. By generating an information totem to add room and space related information between assets, the transition between BIM and FM is performed in an easier way for the FMT to adopt. The observations accrued from the case study have shown how an object orientated workflow can provide structure and develop complex as-built BIM models whilst embedding key O&M related information. This paper has reported upon the use of a semi-automated tool-kit promoting the use of object-orientated workflows to increase coordination, ease of communication, information exchange, ease of navigation. Future work needs to look at how information totems could be linked into existing Computerised Aided Facilities Management (CAFM) systems to be utilised at during the O&M stages. Additional development of the totems is anticipated and future research efforts will now develop a fully automated information totem.

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Stimulating BIM-related supplier innovations in infrastructure projects

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Abstract

Building information modelling (BIM) is a paradigm shift in the construction industry that transforms processes to achieve greater efficiency and effectiveness. There is an increasing need for rapid development of BIM, and no organisation can do it alone, and innovation collaboration with suppliers and other external organisations is an important means to complement an organisation's knowledge base. The aim of this study is to explore how BIM-related supplier innovations can by stimulated by a public owner in infrastructure projects. Specifically, the study looks for the role of procurement in innovation. The study utilises an in-depth embedded single-case study method with 21 thematic interviews. The study applies 'innovation catalysts' identified in previous research projects as a frame of reference to identify different tactics the public owner can introduce to influence antecedents for innovation. The results of this study show that, to date, the public client's efforts to enhance BIM-related innovations has been acknowledged by suppliers. However, the results have not always been satisfactory. The results of this study suggest the probability of BIM-related supplier innovations can be increased by systematically implementing the innovation catalysts. Reciprocal, long-term, and cross-project collaboration activities are needed at different levels of the overall project organisation and within the industry, and the consistency in communication and activities needs to be ensured throughout the organisation. The incentives and requirements included in the procurement documents are suggested to be a secondary tool to promote supplier innovation, after (other) antecedents for innovations are in place.

Keywords: BIM, supplier innovations, procurement

1. Introduction

The use of building information modelling (BIM) in its current context has evolved in building construction. For the infrastructure sector the terminology has not settled; e.g. InfraBIM has been suggested. In this paper, BIM is also used to cover the processes and technologies related to modelling in the infrastructure sector. The basic benefits of modelling are mostly the same, with some differences, due to the nature of operations and business in the sector. The core features of

BIM technologies, a digital 3D representation of designed structures with computer-readable semantic data, have developed into wide utilisation varying from software development to process re-engineering or "paradigm shift" (Shelden 2009), even supporting project delivery methods like Integrated Project Delivery (IPD) (e.g. Porwal and Hewage 2013). Benefits of BIM utilisation have been evaluated in several empirical research projects (see, for example, Azhar 2011; Barlish and Sullivan 2012; Bryde et al. 2013) and reviews (Smart Market Report 2014), proving the overall influence to be positive.

No organisation can develop BIM alone, and innovation, in general, is increasingly becoming the outcome of collective effort rather than the output of a single organisation (Chesbrough and Crowther 2006). Suppliers, including designers and contractors, are natural partners to the owner to collaborate in BIM-related innovations, as the benefits of BIM are achieved only if BIM is used at every stage of a supply chain. Even though the potential of involving suppliers in the innovation process has been recognised by previous authors (Schiele 2010), empirical analysis of supply-side involvement in the focal organisation's innovation is still scarce (Luzzini et al. 2015).

To respond to this call, this study aims to answer the following research question*: How can BIM-related supplier innovations be enhanced by the public client (owner) in infrastructure projects* To research the phenomenon empirically, an embedded single-case study was conducted. We acknowledge that there are other approaches to enhance BIM-related innovations, but as the whole industry is built up in a project-based mode of delivery, this paper focuses on innovations developed as part of infrastructure projects, where the results directly support the investment project's goals. Public owners have a significant role in the development of BIM. Public owners have an interest in developing the industry as whole, and also have possibilities to develop, as they are significant players in the field due to their large number of consecutive projects. Here, we define supplier innovation as innovation developed by or with suppliers (Aminoff et al. 2015). In this study, a modern definition of innovation is used. According to this definition, in addition to traditional product or service innovations, innovations can also be related to operating practices, management methods, or processes (Kamensky 2010).

2. Literature review

As this study is positioned at the intersection of supplier innovation management, innovation in construction projects, and BIM/digitalisation in the construction sector, we briefly discuss all of these aspects here.

2.1 BIM literature

BIM research literature contains a vast number of technology development reports and case studies of implementation. The innovation aspect in the BIM literature focuses on the adoption and diffusion of BIM methods. Taylor and Levitt (2004) found that systemic innovations diffuse more slowly than comparable incremental innovations in the project-based building industry. Succar and Kassem (2015) define BIM as organisational and systemic innovation rather than solely technological solutions proliferating incrementally. They also present a comprehensive framework for BIM adoption (including implementation and diffusion at market level). Hua (2014) found that BIM diffusion is influenced by seven innovation culture dimensions, which are creativity, attitude to change, attitude to technology, attitude to learning, institutions, communication, and tolerance for dissenters; and communication was found to be the most prominent one in several phases of the diffusion. Linderoth (2010) argues that the disruptive nature of networks constituting building and construction projects creates the greatest challenge to maintaining and re-establishing the BIM network in consecutive projects. Linderoth (2010) emphasises the clients' role in demanding BIM usage and concludes another aspect: "When clients and regulative authorities start to demand use of BIM in building and construction projects, the issue of whether or not to use it is resolved". Porwal and Hewage (2013) introduce a partnering framework for public construction projects and suggest BIM adoption through BIM-partnering and the development of a collaborative BIM model for the construction process. Love et al. (2014) point out that BIM implementation is not static, and asset owners should consistently ensure that BIM benefits are materialising at the right time.

2.2 Management of supplier innovation in infrastructure projects

From an innovation perspective, the construction industry can be approached as a complex system. For each project, a large group of organisations (owners/clients, contractors, designers, material suppliers, regulators, etc.) have to collaborate as a network for the outcome. In terms of innovation, this network creates multiple sources of innovation, initiated from both the top of the project organisation (clients, regulators, professional institutions) and from the bottom of the organisation (contractors, specialist consultants, designers and component suppliers) (Davies and Harty 2013). Previous research suggests that understanding the processes by which BIM is developed, adopted, and diffused requires consideration of the networked and project-based nature of the industry (Davies and Harty 2013). Significant amounts of the industry's work are delivered in and through projects, and temporary project organisations also make up a large percentage of the overall construction organisation. Previous literature has proved that clients can enhance innovation in construction in a number of ways (Blayse and Manley 2004; Lahdenperä 2007). In Section 4, we present innovation catalysts. Innovation catalysts are a systematic way to foster innovation in construction and infrastructure projects.

As the construction sector is not unique in all respects, the literature in other industries can also be applied. Involving external partners, such as suppliers, in the innovation process has proved to be useful in many industries (Chesbrough 2003), and recent empirical studies have proved the positive overall effects on innovation of the acquisition of external knowledge (Cheng and Huizingh, 2014; Roper et al., 2013). Recent literature has increasingly treated the topic using different terminology, such as open innovation, involving suppliers in innovation or innovation alliances (Aminoff et al. 2015). If an organisation has the necessary supply management capabilities, it can integrate internal and external resources and extend innovation across organisational boundaries. Interestingly, some authors emphasise utilising the supply network, in that firms should not just focus on innovation input from individual suppliers, but firms should rather adopt a more strategic approach to utilising innovation opportunities from the supply network (Narasimhan and Narayanan 2013). In utilising its supply network, the firm must to commit to supporting innovation across the supply network (Musiolik et al. 2012), and mechanisms for two-way exchange of knowledge need to be implemented (Narasimhan and Narayanan 2013).

3. Method

A qualitative, single case-study design method was chosen to match the state of current theory and the exploratory goals of the study. A case-study design is applicable for identifying emerging themes and patterns, as it allows for acquiring rich and detailed data of the studied phenomenon (Eisenhardt 1989). Further, case research is an effective strategy in seeking to satisfy criteria of methodological rigorousness and practical relevance simultaneously (Ketokivi and Choi 2014). This study aims for theory-elaboration. It focuses on practices related to the focal organisation, and investigates several other organisations that are in relationships with the focal organisation.

The Finnish Traffic Agency (FTA) was chosen as the focal company for this study. FTA is responsible for Finland's roads, railways, and waterways. FTA is the largest client in the infrastructure sector in Finland. FTA's current spend on ongoing projects is 4.4 billion euros, and the purchases form 25% of the total infrastructure market size. FTA's strategic goal is to increase the productivity of the infrastructure sector. The products and services are not produced by FTA itself, but are procured from suppliers operating on the open markets. Given this, FTA (i) has a strong interest in developing BIM, (ii) has good possibilities to influence BIM-related innovations, (iii) and has also a high strategic incentive to develop supplier innovation. Furthermore, FTA has already developed advanced procurement processes and has applied many new procurement methods to ensure a well-functioning market and to promote the productivity of the infrastructure sector. FTA participates actively in various national and international BIM development efforts and initiatives.

We combined multiple data collection methods, with interviews being the main method. Other data sources include informal meetings, presentations, and company documents, and two workshops. In total, 21 semi-structured interviews were conducted in the study. Interviewees included 9 owner (FTA) representatives, 4 designers, 3 contractors, and 5 other experts in this topic. Interviews were conducted in autumn 2014 and spring 2015, and one interview lasted 1-1.5 hours. We selected the interviewees based on several discussions with different managers in FTA. Interviewees were selected so that they represented a good balance of different organisations and different project types where BIM has been used. However, it should be noted that BIM has been mostly used in fairly large projects so far. Interviewees that presented smaller projects had only limited real-life experience of BIM. Data collection instruments included the following topics: interviewee information, and semi-structured questions about supplier innovations, BIM in procurement, and diffusion and adaptation of best practices in the use of BIM. The instruments were slightly modified for each interviewee, based on their position. Data collection was allowed to overlap with data analysis, as recommended by Eisenhardt (1989), in the form of running commentary and field notes to identify areas of emphasis and take advantage of flexible data collection. The interview recordings were transcribed. For the purpose of analysis a conceptual coding process was conducted, to relate the information to the theory (Eisenhardt 1989).

We put a lot of effort into increasing the *validity and reliability* of the findings (Yin 2013). Semi-structured interviews help the interviewers to guide the discussion in the aimed direction, and minimise the risk of bias caused by poorly constructed interviews. The reliability was enhanced by constructing and following a case study protocol. Multiple data sources, such as informants from the FTA, designers, and contractors, as well as additional documents and reports, allowed data triangulation. This increased the construct validity of the findings in accordance with Yin (2013). The conclusions were verified in workshops with the FTA managers, to further enhance the construct validity. Furthermore, a chain of evidence was established by recording the interviews and writing field notes throughout the research process. External validity is addressed by grounding interview themes in extant research and reflecting the emerging findings with respect to previous academic understanding.

4. Framework of innovation catalysts

The study applies 'innovation catalysts' identified *in a previous research project* (Lahdenperä 2007) as a frame of reference to assess the state of the owner's activity. The catalysts were determined *as means of fostering innovation in construction and infrastructure projects*. The work was based on extensive literature by means of contents analysis (e.g. Insch et al. 1997), which offers a sound methodological frame for conducting a rigorous and systematic literature review and is also shown to be common in practice (Seuring and Gold 2012). It is important to note that the categories were formulated in the terms of the material, and therefore the approach of contents analysis was inductive (cf. Mayring 2000). The source documents of the analysis include more than 50 research and practice-oriented papers. To name a few, Winch (1998), for instance, presented a theoretical view of the management of innovation in construction as a complex systems industry, while Ling et al. (2007) compared key factors in innovation grounding in a survey of project clients. Other distinguished sources were offered by Blayse and Manley (2004) and Bossink (2004). The former identifies the main factors driving or hindering construction innovation and ends up with an itemised list of innovation strategies that are widely acknowledged as important to innovation outcomes. Correspondingly, the latter studied, distinguished, and classified various drivers of construction innovation used by construction industry actors to stimulate and facilitate innovation processes. Eventually, the work resulted in numerous principles called *innovation catalysts, pertaining to many different procedures that are considered critical in improving the preconditions for innovation in a construction project context*. They were categorised in 12 areas, presented in a compressed form below, forming the framework for subsequent evaluation.

1. **Active and competent owner**. The owner, whose competence and participation in the development and implementation of the project is important as the setter and driver of challenging and realistic demands, plays the key role in the improvement of innovation possibilities.
2. **The need and performance approach**. Communication of needs and the procurement documents of the owner, which contain performance requirements, are preconditions for

sufficient latitude in development, so that the suppliers have a genuine chance of achieving novel, improved solutions.

3. **Long-term goals**. Solutions must be sought and assessed in continuous owner projects also based on the benefit of their repeated use. Use in a single project and its economic efficiency may be the only applicable criterion.
4. **Partner selection criteria**. The selection of a supplier for a project must be based on a genuine advantage comparison, supported by carefully weighted quality and cost factors, and/or assessment of their implementation possibilities, such as being based on competence.
5. **Comprehensive network co-operation**. Innovations are born as a result of the collaboration of many parties, which means that the team of suppliers and developers taking part in the project must be involved early enough in terms of design, in addition to the owner and the main implementer.
6. **Project organisation**. Conditions for overall optimisation of services are created by procuring services as entities, where the required skills are integrated in contractual frameworks that act as a guide towards the common goal.
7. **Confidence and openness**. Open design and information systems are developed for projects, and opportunities for co-operation are supported through development workshops, common space arrangements, and systematic and faster decision-making chains.
8. **Continuous interaction during the project**. The interaction between the parties, aimed at developing the project, must start early with respect to design and continue with an emphasis on goals throughout the project, with regular evaluations of the co-operation.
9. **Continued collaboration across projects**. The goal should be to conclude comprehensive partnership agreements covering several projects, or to acquire project portfolios in collaboration, which enables deeper interaction, learning, and profitable development of solutions.
10. **Use and ownership of ideas**. Rules of the game and competitive practices are to be developed and introduced so that it is profitable for those coming up with new solutions to present them and so that the innovator gains a competitive advantage from the innovation.
11. **Risk-sharing and payment bases**. Possibilities of co-operation and development orientation are promoted by harmonising the goals of the parties so that the risk of the entity to be implemented, as well as the benefits of its success, are shared between the actors.
12. **Information and knowledge management**. Information management systems are created for processing experiential knowledge and ideas, to enable the accumulation of knowledge (in time, within an organisation) and to serve as a tool in seeking new solution proposals.

5. Results

The following sections present the findings from the empirical data. Table 1 presents the results from interviews related to each innovation catalyst, and the assessments of designers (D) and contractors (C) regarding the current status of innovation catalysts, categorised into three classes: positive (+), neutral (0), and negative (-). The numbers 1-12 refer to innovation catalysts, as presented in Section 4.

Table 1: Research data based on innovation catalyst framework (D=Designer, C=Contractor)

Catalyst	*Assessment*	*Results*
1. Active and competent owner	*D: - C: +*	*The client's forward-looking, competent, and active role in BIM development was appreciated in the interviews. The client has successfully driven BIM-related activities in the infrastructure sector, which was considered to benefit the development of the whole sector. Partly due to these efforts, the foundation for BIM exists. The suppliers follow the client's activities and aim to fulfil the client's emerging requirements.* *The client would improve BIM innovation possibilities by being more active in daily activities in the projects.*
2. The need and performance approach.	*D: - C: +*	*Defining requirements that are not too detailed, giving designers and contractors more leeway and the chance for novel solutions, was perceived as a good strategy for the future in the interviews. This approach has been trialled in some projects; however, the impact on innovation has been very modest.* *To foster innovation, the appropriate level of requirements needs to be complemented with the client's active participation in steering and feedback during project execution.*
3. Long-term goals	*D: - C: 0*	*The innovation targets, incentives, and evaluation of the results are implemented mainly on an individual project level. Based on the data, this approach is not optimal, because the main targets of a construction project typically somewhat contradict the innovation prerequisites. As an example, implementing innovations inherently increases project schedule risk. Furthermore, the project-centric approach does not very effectively support long-term development and learning, which would be important from an innovation perspectives.*
4. Partner selection criteria	*D: - C: +*	*Partner selection criteria are mostly based on company and key personnel references. This does not take innovation capabilities into account. Selection criteria suggested in the literature, namely company innovation processes, practices, and innovation statistics, have not been used.* *The quality criteria in the bidding process have little impact on the results of the process and, thus, are not seen as very attractive from a bidder's perspective.*
5. Co-operation network	*D: 0 C: 0*	*Results on this catalyst are fairly limited. However, in some pilot projects, a larger network of different stakeholders, including research institutes, has been involved. This approach has received positive feedback.*
6. Project organisation	*D: - C: 0*	*Research data indicates that the bidding process and delivery model have very significant implications for the innovation possibilities in the project. Delivery models that are based on co-operation (e.g., alliance) offer much better antecedents for innovation compared to traditional models, where contractors compete mostly on price. Notably, competition based solely on price is used quite commonly when procuring design services.* *Designer-contractor interaction is one important element that can stimulate innovation. The chosen delivery model obviously has a major influence on the interaction. Therefore, acquiring design services and contractors separately is not always the best model from an innovation standpoint.*
7. Confidence and openness	*D: - C: 0*	*The alliance model has enabled an open, innovation-friendly atmosphere and changed decision-making in the projects. The PPP-model and Design-Build have been significantly worse in this respect.* *Pre-project development workshops for the client and bidders have increased the possibility for interaction, and received positive feedback in the interviews. This method has also yielded positive concrete results in the projects.*

8. Continuous interaction during project	*D: - C: 0*	*A two-phase bidding process has increased innovation. However, this method also has some negative effects, as companies that have lost the bidding process have considered the financial compensation from their innovations inadequate.* *The client is implementing a consistent project feedback system that is expected to improve innovation prerequisites and feedback mechanisms.*
9. Continued collaboratio n across projects	*D: 0 C: 0*	*The data indicates that, currently, co-operation over several projects is quite rare. However, the literature suggests that collaboration over a long time and over several projects increases innovation probability significantly, because it enables the use of a learning curve.* *This catalyst clearly has under-utilised potential in the client organisation. Public legislation might set some restrictions in this regard.*
10. Use and ownership of ideas	*D: 0 C: -*	*Some practices used with respect to innovation ownership are not always considered fair. This can be a very significant innovation barrier and should therefore be carefully considered by the client.*
11. Risk-sharing and payment bases	*D: - C: -*	*Data indicates that the risks of implementing innovations in projects are currently primarily on designers and contractors. These innovation risks are amplified by the fact that implementing innovation in the projects inherently adds schedule and financial uncertainties. Significant financial sanctions are often tied to the project's main targets (e.g., schedule and budget). A different risk balance between the client, designers, and contractors is expected to increase interest in the innovation activities.*
12. Knowledge management	*D: 0 C: -*	*The client is actively following the business innovation and research activities in the sector, including R&D investments and the number of patents. Starting to follow these parameters on an individual company level and using this company-level data in the bidding processes would be a strong indicator from the client on the importance of innovation.*

The results indicate that the client has actively implemented some innovation catalyst principles. Some other catalysts have been experimented with in a few projects, but are not used systematically throughout the project portfolio. The third group consists of catalyst practices that have not been used at all. The results suggest that using catalysts as a frame of reference offers a systematic method to analyse innovation practices in the projects. To further improve the possibilities for innovation, the client should focus more on the catalysts that have not been actively used so far. Specifically, efforts should be strengthened in the areas that have been used occasionally, and that have given positive results.

Generally, designers consider their possibilities for BIM-related innovation fairly weak, and were quite critical of the possibilities to develop innovations in the projects. This is somewhat alarming, as designers are in a pivotal role in developing BIM further. Designers naturally play a key role in the first phases of a project, and therefore they create the foundation for the BIM usage during the project lifetime. The possibilities for BIM-related innovations in the later phases of the project are significantly weaker if BIM potential is not fully realised from the start of the project. Currently, modelling means mostly additional work for designers, and this additional workload is not fully taken into account in the designer's fees. A major portion of the BIM benefits are capitalised in the later phases of the project. Contractors, on the other hand, were fairly positive about BIM-related innovations. Based on the research data, contractors seem to have the best overall view of the infrastructure project and the role that modelling can play in it. Contractors also get the most significant financial benefit from modelling. In particular, BIM-enabled automatic machine control increases contractor efficiency and enables cost savings.

The findings from our data emphasise the role of the project delivery model in creating antecedents for innovation, and the alliance model seems to offer much better antecedents for innovation compared to traditional models, where contractors compete mostly on price. Our results also emphasise the importance of consistency in the client's behaviour and communication, as the suppliers are eager to support the strategies of the client.

6. Discussion

The findings of this study contribute to the literature by describing how a public client organisation can stimulate BIM-related innovation. As the infrastructure sector operates in a project-based mode of delivery, it is critical to understand how innovation can be stimulated in the projects. In the literature, BIM innovation is referenced as a somehow monolithic concept, although it is a wide set of methods, technologies, and processes. Each of these should be managed in order to achieve further development. BIM innovation is decentralised and should be implemented in cooperation with suppliers. Innovation in infrastructure projects, driven by clients, designers, and contractors, mainly focuses on added value, cost savings, or productivity, and BIM innovations are seen as enablers for those. In the interviews in this study, the interviewees often discussed innovation in general, and in some interviews it was difficult to guide the discussion back to BIM-related innovation. However, our results suggest that enhancing the antecedents for innovation in general also stimulates BIM-related innovation.

In this study, we utilised a framework of innovation catalysts, which is based on an extensive literature review conducted in a previous project, to assess the empirical research data. Based on the innovation catalysts, there is a multitude of different factors that influence the possibilities for innovation. A client can actively manage these factors. It is important to ensure that the antecedents for innovation are in place in the projects that aim for BIM-related innovations. Our results emphasise the role of procurement in innovation, as many of the identified methods that improve the antecedents of innovation require the use of advanced procurement strategies. Thus, this study also brings a further aspect to the purchasing literature, which discusses the involvement of procurement in supplier innovation (Johnsen 2009; Luzzini et al. 2015). Secondly, we observed that the perceptions of designers and contractors differ significantly, and this might prevent innovation goals from being reached. The main reason for this is that designers see that they do not get enough benefits from using BIM, and see it mainly as extra work. This is supported by the previous literature on inter-organisational innovation, which emphasises the importance of benefitting from innovation (Luzzini et al. 2015). The previous literature has also discussed the importance of congruencies in perceptions in achieving relationship targets (Aminoff and Tanskanen 2013). Thus, the client should focus on making sure that designers also get, and understand, the benefits of using BIM, either in the short term or the long term. There is some evidence (Barlish and Sullivan 2012) that the total costs of construction project have been lower than expected, even though the design costs have been higher due to BIM-based design.

Our study extends – in the context of BIM innovation – the previous authors' proposition (Tawiah and Russell 2008; Lloyd-Walker et al. 2014; Lahdenperä 2007) that the delivery model influences the probability for innovation in general, with the alliance model offering the best antecedents. In theory, the PPP project model also opens up wider innovation possibilities, as the whole life-cycle of the construct, including operation and maintenance phases, is open for innovation. However, based on the data, PPP models have not led to good results from the viewpoint of innovation. In PPP models, the tight schedule and financial constraints are dominating criteria, and this leaves very few possibilities to take risks during the project. Risk inherently goes hand-in-hand with innovation. Our results also indicate that extensive PPP tender processes that are implemented in multiple phases create a difficult situation for bidders. They need to consider how much information to put into the tender response without revealing critical information to their competitors. Our results also emphasise the importance of consistency in the client's behaviour and communication, as the suppliers are eager to support the strategies of the client. This is a common challenge in supplier innovation management (Luzzini et al. 2015), as there are different interests and objectives in different parts of organisations. Consistency is at risk, specifically, when the owner involves a separate construction management consultant to manage the project. Thus, by putting effort into systematic project-level influencing tactics, the client could enhance development and innovation activities. Moreover, in the project-based industry, the diffusion of innovation into consecutive projects has been seen as problematic (Taylor and Levitt 2004; Linderoth 2010). It is obvious that the long-term asset owner should have the motivation and competence to support this kind of BIM implementation across projects. The results of this study also propose that one project is too short a time to assess innovation, and looking for innovation across projects might yield better innovation results in the context of BIM innovation.

This study presents initial but promising results on stimulating BIM-related innovation in infrastructure projects. The empirical context was, however, limited to a single case study, and thus the results need to be verified with further case studies. Second, it would be interesting to study how BIM-related innovation can be developed using approaches other than as part of an infrastructure project, for instance using innovation procurement models, such as the pre-commercial procurement model (PCP model).

7. Conclusions

Building information modelling (BIM) is a paradigm shift in the construction industry. BIM transforms and digitalises processes, and therefore increases efficiency and effectiveness. Importantly, BIM innovation is an enabler for more comprehensive digitalisation of the construction process. Because BIM influences many aspects of the construction process, BIM development and innovation requires a joint effort and good co-operation between many parties. This requires careful consideration, but can be very powerful when implemented successfully. This study investigates how BIM-related supplier innovation can be stimulated by the owner of infrastructure projects. Our results highlights that a public sector owner can stimulate supplier innovation by actively increasing the antecedents of innovation. We identify several tactics that a client can use to stimulate BIM-related innovation and, thus, to manage supplier innovation. Reciprocal, long-term, and cross-project collaboration activities are needed at different levels of the organisation. The traditional way of managing infrastructure projects by sanctions does not optimally support innovation. Furthermore, based on the study, using economic incentives for innovation is not sufficient in many cases, as other project priorities might be in contradiction with the innovation targets. Innovation catalysts offer a systematic framework for the client organisation to assess the possibilities and preconditions for innovation in any given project. The results propose that the selection of delivery method strongly influences the antecedents for innovation – with the alliance model supporting innovation best.

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Learning From SamBIM - A Norwegian Innovation Project About BIM-driven Collaboration in Ambitious Building Projects

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Abstract

This paper reports and discusses the status in a Norwegian research-based innovation project called ”SamBIM – BIM-driven collaboration in the building process”. The overall aim of SamBIM is to develop BIM-driven processes and collaborative models that boost value creation in construction projects, the AEC-industry and in the SamBIM-companies. SamBIM is funded by the Norwegian Research Council. The project partners are leading and R&D active companies in the Norwegian AEC-industry, representing various parts of the building process value-chain. SamBIM focuses in particular on the interface between programming, design, and the production phase. Important characteristics of the project is the holistic and interdisciplinary approach to phenomena studied in five ambitious real-life projects, the action research inspired methodology, and the use of change-agents as the "innovation gear" between research and practice. The SamBIM project concludes in 2016.

In this paper, we present preliminary results of the case studies. We furthermore investigate different foci, implementation angles, practice, and development of BIM-driven collaboration, both in the individual case project and in the SamBIM project in general. The paper discusses possibilities and challenges related to the research design and methodological approach of the innovation project. Knowledge development and learning across maturity levels, formal and informal implementation strategies, collaboration across scales (multidisciplinary dimensions, life-cycle perspectives), process models for collaboration, and measures to obtain high quality BIM-driven collaboration in the building process are among the subjects appraised. The multidisciplinary profile of the research team has been fruitful in order to grasp the complexity of the observed phenomena. The broad approach has made it possible to view SamBIM topics from different traditions, both practically and theoretically. The research has contributed to increase the industry partner's knowledge, as it has contributed to the scholarly literature (particularly through the two embedded Ph.d-studies).

Keywords: BIM, Building process, Collaboration, Case study, Implementation.

1. Introduction

In this explorative paper, we present and discuss the first lessons learned in a Norwegian ongoing research-based innovation project called "SamBIM – BIM-driven collaboration in the building process" (2012-2016). We address two main questions:

- How can we identify main drivers for successful BIM-driven collaboration?
- How can in-depth case studies of the building process in real-life projects reveal such drivers?

Implementing new technology alone does not necessarily improve the way we work and interact in building projects. Improvement seems to require an understanding of the interrelationship between technological, processual and people-related factors (Moum 2008, Owen et al. 2010). To manage and implement change and innovation processes is epically challenging in the AEC-industry (Architecture, Engineering, and Construction). The industry has some particular characteristics (Dubois and Gadde 2002, Eccles 1981), making innovations challenging to deploy (Harty 2005). Harty (2005) points out five factors central to understand how innovations are deployed in the AEC-industry: 1) Tasks are often conducted as collaboration between several firms, with own resources, practices and goals. 2) The work is project-based, and there are often large numbers of people and companies involved. 3) The work is dependent on information sharing across organizations. 4) The tasks intersect organizational boundaries. 5) Each involved firm influences on the project by own practices and expectations.

Inter-organizational collaboration, complex interdependencies, and the absence of a single actor who can ensure a unitary implementation and use of BIM for the whole project characterize the context of the SamBIM-project. In the following, we describe the SamBIM scope, objectives and the methodological approach. We furthermore present the case studies and some first tentative findings, before we explore on the two questions above. We wrap up the paper with some concluding remarks.

2. SamBIM's scope and objectives

The successful collaboration and interaction between the people involved in the programming, design and production of building projects is a key to value-creation. This has traditionally been a challenging quest in temporary and non-continuous project teams. Such teams are typically comprised of companies who have never worked together before, who are representing different roles, interests and disciplines, and who are responsible for different parts of the process. The implementation and use of BIM (Building Information Modelling) is expected to improve collaboration and enable new and more efficient ways of working. Around fifteen years ago, the first companies in the Norwegian AEC-industry started implementing and using various BIM-tools. The implementation of the first generation of BIM demonstrated positive effects on design team coordination. Still, the industry is yet not enhancing the full potential of BIM beyond the goals and achievements of individual participants and phases. An initial state-of-the art review in SamBIM identified a need for more holistic knowledge on BIM-driven cooperation across phases and actors. SamBIMs multidisciplinary approach relates to architecture, technology and construction management as well as organizational studies and sociology.

The overall aim of SamBIM is to develop BIM-driven processes and collaborative models that boost value creation in the SamBIM partners, in the building projects, and in the AEC-industry. This is to be obtained by processes that are more efficient, customized end-products, better use of resources, reduced costs, less process-related building defects, and less waste. In SamBIM, leading Norwegian AEC-companies and research environments are together identifying and developing knowledge. Experiences are gained from exploring collaborative models and processes in real-life building projects with high BIM-ambitions. The partners expect research outcomes and innovations with positive impact on the planning and production of buildings, such as:

- Successful adaption of new working methods, for instance Lean Construction principles, ICE (integrated concurrent engineering) and more;
- Improved competence of the client, consultants and contractors when it comes to purchasing and supplying services in BIM-supported building projects;
- Improved information flow and coordination – with particular focus on the interface between programming (client requirements), design and production of building projects
- Better understanding of roles, responsibility and tasks – and of management and organizational drivers and barriers in BIM-ambitious building projects.
- Less errors and better buildings.

3. Methodological approach

SamBIM is an Innovation Project for the Industrial Sector funded by User-driven Research based Innovation (BIA), a programme of The Research Council of Norway (RCN). The BIA programme aims to promote value creation in Norwegian trade and industry through research-based innovation in companies and the R&D environments with which they cooperate (RCN 2015). Innovation Projects are owned by a company or an organization. They include research activities and knowledge development needed for implementing innovations and value-creating renewals. These projects call for a research methodology enabling a high degree of interaction between the industrial partners and the involved R&D environments. A successful implementation enabling a subsequent value-creating effect in the companies is crucial.

The SamBIM methodology addresses the premises of RCN in several ways (Fig.1). Firstly, action-research inspired case studies of real-life building projects serve as an arena for both data collection and interactive knowledge development. Important criteria for selecting the real life projects were: 1) High ambitions of BIM-use and collaboration, and 2) Participation of a SamBIM company in the project. The research group has carried out open-ended and semi-structured interviews (individuals and groups) at different levels in the companies: at strategic level (management, client), tactical level (project management), and operative level (architects, consultants, BIM advisers). The group has furthermore observed project meetings and other project process related activities as well as relevant documents. The questions are targeting processes, people involved, technologies used, and the interrelationship between these. This

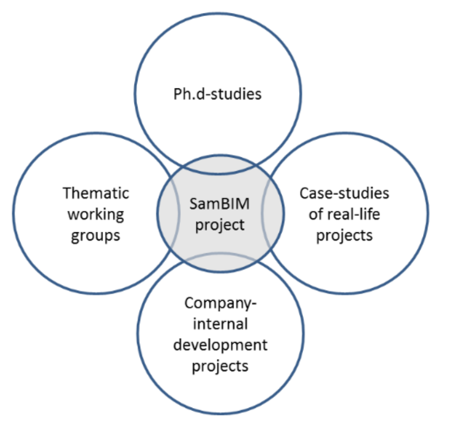

Figure 1: SamBIM as a learning hub

paper primarily presents findings from these case studies. Secondly, based on the data from the first case studies, thematic working groups were established to elaborate on cross-case challenges. Thirdly, the industry partners have kicked off company-internal development projects. Fourth, Ph.D-students are digging deeply into core issues of SamBIM. SamBIM is a learning hub, interconnecting and boosting knowledge development and implementation across the arenas in Figure 1. An important measure for ensuring a close interaction between the different learning arenas, and between the industry- and research partners, has been the so called "change agents". Each of the companies involved have appointed an employee to this role. The change agents support SamBIM as "innovation-gears" and gate-openers, acting as two-way contact points between research and practice. They assist the research activities by driving necessary internal coordination, mobilisation, and information work in their companies. They are giving access to case studies, driving forward some of the thematic working groups, and they are active participants in workshops and SamBIM project meetings.

4. SamBIM as a learning hub

4.1 The SamBIM consortium

The project owner of SamBIM is Skanska Norway, one of the biggest contractors in Norway. Skanska's industry partners are Statsbygg (building commissioner), Multiconsult (an interdisciplinary consultant company) and LINK Architecture. All of them are R&D active and linked to international sister companies or equivalent organizations in other countries. They are front-runners in BIM implementation, and are involved in networks and joint initiatives such as BuildingSMART, Lean Construction Norway and more. Together these companies represent the stages of the building process crucial to SamBIM: programming, design and production. The industry partners have committed a multidisciplinary research group as required by the complex and broad objectives of SamBIM. The R&D partners are SINTEF Building and Infrastructure, Fafo, and The Norwegian University of Science and Technology (NTNU). Around five researchers and two Ph.D-students are involved in the project on a continuous basis, with expertise from architectural and engineering sciences, technology implementation, process-related research and social sciences.

4.2 Thematic focus areas

Both researchers and industry partners contribute in the thematic working groups, established by the need to dig deeper into specific topics:

- *Barriers and drivers for collaboration*; aims to identify barriers and drivers for co-location/integrated concurrent engineering in the design phase of constructions projects, opportunities and obstacles for mutual adaptation of technology, and organization and process among actors in the design phase. *Ambition:* to publish a publicly available *collaboration guide*.
- *Lean Construction;* aims to facilitate arenas where topics related to Lean Construction are discussed and further developed, and to obtain a more unambiguously perceived term, both by researchers and industry partners. *Ambition:* to collaborate with the Lean Construction Norway network to spread the results of the SamBIM project.
- *A common process model;* aims to develop a common process model for the building process, from cradle to grave. The SamBIM findings have been communicated to a national initiative on a new norm for describing the stages of a building process, inspired by the RIBAs plan of work in the UK.

4.3 The case studies – tentative findings

The SamBIM-team has carried out five case studies of real-life building projects (Table 1). Two of them are still ongoing (spring 2016). This section briefly presents tentative findings from each of these case studies.

Table 1: Overview of the SamBIM case studies.

Case / Characterictics	*Risløkka*	*Veitvet*	*Deichmanske*	*Urbygningen*	*Eikefjord*
Function	*Road authority building (refurbishment)*	*School building (new)*	*Public library (new)*	*University building (refurbishment)*	*School building (new)*
Phase/when case-study	*Design (Oct. 12- april 13)*	*Design, 2013*	*Design, 2013-2014*	*Design & construction, oct. 2013 -*	*Design & construction 2014 -*
Project delivery method	*D-B*	*PPP*	*D-B-B*	*D-B-B*	*D-B with user participation*
SamBIM actor involved	*Statsbygg*	*Skanska & LINK arkitektur*	*Multiconsult*	*Statsbygg & Skanska*	*Skanska*
SamBIM focus/initativ	*BIM, ICE*	*BIM, PPP*	*BIM, process model*	*BIM, ICE, Lean, "BIM kiosks" (on-site)*	*Procurement, BIM, collab. model, lean, big-room.*

4.3.1 Risløkka

The case deals with the refurbishment of a medium-sized office building located in Oslo, for the Public Roads Administration. Statsbygg acted as building commissioner. Already in the pre-design phase, Statsbygg appointed this project to become a SamBIM case study. Because of the connection to SamBIM, Statsbygg and the design team agreed on testing out the following Lean Construction-inspired work principles in the design phase:

- Co-location of the design team and Statsbygg twice a week;
- Working principles inspired by *Integrated concurrent engineering;*
- The use of a so-called planning matrix and *action items.*

Bråthen et al. (2014) and Bråthen and Moum (2015a) identify driving and restraining forces affecting the BIM implementation in this case study. Rather than just studying its effects, the actual implementation was also in focus. The analysis displays that a successful implementation of BIM largely depends upon a participative and co-operative process at the ground level. At this, the significant project participants must be involved in the development of a BIM-implementation-plan. This plan should reflect interests and goals of the involved parties. The analysis points out that related discussions and negotiations can ensure ownership and the design team participants' commitment to an innovative and, for some, unfamiliar BIM-process. The study also shows that working principles based on Lean Construction contributed to a more dynamic design team. Especially the combination of BIM and co-location opened up for working in a new and more efficient way. When working co-located the designers used BIM to show each other possible solutions and problems and could make clarifications and decisions “there and then”. According to our informants this implied faster decisions and better interdisciplinary working compared to a “traditional design process” (Bråthen et al. 2014). However, such a way of working requires that all participants are present and have decision-making authority.

4.3.2 Veitvet

The Veitvet primary and lower secondary school was a public-private partnership project (PPP), partnering the turnkey contractor and property developer Skanska and the municipality of Oslo. It was a Future-build and BREEAM Very Good project, with high environmental ambitions (passive-house level). It seemed that the project had a high potential for innovation and collaboration between the professional participants of the building process. The SamBIM partner LINK Architecture had a role as responsible architect. Initially, the BIM ambitions were high, and the ambitions from the research project SamBIM should be implemented in the Veitvet project. Due to different circumstances, the project was however withdrawn as a case quite early in the SamBIM project.

The findings reveal that the project in practice seemed to develop into a traditional turnkey project, and that the formalized BIM requirements neither were met nor implemented. The collaboration seems to have failed, partly due to challenges concerning the PPP model and contractual structures between the "partnering" participants (fixed prices), and partly because the model for collaboration was not sufficiently developed and/or rooted in the contractors' management. Both BIM model and paper drawings were requested by the project management, which may have resulted in an unclear perception of the model for project management and collaboration (as a mix of traditional management and BIM) (Flyen 2016a). Even if Veitvet was terminated as a SamBIM case project, the experiences had major ripple effects and seem to have made a vast contribution to the later development of a Skanska process model for collaboration used in subsequent projects.

4.3.3 Deichmanske

In 2013, Oslo Agency for Cultural Affairs commissioned a new library building. The new main branch of Deichman, Oslo's public library, is currently under construction in Bjørvika. The SamBIM partner Multiconsult won the main engineering contract for the new library, including the responsibility for coordinating the design team. Together with three other consultant companies, they are responsible for the detailed design phase. Multiconsult has for several years been developing a generic process model for BIM-enabled projects. As a part of the Deichman project, Multiconsult wanted to streamline and improve their model further, through experiences and insight from this significant project. Related to this aspiration, SamBIM's research partners have mainly focused on the following topic in this case:

- Effects of connecting BIM to the process model through milestones. This implies that decisions about the model status in different zones of the building will be frozen at a certain date.

Skinnarland (2015) found that using a Multiconsult process model has been a valuable experience for the various actors in the design team. Using the model puts pressure on the actors to make decisions in accordance with the model, often on an earlier point of time in the process than they normally do. The informants considered the model to have contributed to more and better interdisciplinary collaboration within the design team. However, Skinnarland (2015) found a mismatch between Multiconsult's position within the design team and their possibility to put pressure on the other companies to make all their decisions in accordance with the model. Consequently, one important conclusion from the case study is that too little attention was devoted by Multiconsult on core elements in the implementation and development process of the process model. The model was introduced to all participants in the design team without sufficient discussion. Hence, a necessary ownership was not created, nor a common vision for the use of the process model. These shortcomings were probably significant for the less successful results compared to what was expected when using the model in the detailed design phase.

4.3.4 Urbygningen

The case deals with the refurbishment of a University building named Urbygningen at the Norwegian University of Life Sciences located outside Oslo, with Statsbygg as the building commissioner. The preliminary design completed in 2009. In 2013, Statsbygg initialized the detailed design phase. The ongoing construction phase started in august 2014. The design team consists of several Norwegian, Oslo-based companies. The SamBIM partner Skanska was chosen as the general contractor. Statsbygg wanted to test the following in the design and construction phase, respectively:

- BIM combined with co-location of the design team, methods inspired by lean design methods;
- BIM for site workers in the construction phase ("BIM kiosks").

Statsbygg's expectation was that BIM and the lean-design-inspired work principles would lead to better collaboration among the involved actors, and thus lead to an improved design process.

The data suggest that this principally occurred. The findings indicate that BIM combined with some of the lean work principles yielded good results regarding the intentions, through linking the team stronger together, technologically as well as organizationally. In particular, it turned out that the combination of BIM and co-location of the design team created good results. The findings indicate that this approach helped to improve the inter-organizational and interdisciplinary collaboration. It fostered faster communication and made improvements in latency, as well as contributing to a better social climate in the design team. However, the data also suggest that not all parts of the contractual "BIM and Lean-package" were equally successful in practice. The analysis indicates that the various pieces of the lean and BIM concept were emphasized differently in the implementation process. Elements given little or no attention in the implementation process are less likely to lead to good results. In the construction phase, Statsbygg and Skanska introduced so-called «BIM computer-kiosks» in order to allow site workers on-site access to 3D models. Bråthen and Moum (2015b) investigated the use of the computer kiosks and the related consequences. The findings indicate that there are great advantages by adopting BIM and similar technology at the construction site. This relates, among others, to the fact that the workers obtain a more holistic understanding of the planned building through the excellent possibilities for visualization. The workers get the ability to investigate particularly complex issues and to access details that hardly can be seen on a traditional paper drawing. In addition, the findings indicate that in certain cases the data kiosks facilitate a greater level of face-to-face collaboration between site workers. This occurs because workers meet, both planned and randomly, to discuss in front of the computer kiosk while using the model for visualizing complex issues. This means that the data kiosks can pave the way for new on-site collaboration forms.

4.3.5 Eikefjord

The Eikefjord primary and lower secondary school case is a comprehensive demolition- and new building project situated on the coast of Western Norway. The project- and building owner is Flora municipality. The execution model is interaction based turnkey contracting. The SamBIM partner Skanska is the Turnkey contractor (engineering, procurement and construction). The researchers from the SamBIM project have been following the project from the initiation of the design-build and tendering competition, through the design process and start-up of construction works. Eikefjord is the fifth and final case-project in SamBIM. The process encompassed demolition, relocation and temporary housing of school functions, building of the new school and sports arena, and build-up of outdoor areas. The school operations were to be running parallel to the demolition of the old school and building of the new, with operations partly in the localities of the old school, temporary barracks, and gradually employing the new buildings. Skanska generated an internally developed collaboration process model prior to the initiation of the early stages in the design-build tendering competition. The case project was a pilot for the new process model. The project team was complete already from the initial stages of the competition, adapting full collaboration, team building, and collective experience learning from early design and composition of tender. Skanska managed the project and the project design team, had the BIM coordinator and a process supervisor/change agent to follow collaboration process. Consultants, architects, and manufacturers were both locally- and

Oslo based. Both collaboration- and BIM ambitions were initially high, and the research focused on the following areas in the collaboration process model employed in the case project:

- Implementation of a collaborative focus from initialization of design-build and tendering competition;
- Lean-construction inspired backwards planning/scheduling and implementation of tendering, design and construction stages;
- High BIM-ambitions, both in tendering, design, and construction, and as a support tool for close collaboration;
- Workshop-based collaboration approach, with frequent gatherings;
- Virtual and physical BIG-ROOMs in the design phase.

The primary focus of the newly developed process model ensured collaboration and co-localization from initial start-up, and upheld the baseline goals agreed upon throughout the whole of the process. Due to the partners' different localities, a continuous focus on collaboration has been imperative. The use of virtual and physical BIG-ROOMs, frequent workshops, and clarification of expectations for deliverables for each other to the next gathering has been important drivers to achieve this goal. The Lean construction-inspired scheduling approach yielded complete overview of all participants and interfaces. Both holistic and interface coverage between professions has successfully been ensured by the all-team and two-party clarification meetings during the workshops. The consensus-based rules for collaboration and workshop-based process ensured a rapid and effective design process, but required that all participants were present and had decision-making authority in the workshops (also the owner). The results of the earlier case projects in SamBIM seems to have inspired, and partly driven, the development of the Skanska collaboration model. The experiences with the model so far are very promising in terms of efficiency and quality of both collaboration and project results (Flyen 2016b). The model has thus proven to be an important driver for collaboration and the use of BIM in construction projects. Further, the participants have expressed that this way of collaboration is inspiring and positive, and that they want to continue to pursue this approach in further projects.

5. Discussion - Learning from SamBIM

What are the first lessons learned across the single case studies and adjacent activities? In the following, we discuss how the SamBIM team has identified main drivers for successful BIM-driven collaboration. We elaborate on three key topics: 1) learning loops and maturity levels 2) implementation strategies and, 3) commitment and continuity.

5.1 Learning loops and maturity levels

Three factors were particularly challenging throughout the project: 1) to achieve a shared understanding of ambitions, activities and roles, 2) to find appropriate case studies and, 3) to close the gap between the ambitions and the various maturity levels in the organizations and the projects. The initial ambitions of SamBIM were high. The starting point was a broad and holistic view on developing new ways of collaboration, enhancing the full potential of BIM. The partners wanted to develop new generic models and methods, which, in the next step, should be applicable for other actors in the Norwegian AEC-industry. To orientate in this rather complex landscape of interdependencies, and to operationalize the overall objectives into definite actions, required much effort in the first stage of SamBIM. The related discussions between the researchers and the practitioners (and the study of state-of-the-art elsewhere/in the industry) gave valuable guidance. Based on the knowledge gained from the case studies and the discussions about the goals and ambitions, the SamBIM-team decided to establish three thematic working groups as an arena for elaborating the selected cross-case topics as previously described. An important function of this work is to transform the pool of empirical data into definite and applicable outcomes for the industry partners. Important topics in the SamBIM-team discussions were e.g.; to which degree can the SamBIM project realistically hope to influence on cultures of collaboration within real-life projects and organizations? What is process-innovation for each of the partners involved?

Finding real-life projects to match the high ambitions of investigating new ways of collaboration and advanced BIM-use from early design to production was challenging in the first stage of the SamBIM-project. The partners had thus to apply a rather pragmatic approach to narrowing down the scope and limiting the ambitions. It was necessary to adjust to the restraints of the available case studies, and to the maturity of the involved organizations. Still, as the project developed and the insight and the maturity of the industry partners increased, new cases replaced or succeeded the initial ones. The new projects could thus benefit from the preceding experiences. An example is Skanska's steep learning curve on their way from the Veitvet to the Eikefjord case.

Would SamBIM have benefited from a more limited scope and more mature case studies from the beginning? Not necessarily. To move from the overall picture down to the details, and to research the not-perfect real-life situations might have been challenging, time-consuming and partly painful. This process has however also revealed findings and experiences, which might otherwise have remained undiscovered. More important, this process has been useful in order to harmonize the progress with the actors' need for time to move upwards on the learning ladder, step by step.

5.2 Formal and informal implementation

The case studies show, in different ways, the importance of a good understanding of implementation drivers and related strategies. An obvious implementation driver for "SamBIM-working" (BIM-driven collaboration) is formal contractual requirements of the client (for instance early contractor involvement and co-location/big-room solutions). The SamBIM findings do however indicate that this is not enough to achieve successful implementation and related change of traditional practice. Not only formal, but also informal drivers of implementation can be powerful. For instance a dedicated design manager (or a change agent), who, with a personal engagement and belief in what he/she is doing, motivates and inspires colleagues or a team to try out new technologies or ways of working. A good implementation strategy should include formal measures, as it should take into account, be aware of, and utilize the power of informal drivers such as involvement and participation of involved parties.

5.3 Commitment and continuity

Initially, one of the case-study criteria was that at least one SamBIM industry partner had to be involved in the building case projects. The role (and the authority) of the partner in the project affects the ambitions and possibilities of a broad implementation. Statsbygg and Skanska in their client or turnkey contractor role could put pressure on the implementation of the SamBIM-approach (top-down). The architect or the consultant company (bottom-up) did not have the same impact in the projects with an external and not "SamBIM-committed" client. To create interest and commitment among all building project participants, would enable a broader impact and probably also enhance greater benefits. This is however not always possible, and calls for activities with realistic scope, adjusted to the constraints of what is possible to test or change. Tight collaboration between research partners and industry partners is an important premise for success in innovation projects such as SamBIM. In AEC-companies, there is often a high labor turnover and change of people in management positions. The SamBIM-companies have been no exception to this. Throughout the project period, the team members in the SamBIM group have changed several times, including the project management. This creates challenges for the team building and the continuity of the work. The same situation has also partly characterized the building projects studied. Changes in work force can affect both positively and negatively on the progress and success of a project. They are however unpredictable and not possible to influence on. This makes it even more important to create robustness in organizing such tight research-practice collaborations.

6. Concluding remarks

A motivation and crucial expectation of the industry partners (and the Norwegian Research Council) is that the SamBIM-activities will contribute to actual improvement of their practice. This is relevant both for the building projects they are involved in, and for their own organizations. In order to wrap up this tentative report, we summarize how in-depth case-studies of the building process in real-life projects has revealed main drivers for successful BIM-driven collaboration:

- Learning across the case-studies has been highly valuable. To develop knowledge step-by-step from case to case has given an added value to the SamBIM project beyond what would have been possible with parallel and isolated cases;
- To develop and implement research-based knowledge on holistic, “soft” and hard-to-measure issues in real life settings is challenging. In SamBIM, it has been important to allow for maturation, unexpected findings, necessary corrections and limitations as the insight and understanding among the partners have gradually grown;
- The dynamic interchange between the four knowledge development arenas (Figure 1) has been highly valuable. The activities have boosted each other and the progress of the SamBIM project. They have also stimulated learning loops and continuously pushed the partners into investing in new fields;
- The multidisciplinary profile of the research team has been fruitful in order to grasp the complexity of the observed phenomena. The broad approach has made it possible to view the SamBIM topics from different traditions, both practically and theoretically. The research has contributed to increase the industry partner's knowledge, as well as to the scholarly literature (the latter particularly through the Ph.d-works);

- The close interaction between the researchers and the industry partners has been a driver in SamBIM, with the dedicated change agents in front;
- The complexity of both the consortium and the research requires clarified roles and responsibilities, and a common understanding of aims and ambitions;
- In SamBIM, it has become important to both strive for the high and ambitious goals (long runs), and grasp for the low-hanging fruits (short runs). The Urbygningen BIM-kiosk or the big-room of Risløkka enhanced an immediate effect which was useful and motivating, and which created pride and ownership among the actors involved.

The SamBIM project will be completed in the autumn of 2016. Important work to be done in the last stage of the project are the cross-case and cross-activity analyses and summaries, the deliveries of the thematic working groups, and the dissemination of the findings from the project in its totality.

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The Implications of BIM Use on Communication Channels in the Design Process

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Abstract

This research aims to explore the implications of building information modelling (BIM) implementation for existing communication channels used in design processes across various professionals in the Kingdom of Saudi Arabia. Although there is much research on communication channels in terms of their effectiveness, related to collaborative environments such as face to face meetings vs. computer-mediated communication (CMC), there is relatively little research known about the consequences of implementing BIM on the existing mechanisms used for communication within firms. In doing this research, three different sets of concepts have been mobilised with the aim of understanding the dynamic processes of communication across diverse professionals in general and within BIM collaborative environments in particular. These concepts are theoretical models of the communication process (from linear to interaction processes); team theory, and cross professions collaboration theory. These were reviewed to identify 38 distinct factors, selected in relation to how relevant they are to potential changes in communication channels. The factors are grouped into three major themes; collaborative team characteristics, leadership and methodology of information exchange. These are then used to develop a framework to examine the implications and effects of BIM on communication channels. Empirically, a pilot case study strategy is employed, with data collected from four medium-large firms in KSA through semi-structure interviews and a questionnaire. The initial findings of the case-study reveal that the changes in communication channels experienced through using BIM differed depending on several factors. Although many factors were common across the three sets of literature, their influences empirically were diverse. Factors such as resistance by professionals to change to new or alternative communication channels not only referred to the lack of training or education but also, to a 'familiarity' factor. Furthermore, there is an influence of 'spreading rumour' (pre-existing assumptions and expectations) on adoption of communication channels which appeared more at the decision maker level.

Keywords: Communication channels, BIM, Professionals, Influential factors, KSA Firms

1. Introduction

There is an ongoing debate about what BIM is. A number of definitions from professionals and researchers alike have described the BIM philosophy in different ways. For some, BIM is *'data sharing, and not only data exchange'* (Nour 2012: 1), for others it is an integrated model (Sebastian 2011), or it is *'a software application'* (Aranda-Mena et al. 2009: 420), or shared digital representations, and language allowing interoperability (McGraw-Hill 2008). As the perceived definitions differ, this leads in turn to enquire about how design representations are exchanged across BIM communication channels. This research aims to explore the implications of building information modelling (BIM) implementation for existing communication channels used in design processes across various professionals in the Kingdom of Saudi Arabia. The paper is structured as follows; first, relevant literature on communications, teams and collaboration are used to describe the extraction of factors which may influence communication channels in BIM projects, following this, the iterative research approach for this pilot study is discussed. The analysis is then presented under main themes of team characteristics, leadership, and information exchange processes, before the main findings and conclusions are described.

One of the core features of BIM is 'interoperability' (Succar 2009), defined by IEEE (1990: 114), as *"the ability of two or more systems or components to exchange information and to use the information that has been exchanged".* This process of exchange and sharing of information reflects two pillars of BIM work; communication and collaboration (Azhar et al. 2012). Referring to the findings in the literature, in relation to the role of the collaborative team, there is a consensus about team work is a third pillar. Reviewing the literature in BIM shows a consensus about the main challenges faced in successfully implementing new innovations (i.e. BIM) in general, and information sharing in particular. These common challenges include lack of training team members, and resistance to change (see e.g.; Azhar et al. 2007; 2012; Dossick & Neff 2011; Harty 2008; Homayouni et al. 2010). Although the keystone of (BIM) is the communication process, which enables stakeholders, to collaborate effectively and deliver correctly the desired information (Xue et al. 2012), there is still some deficiency in communication processes within BIM projects. Moreover, to date there is relatively little research about the consequences of implementing collaborative approaches such as BIM on the existing communication channels used. In this respect, this study will identify 'what' happened to the existing communication channels and 'why'. In this study, the channel refers to *'as the medium of communication: the material through which the content is sent'* (Dainty et al. 2006:112). The research draws on three theoretical approaches: communication theories, team theory (Brennen et al. 2007), and cross-profession collaboration theory (Amabile et al. 2001). In doing so, selected factors from those theories have been addressed in relation to how relevant they are for recognising changes in communication channels. This study consisted of selecting 38 factors, which were grouped into three major categories (themes): the methodology of information exchange, collaborative team characteristics, and leadership.

In the communication literature, definitions of communication reflect at least two concepts. The first describes communication as the process of exchange information among sender and receiver to equalize information on both sides (Otter & Prins 2002). This approach focuses more on the ‘transmission aspects’ of the communication process forming a linear model and one-way process (Eckert et al. 2005). The second describes communication process as; *'transmitting messages from one person and the receiving (and successful understanding) of those message by another'* (Torrington & Hall 1998:112). Roger and Kinck (1981:63) describes the communication process as; *a' process in which the participants create and share information with one another in order to reach a mutual understanding'*. Emmitt and Gorse (2007:3) define communication as, *'sharing of meaning to reach a mutual understanding and to gain a response'* and this definition has been used widely in the communication literature. These definitions focus on, as Maier et al. (2008) referred to, obtaining an equal understanding, rather than measuring the information flow from-and-to the receiver. In the design process, sharing a mutually understating between participants is a fundamental prerequisite for any successful communication process (Eckert et al. 2005). In this regards, three communicational models are used. With growth in network speeds, information communication technology (ICT) opens opportunities for professionals to communicate in a different way; from texting, chatting, to visual communication (Sidawi et al. 2012). Beside this, in collaborative design environments, communication becomes much more complex, and professionals have numerous choices of various communication channels to employ (Gabriel & Maher 2002; Eckert et al. 2005). The availability and diversity of communication channels has been proposed by Gabriel and Maher (2002) as the main criteria for the success of collaborative communication. Nevertheless, in general, there are studies pointed to influential factors behind either the changes in channels in particular, or on the selection of those channels which may differ from one work environment to another. Despite the distinction of contexts, there is a consensus on some of those influential factors, for instance individual’s preference (Watson-Manheim & Belanger 2002; Gabriel & Maher 2002), organizational culture (Homayouni et al. 2010; Watson-Manheim & Belanger 2002) and physical environment (Dainty et al. 2006; Watson-Manheim & Belanger 2002). Interestingly, scholars’ views toward communication and collaboration (e.g. Ebrahim et al. 2009) also suggests that a team member is a leading unit in the process of communication and collaboration, who impacts and is influenced by the surrounding environment. Within the context of the design process, it is fundamental to understand the core role of team members within communication process; as being a sender and receiver.

In our study, the categorization process was conducted via sequential steps: 1) Break down all the most possible influential factors from the three literature areas; 2) Identify factor definitions from different sets of literature; 3) Group the factors into themes; 4) comparison and rearrangement of the factors (an iterative process); 5) Arranging them in a schedule in which classified them into three various themes, and under each theme, factors and sub-factors. Such categorization has been developed in order to address the possible impact of these sub-factors either to main factors, or directly to communication channels used. This process facilitated recognition of themes in the aim for developing an analytical framework, and in order to empirically examine the implications of BIM on communication channels used. These three themes are; Methodology of information exchange, Collaborative team characteristics, and Leadership. Importantly, the overlap between these factors within each theme, or across these three themes assists in developing questions for the pilot study in relation how these factors are relevant to change communication channels used. The factors have been extracted from three main sets of literature and relevant theories mentioned above; in terms of their potential influence on these main areas, and subsequently to their potential to change communication channels used. Surprisingly, despite considerable commonality between these factors, some differences appeared. The main aim of this research is to explore the implications of BIM execution on existing communication channels in the design process used by various professionals. In order to accomplish this aim, the objectives are; a) to understand how the communication process works; b) to identify various factors influencing change in communication channels used, and; c) to identify the communication channels enabled by BIM tools. To meet the purpose of the study, a case study strategy will facilitate to answer questions of 'what' happened, and 'why'. However, conducting a pilot study is also an initial step to refine the empirical questions, to identify suitable cases, and test the data collection approach for further empirical study.

2. Research Design

To meet the purpose of the study, a case study approach facilitated gaining a rich understanding of the research context (Morris & Wood 1991). Additionally, applying a pilot case study approach as an initial phase contributes in revising the data collection plans in order to be appropriate to the context of data, and rehearse procedures to follow (Yin 2009). Importantly, using a case study strategy from Saunders et al. (2009) perspective enables answering our research question in regarding of 'what' happened in communication channels, and 'why'.

Based on the reviewing the communication literature, employing a qualitative method is appropriate in seeking to understand communication channels, and this is usually achieved by using semi-structured interviews. Questionnaires were also developed to try and collect contextual data, and to refine the interview protocol. Observation is also common in communication research. However, this was excluded from the pilot study owing to the nature of Saudi’s society, which makes it difficult for this technique to be applied successfully, especially for female researchers. The data was collected from the three firms, and the last case was with a participant from the Ministry of health in KSA. The research was conducted using telephone interviews between June and August 2015.

This research was designed to pursue a sequential exploratory strategy, hence questionnaires followed by interviews employed. The two main objectives for initially distributing questionnaires were to identify the different kinds of communication channels used, and to measure the frequency of the use of these identified communication channels within BIM. Not only that but the quantitative data also helped further to crystallize our empirical interview questions by narrowing our focusing for the most likely influential factors (Creswell 2009). A triangulation strategy was employed within each case for the pilot study target which facilitated us to test the research interview questions for anything unclear or uncomfortable in relation to the context (Bryman 2012), which improved the questions quality (Yin 2009). It is worth noting that, the interview questions used were initially drawn from the literature, and tested with experienced professionals with BIM for more than 4 years. The interview questions were refined using the questionnaires’ responses providing insights into the numbers and types of channels and potential influential factors that were discussed in the interviews. The semi-structured interviews were conducted with an architect, BIM coordinator, and project managers across four organisations in order to get a range of viewpoints.

3. Analysis and Preliminary Results

3.1 Theme 1: Team characteristics

Resistance to Change: With regards to resistance to change, respondents referred to several factors. A recurring one was having had previous negative experiences with either particular approaches, software, or technology used to communicate. Besides this, negativity by some who had a previous negative experience shared their colleagues either at the individual or manager level was evident. However, based on the respondents' views, those people who 'resist change' have generated incorrect information regards, for example, the difficulty level, and effectiveness for desired tasks. It was thought that external software salespeople played a role in convincing individuals and management to adopt certain BIM communication approaches over others. Also, the BIM coordinator noted that *'We are obliged to follow up with the senior management directives particularly which related to the mechanism used for communication channels for information exchange'* (BIM coordinator, Case 1). However, it was thought that there has not been an obvious change in communication channels used, particularly at the level of individuals. In this respect, the project manager (PM) for the medical centre project in Riyadh, commented that: '*one of the challenges we were faced with is to get our employees away from using the communication channels were not listed in the planned communication model. Especially for large-projects cases, using normal E-mails system by some, were wasted the required information from the rest of the team members, especially if such person has been changed'* (PM, Case 2).

However there was a difference between the use of specific communication channels (such as email) and technologies. The participants were often surprised when asked about the role of spreading 'incorrect' rumours in changing or resisting changing the communication channels used. From their responses, the influence of rumour appeared more on technology use in general, rather than channels, in particular. In view of this, at the end such technology can involve use of a range of alternative channels. Therefore, the ultimate influence will be at those channels. Along with rumour impacts, there is an indication that change or impact is rooted in resistance or the influence of software vendors *'as one of the influential factors, most likely generated by the members who against to change, and a software salesman'* (BIM manger, Case 3). Individual preference was also important. Respondents noted that, *'Individual's preference is existing, playing a vital role on communication channels used, and appeared more obvious especially by the decision-makers'* (PM, Case 2). However, in another response, seems that the individual preferences are often constituted as a considerable challenges to the project manager. Thus preference led some professionals to remain using the hand sketches and the typical E-mails as a means to exchange and shared information, interpreted by the PM as due to a *'familiarity issue'.* (PM, Case 2; PM, Case 4). The last sub-factor is the presence of older generations within the teams. Within a BIM environment, and from the BIM coordinator's perspective *'the old generation refused to utilize a new technology, because they believed such technology will reduce their value and capabilities,..Yeah, don't surprise, this is what they believed'* (BIM coordinator, Case 1). Such resistance led other professionals to return back to use the traditional means which are not including on the communication protocols; for exchanging and sharing information. For instance, FTF meetings, hand sketches, E-mails and paper-based documents. Related to this, some responses showed the influence of the lack of computer skills (e.g. as related to Encoding-Decoding Knowledge). The BIM coordinator said *'sometimes we defined an assistant to do all the technical things for him; due to their deficiency on how to dealing with the technical issues, and the process for encoding-decoding.* This in turn, *'led some to use alternative channels….. thus, had made some changes in the type of communication channels used, and then on the workflow process'* (BIM coordinator, Case 1).

The diversity of skills, knowledge, and experience among professionals: As inferred from the dialogue with the BIM coordinator the influence of the diversity of skills, experiences, and knowledge among professionals on channels used is an important factor. He indicated that '*Because of the different skills and experience among the engineers; it was one of the reasons behind the misunderstanding of the outputs of the BIM simulation programme,.. especially appeared more on the technical and mechanical drawings stage...Oh yeah, in this case, some experienced professionals do not have any choice, except to follow the lower-skilled professionals on their way to design, by using a 2D projections (CAD),.. Certainly, in that case, they used E-mails as a channel to exchange rather than BIM server'* (BIM coordinator, Case 1). In the other hand, increasing the level of the professionals skills and experience, from the perspective of some respondents, contributes as well on making changes on communication channels. They were depended more often on BIM tools not only for exchanging data but also, for shared what other professionals were exchanged as well. Thus it contributes to *'reduce the dependency degree on the typical known communication channels, for seeking the desired information'*(BIM coordinator, Case 1).

The presence of competition among professionals: Within BIM collaboration, and when attempting to explore the interrelated impact between the role of rumour and changes in channels, rumour often appeared at the managers' level. However, at the individual level it was less obviously noticed. And, consequently referred to the existence of the high competition level among professionals, as interpreted by the BIM manager: *'In my experience, I haven't seen it much because there are some challenges, and the high level of competition. So, people just focus to be the best, yes to be the best.. the negative actor might be existed, but his influenced could not be noticed'* (BIM manager, Case 3). This suggest a more change oriented factor where the competition to perform can lead to individuals adopting new technologies and communication channels.

3.1 Theme 2: Leadership

It appears from responses that there is an important role played by the team leader or manager for making changes on the existing channels used for communication. Some of these are explicit and appeared more directly, and others indirectly. Nevertheless, they still have influenced the communication channels used. For instance team member selection (e.g. in terms of collaboration skills, experience, etc), availability or provision of training and educational courses, and lack of clear task coordination. Although classifying the influences type on communication channels as either is direct or indirect is beyond the scope of this pilot study some interrelated impacts have appeared which resulted from such factors. For instance, the individuals' differences for absorbing a new technology, and refusal to change by the old generation are restricting other team members to older (traditional-typical) types of communication to exchange and share the CAD files by E-mail, and paper- based documents. As was said by the BIM coordinator, *'In any project, normally team working at the same level of the performance and experience, and such selection is a core role of leader... Another strong factor is the type of the project, some projects are less difficult, the choice of the employees must be commensurate with their performance, background, experience, and skills'* (BIM coordinator, Case 1).

Another emerging factor is the lack of providing appropriate technical training, and educational courses according to the project and firm needs. Along with these, the lack of tasks coordination in terms of setting up a technical FTF meetings, especially at the outset of the project is considered as having some impact on channels. Typically, such procedure uses to clarify what the information requirements are, and who is responsible for what tasks...etc. However, the initial findings have not shown a direct influenced on the existed channels. There were expectations from the respondents, such as the project manager, that *'ambiguity around the provided information regarding what, and to whom they have to send such information… or sometimes, what the required information is, might lead to the need for documenting the communication process which will occur between the sender and receiver'* (PM, Case 4). However, when was being asked to provide examples, he commented by saying that *"Yes,.. Example, ok if the required information is almost enough to be sent via phone call, or through informal FTF conversation,.. but the sender, or might be the receiver were afraid, that the other person might be stated he didn't receive anything,.. oh yeah, in that case might the actor use some means which provide a documentation feature, let say, E-mail system'.* However, the initial findings have not shown a direct or clear influence for the lack of tasks coordination as a factor on the existing channels. It suggests, however, that it can impact on the trust level between participants, which subsequently leads to revert to alternative channels. For instance, using the E-mails as a substitute for the phone calls; for the documentation purposes. It is worth mentioning that all the participants without exception indicated the influential role of the decision makers in terms of identifying the communication protocols. Such protocols refer to the required communication channels, and the applications for project management to be used. Such decisions are according to the project, and the firm needs.

3.2 Theme 3: Information Exchange Processes

The responses indicated that interoperability, which BIM technology should provide, facilitated the process of sharing, exchanging and modifying information and documents. In terms of BIM changing the communication channels, the BIM coordinator said that *'The process became clear to all participants which facilitated communication process and information exchange...*

person has the ability to see all adjustments, instead of talking with each person and explaining individually to him ..Or, send a request for information via E-mail' (BIM coordinator, Case 1). Another PM stated that, *'the E-mail system has not used mainly as before in BIM-enabled projects'* (PM, Case 2). In view of this, it appeared that BIM has reduced not only the frequency and use for the FTF meetings but also reduced use of the E-mails system and hand sketches as well. Along with this, delayed responses by less active participants (e.g. old generations) and the differences in time zone were contributors. For instance, inactive participants resulted in shifting from exchanging the BIM models using a BIM server, to utilizing CAD and exchanging via E-mails. The majority of the respondents did not indicate a clear and direct impact of incentive and rewards structure in changing communication channels. However, one of them said that *'it might be influenced, especially on some cases. Such case, when the team member who did their duty correctly, and at the competitive time'.* In exploring how this might work, and influence channel use, The BIM coordinator said *'BIM has facilitated the process for sharing information around design details, but not shown of how they did these procedures'.* He consistently said that *'if the work procedures have done, or the technical issues have sorted it out, but in easier and faster way than what we planned to, normaly leader asked him for sharing these knowledge with other team members, and this person is rewarded for his efforts'.* In view of this, we could infer from his dialogue that the reward structure was contributing to improving the process for sharing knowledge, and addressing the lack of technical skills considered by respondents as one of the influential factors towards changes on channels used. Consequently, the rewards structure eventually influenced the communication channels used. In addition, the responses are shown to influence both the project characteristics (e.g. project's needs, scale, types, and the level of complexity), and the contract form for the partnership agreement. In view of this, the lack of information provision regards the contractual agreement, in terms of clarifying the communication protocols such as the number of meetings, communication means (e.g. channels, project management applications) had made changes on communication channels according to both of the project managers for Case 4; and Case 2.

4. Discussion

In an effort to illuminate the identity of the influential factors implicated in changes in communication channels, we performed a case study approach for (4) cases with (4) interviews (4) interviews and (8) questionnaires. The above analysis from the preliminary interviews yields several findings that relate to the previous research in the communication, team, and collaboration literature. In this regards, the empirical result of this research uncovers some emerging influential factors as shown in Figure (1). The evidence from the case studies supports the literature suggesting influential factors, but in our study their type of effects were different. Our empirical findings revealed sets of relationships in relation to the aspects for communication, teamwork, and collaboration, and subsequently their potential influences on communication channels used. Although the evidence from the case studies supports the literature suggesting that individual preference, resistance to change, and organizational culture are important, it is worth noting that, the factor we have termed 'spread of rumour', has not been addressed yet on communication literature but appears an influential factor behind channels changes during the design process. Our findings disclosed that it played a critical role at the level of the decision maker (i.e. manager) alongside the influential role of the software vendors in selecting technologies and therefore communication channels. However, the influence of rumour was more difficult to see at the level of individuals. This is due to, as respondents referred to, the presence of high competition level among professionals within BIM work environment. This resulted on developing their skills constantly, and following up the managerial instructions.

Figure 1: The emerged influential factors, and themes

To illustrate this, the individual's preference for using some certain communication channels instead of others was due to several factors, with the familiarity factor as one of the main causes, despite having training and educational courses. Our findings are consistent with the findings of Watson-Manheim and Belanger (2002), despite the context being different, that there is consistency in term of factors, and in the interpretations behind impacts and changes. The familiarity factor appeared more clearly with the older generation professionals who are claimed to have a lack of computer skills. These previous factors constitute the action of 'resistance to change'. Within a BIM-based project the relative absence of hand sketches as a 'familiar technique' was considered less acceptable for older generations. It was found that the need for using hand sketches as non-verbal communication paired with BIM tools is being used less than before (i.e. non-BIM cases). But our findings suggest, in this respect, that the absence of such techniques might constitute a threat to older professionals' status and the level of their hand-drawing skills developed during their careers. Such skills may be the very reason why they arrived at such position in their companies. Alongside this, we might also consider the importance of hand sketches as a visual language as Sebastian (2011) stated, and a vital communication tool from the view of Homayouni et al. (2010) which is used to support clear communication during meetings. Although FTF meetings may be the most preferred means to communicate (Gabriel & Maher 2002), our findings are consistent with Dossick & Neff (2011) in terms of hand sketches being used less during meetings in BIM projects. Surprisingly, the skills, experiences, and knowledge as high or low for the team members, have contributed to making changes on communication channels used. To illustrate that, highly skilled professionals can shift faster between using the traditional channels (e.g. E-mails system, phone calls) to utilizing BIM tools (e.g. BIM server, open request on Revit® building design software). In contrast, at the low-level skill, the need for face to face discussion remained along with emails for making inquiries. The main feature of BIM as an interoperable system, not only potentially produces a free error design, but also facilitates sharing what others have exchanged, pointing to problems identification and inquires directly in the Rivet models. These features not only reduce design errors but also, reduced the dependency degree on (one to one) meetings, emails, paper-based documents (e.g. hand sketches) and informal discussion. These findings seem to be agreed with the findings of Dossick & Neff (2011) in examining the changes occurring by using BIM. In addition, another influential factor is the documentation requirements and the need to record the communicational content to provide evidence for the process of exchanging the official information among professionals. Particularly, it found the work environment sometimes characterized by a lack of task coordination among professionals. Furthermore, if there is a lack of trust, there is arguably a need to record the process, which is consistent with Watson-Manheim & Belanger's (2002) findings regarding influences on channels choice. However, this could also be attributed to ineffective leadership, as indicated by Ebrahim et al. (2009), and Amabile et al. (2001). Another common influential factor from the communication aspect, is the communication protocol's form included in the contractual project requirement, and partnership agreement. Our findings are consistent with Emmitt & Gorse (2003) in that the definition of the formal communication channels are associated with the contractual requirement for each project. The communication protocol, as our results revealed, differed according to project types, project scale, partner type, and the level of complexity. This diversity in protocol resulted in changes of the channels used from context to context. These findings seem to be agreed with Dainty et al. (2006) in arguing that the need to expand communication across organizational boundaries is an inevitable consequence of increasing the project scale, and subsequently results in expanding types of channels used. Furthermore, our findings indicate that the project management applications and their variety are based on the project type or firm's need which can cause differences in communication channels used from context to context. According to the questionnaire results, our study reveals some of the current types use of communication channels, and how often they are being used on the BIM-based project. However, our preliminary results did not allow us known about the percentage rate of used for each channel or whether this percentage rate for a particular channel is decreased, or increased after implementing BIM. However, overall the use of email, FTF meetings, video conferencing and phone calls are still employed within BIM environments, but the use rates are less than non-BIM projects.

5. Conclusion

This paper explored our key question of what happens to communication channels with BIM-enabled projects and why, by employing empirical case studies on the emerging role of the technology (i.e. BIM) on communication processes within design. Our study presented a comprehensive list of factors which have been examined by the relevant theories; communication, teamwork, and collaboration literature, to date. Such factors categorized according to their influences in such areas of literature which in turn, facilitated the previous process of data analysis. This study identified 38 factors, which can be considered as a guide to figure out the potential changes on communication channels used, as a new approach that has not been addressed yet in the current literature. Such addressed factors are the fundamental step in identifying the changes on channels for any new technology. This study provides a first step in this direction. Based on such analysis for the pilot case study and literature, there is some commonality on the influential factors across various research areas. However, the results presented in our study are seen as an initial attempt, therefore more extensive research needs to be undertaken to understand the implications of BIM. In this respect, this study concludes that relying on communication theories only, such as were used initially, are not sufficient to understand and subsequently interpret the occurred changes thoroughly in a complex environment (i.e. BIM). Therefore, the employing of the three communication theories, although there are relatively diverse, including teams and collaboration, have provided another dimension and insights to our study. Finally, a few limitations of this pilot study should be noted. First, the much of data is reliant on a relatively small number of participants' feedback. Second, there is no substantive quantitative data to help verify these views, for instance with indications for the percentages rate for using each channel. These will be considered as further research is undertaken.

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Integration of FM Expertise and End User Needs in the BIM Process Using the Employer's Information Requirements (EIR)

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Abstract

Projects in the construction industry typically involve complex information flows from early design, through construction, to facility management (FM). Building Information Modelling (BIM) tools and workflow processes are considered key enablers for collaboratively managing such information across phases of the project lifecycle. With the increased adoption of BIM by the construction industry, there are heightened expectations for increased engagement of facility managers (FMs), users and clients in the BIM process. This is based on the proposition that BIM can benefit the operational phase of a building, which contributes the most to the building lifecycle in terms of overall cost, sustainability and usability. The study aim was to investigate current levels of understanding and adoption of BIM by facility managers in practice. Three research questions were investigated: (a) *How client and FM engagement with BIM workflows can be improved through early contemplation of their requirements*; (b) *what are the perceptions about BIM and its potential impact on the FM industry from an FM, user and client perspective* and (c) *what information is required by FM from the BIM process to maximum optimisation of assets in the operation phase*.

Mixed research methods, including: a literature review of academic and industry publications (e.g. case studies, industry best practice, standards and guidelines), an online survey of FM professionals and focus groups, were used to address the posed research questions. The findings highlight the need for further education regarding BIM guidelines and standards. In particular, new and more FM/client-focussed BIM strategy documents, EIR and other templates are required. Many existing templates (e.g. EIR) are not focused on client's needs. Guidance is required on developing BIM strategies based on understanding the client's Organisational Information Requirements (OIR) and Asset Information Requirements (AIR) in order to develop an EIR that specifies what, when and how information should be delivered. This will improve timely decision making during design and ensure that the right and correctly structured information is delivered to clients at handover for their Asset Information Model (AIM) to help optimise the operation of their assets.

Keywords: Facility Management (FM), Building Information Modelling (BIM), Employer`s Information Requirements (EIR), Asset Information Model (AIM)

1. Introduction

BIM is driving rapid change throughout the design and construction (D&C) industry and increasingly is becoming the chosen process across Europe and the wider world for the planning, D&C of buildings and infrastructure projects. Many D&C professionals have already gone through the paradigm change required to adopt and implement BIM. However BIM has not yet had a significant impact on the FM industry. This is creating a growing knowledge gap about BIM between the D&C and FM industries. The BIM workflow process when managed properly should start with a clear specification of the client's asset operation and maintenance (O&M) information needs in the EIR. At present, this is not happening, as many clients and FMs do not yet have adequate knowledge and experience to fully engage in the BIM process. If this problem is not addressed many potential benefits of BIM may not be fully realised.

2. Literature review

There is growing recognition that BIM can deliver significant economic, social and environmental benefits in the creation, O&M of assets and buildings, especially when value is considered over the whole life cycle. The UK Government for example recognised the added value BIM can deliver in its 2011 Construction Strategy as an aid to ensuring "the country gets the social and economic infrastructure it needs for the long-term" (Cabinet Office, 2011). With respect to ROI and who benefits most in the BIM process; the *SmartMarket Report* (McGraw Hill Construction, 2014) reports "three quarters of all contractors' surveyed report a positive ROI on their investment in BIM". However the key beneficiaries of BIM are ultimately clients and end users (Eastman, et al., 2011). Other research looking at ranking stakeholder financial benefits in relation to BIM has indicated that clients benefit most financially from BIM followed by FM (Eadie, et al., 2013). This is because BIM models and their associated information can be used throughout the whole lifecycle of buildings, infrastructure and assets (BSi, 2013). This is critical to understanding the most significant savings and benefits can be realised over the longer operational use phase.

In relation to whole life costing, research shows up to 80% of the O&M cost of an asset can be influenced in the first 20% of the design process (ISO, 2008). FM operational expertise and input is thus critical in the early stages of design to avoid expensive decisions which can have long lasting implications (Ashworth, 2013). Other research shows that FM and the O&M of a building equates to 60% of the overall costs of a project (Akcamete, et al., 2011). They suggest significant financial gains can be achieved by specifically targeting this aspect of a project. Clients, in particular, can achieve worthy benefits on their construction projects by adopting BIM technologies and workflows to guide their delivery process to higher quality and performance for a whole building life cycle (Eastman, et al., 2011). Research also shows 39% of contractors assign greatest value in projects to adding O&M data to models for the owner (McGraw Hill Construction, 2014). However, research shows that BIM adoption in the O&M phase is currently less than 10% and potentially significant unrealised benefits could be achieved if more focus was given to the impact of BIM in the O&M phase (Eadie, et al., 2013).

To help stakeholders the UK government has put in place a framework of BIM standards and guidelines for the BIM process. PAS 1192-2 (BSi, 2013) states the start of the BIM process should be a "clear understanding of the client`s OIR and AIR" and that one of the "fundamental principles of level 2 information modelling is the provision of a clear EIR". It defines the EIR as a "pre-tender document setting out the information to be delivered, and the standards and processes to be adopted by the supplier as part of the project delivery process" and that the "EIR should be incorporated into tender documentation to enable suppliers to produce an initial BIM Execution Plan (BEP)". The Government has provided an EIR template for stakeholders (BIM Task Group, 2015), however the author believes that a more client focused template is required.

PAS 1192-3 (BSi, 2014) describes the ultimate purpose of the BIM process is to "provide information into the client Asset Information Model (AIM)" which should be "the single source of approved and validated information related to the asset(s)". BIM can provide a fully populated asset data set for CAFM systems and therefore reduce the time needed to obtain and populate asset information. This enables FMs to achieve optimum performance more quickly, reduce running costs, and refine target outcomes (BIM Task Group, 2015). The data should include: "data and geometry describing the asset(s) and the spaces and items associated with it, data about the performance of the asset(s), supporting information about the asset(s) such as specifications, operation and maintenance manuals, and health and safety information". However clients/FMs are the only stakeholders that ultimately understand the client needs, and can specify these for the EIR at the start of the BIM process. BS8536 (BSi, 2015) aims to help, promoting "the early involvement of the operations team or FMs and by extending the commitment of the D&C team to post-handover asset aftercare to ensure its correct, safe, secure and efficient operation in line with environmental, social, security and economic performance targets". Thus to ensure the BIM process works fully, the client/FM have to be included early.

With respect to FM knowledge and awareness of BIM; surveys such as the BIM4FM survey (A working group of BIM Task Group) have tried to understand the perception of BIM by FM, end users and clients. The survey found that "although people are aware of BIM there is still a significant audience that is unsure of how BIM is used within the built environment" (BIM4FM, 2013). 63.2% of respondents were "unsure of whether their organisations plan to use BIM in the future". The NBS National BIM Report 2015 (NBS, 2015) also provides some useful insights from the construction industry perspective on BIM: 50% said they were currently using BIM and 95% of respondents believe "they will be using BIM within 5 years". However 67% also reported that "the industry is not clear on what BIM is yet". Other research work has shown that many D&C professionals (93.6%) agree with the UK Government's BIM strategy decision to mandate level 2 BIM on all public sector projects by 2016 (Eadie, et al., 2015).

3. Methodology

A mixed method approach was used; 1) a literature review to identify issues and to design the online survey form, 2) A survey conducted through two Swiss FM associations with the aim of understanding and establishing a benchmark of the understanding and adoption of BIM and how it will impact on the FM industry (399 people accessed and 68 completed the survey), 3) A focus group workshop titled "*FM and BIM in Research and Practice*" using results from the questionnaire to select topics for discussion. Three separate focus topics were discussed with the aim of establishing the information needs/outputs to inform the creation of a more FM client-orientated EIR. Topics were: (a) *FM operational:* information needed for space management? (b) *FM financial*: information needed for decision making? and (c) *FM personnel*: training/skills needed to be able to engage with the BIM process? A final focus group with all attendees then discussed, reflected and summarised the individual group findings.

Twenty participants engaged in the focus groups with stakeholders across the whole life cycle. International representation came from; UK, Switzerland, Germany, Denmark, Norway, Netherlands and the US. Participants were from professional bodies; IFMA, the Danish FM Network (DFM), the Norwegian FM (NBEF) and the British Institute of Facility Management (BIFM) Soft Landings team. FM and D&C practitioners attended from; BAM UK, BAM Deutschland AG, Mace Macro, ISS, Halter AG, eneco, Robertson FM, FES FM, Auwiesen Immobilien AG, UniversitätsSpital Zürich and Glasgow Life. Academics attended from; Zurich University of Applied Sciences (ZHAW) and the Netherlands Hanze University, Groningen.

4. Survey findings

There were 68 fully completed online questionnaires, a response rate of 17.04% from the 399 people who opened the survey. The respondents included stakeholders over the whole life cycle of a building: 18 planning consultants, 15 internal FM providers, 14 building owners/agents, 9 external FM providers, 3 CAFM[1] suppliers, 2 architects, 2 investors/clients, one building contractor, one procurement manager, one data manager, one surveyor and one government administration officer. The profile of company size by no of employees is shown in Figure 1. The majority, 38.2% of respondents were from companies with 1000+ employees.

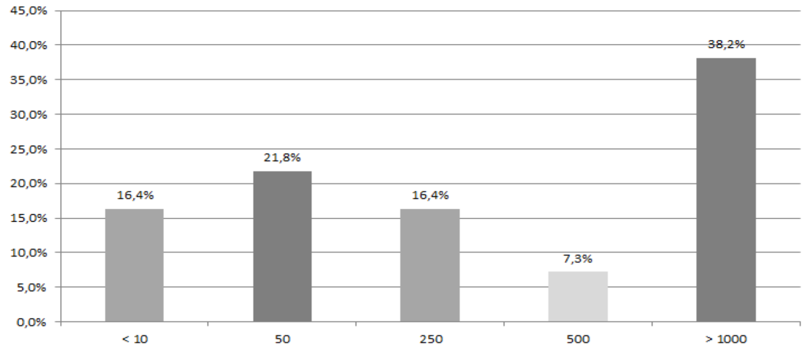

Figure 1: Size of company by number of employees

Respondents :down of the type and size is shown in Table 1.

Table 1: Type and size of real estate managed by the respondents

Type of space	**Total m2 (Gross)**	**Average m2 (Gross)**
Office / administration	7,707,293	296,434
Laboratories / industry	2,395,407	140,906

[1] CAFM: Computer Aided Facility Management

Residential / flats	2,008,700	223,189
Retail	1,818,500	363,700
Public offices and buildings	1,805,025	361,005
Other	1,759,500	351,900
Hospital / care home	1,730,000	173,000

They were asked about general knowledge/experience of BIM and how they perceive BIM will impact on the FM industry. With respect to experience: 41.2% had no experience with BIM, 33.8% had some, and 25% gave no answer. The majority of respondents (55.4%) as shown in Figure 2 believe BIM will have a significant impact on the FM industry within 5 years.

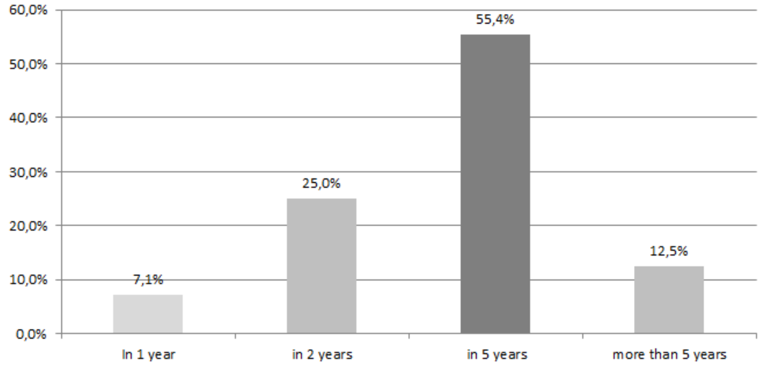

Figure 2: Timescale for BIM to impact on the FM industry

The respondents were then asked about their perception and understanding of BIM with a series of questions (previously used in the NBS survey). Table 2 shows their responses. A Linkert scale was applied and the mean score calculated using the numerical values (1=disagree, 2=somewhat disagree, 3=somewhat agree and 4=agree). The table scores were ranked according to the mean score.

Table 2: Perception and understanding of BIM

Question/statement	**Agree %**	**Somewhat agree %**	**Somewhat disagree %**	**Disagree %**	**Mean score**
The FM industry is not sure what BIM actually is (n=54)	33.3	57.4	7.4	1.9	3.22
BIM is all about real time collaboration (n=53)	26.4	41.5	17.0	15.1	2.79
BIM is all about software (n=54)	3.7	13.0	53.7	29.6	1.91
BIM is for new buildings not existing buildings (n=55)	3.6	14.5	27.3	54.6	1.67
BIM is simply a synonym for 3D CAD drawings (n=55)	0	7.3	16.4	76.3	1.31

Respondents were asked about their familiarity and knowledge of the Governments BIM guidelines and standards as well as the Swiss BIM guideline "SIA Merkblatt 2051 BIM" which is currently in development. The answers are shown in Table 3:

Table 3: Knowledge and familiarity with BIM guidelines and standards

Guides and Standards	**%**
Swiss guideline SIA Merkblatt 2051 BIM (In development)	25.0

ISO 15686 Building and constructed assets – Life cycle costing	13.2
Other: (See below for details)	7.4
PAS 1192-2: 2013: Capital/delivery phase of construction projects using BIM	7.4
BS 1192-4: Fulfilling employers information exchange using COBie: code of practice	5.8
PAS 1192-3: 2014: Operational phase of assets using BIM	4.4
ISO 55000: 2014 Asset management	4.4
CIC BIM Standard Protocol for use in projects using Building Information Models	2.9
CIC Guide for Professional Indemnity Insurance when using BIM	2.9
CIC Outline Scope of Services for the Role of Information Management	0

Other guidelines and standards the respondents were familiar with were; the Swiss “KBOB Guideline for Building Documentation in Buildings”, the “Penn State BIM Planning Guide for Facility Owners”, the “NATSPEC” document suite and the German “Research Initiative ZukunftBAU”. Respondents were also aware of various online forums promoting BIM best practice such as the UK BIM Task Group, BuildingSMART, COBIM from Finland etc.

Respondent’s perceptions of the potential benefits of BIM to FM are shown in Table 4. A Linkert scale was applied and the mean score calculated using the numerical values (1=disagree, 2=somewhat disagree, 3=somewhat agree and 4=agree). The table scores were ranked according to the mean score.

Table 4: Potential benefits of BIM to FM

Potential benefits of BIM to FM	**Agree %**	**Somewhat agree %**	**Somewhat disagree %**	**Disagree %**	**Mean score**
Direct data transfer to FM CAFM/other systems (n=50)	50.0	44.0	2.0	4.0	3.72
Simulations e.g. energy use, fire evacuation etc. (n=51)	47.1	37.3	15.6	0	3.61
Improved transition construction to operation (n=55)	56.4	30.9	7.3	5.4	3.58
Visualisation of buildings for customers/investors (n=55)	49.1	40.0	9.1	1.8	3.56
The use of BIM may improve profitability (n=42)	26.2	50.0	19.0	4.8	3.55
Faster cost and life cycle cost estimation capability (n=51)	41.1	39.3	15.7	3.9	3.47
Improved space management (n=53)	41.5	37.7	18.9	1.9	3.43
Improved asset maintenance response times (n=52)	36.5	44.2	11.6	7.7	3.37
Reducing the cost of insurance for buildings (n=40)	7.5	25%	52.5	15.0	2.90
Improved health & safety for operational FM tasks (n=47)	10.6	29.8	42.6	17.0	2.74

Respondents were asked how they thought FMs could make best use of BIM to help FM. The results were ranked based on frequency of mentioning and are shown in Table 5. Respondents also identified other potential uses as: exact planning during construction, quantity surveying, data-imports for CAFM tools, business continuity and service and maintenance optimisation.

Table 5: Ranking of possible uses of BIM by facility managers

Possible uses of BIM by FMs	**% Response**

Life cycle costing	28.85
Cost savings	26.92
Increasing operational efficiency	26.28
Reduction of carbon emissions and energy savings	12.82
Other	3.21
I don’t know how facility management will use BIM	1.92

The respondents concerns with respect to the adoption and implementation of BIM were ranked based on frequency of mentioning as shown in Table 6. Other concerns identified were: legal liabilities, early FM involvement, uncertain ROI, stakeholder buy in, familiarisation with BIM, data management and the danger of BIM creating a “data cemetery”.

Table 6: Concerns regarding BIM and FM

Concerns regarding BIM	**% Response**
The cost of implementation (time and resources)	19.61
Data management	19.61
Availability and knowledge about BIM guidelines and specifications	15.03
Basic BIM knowledge/training and its benefit to our operation	14.38
The incorporation of BIM into contracts and legal concerns	12.42
Unfamiliar technology and integration with CAFM tools	10.46
Other	8.50

Respondents were asked about their perception of possible barriers to the adoption and implementation of BIM. Their responses were ranked based on frequency of mentioning and are shown in Table 7. Other possible barriers included: fear of change, people wanting to stick to traditional work practices, if we can really achieve collaborative working, needing to change existing fee systems, lack of BIM standards, ROI on BIM, lack of coordination regarding implementation of BIM in the FM industry and ongoing management of BIM models and associated data in the operational phase.

Table 7: Possible barriers to the adoption and implementation of BIM

Possible barriers in the adoption and implementation of BM	**% Responses**
Lack of internal expertise	23.48
Costs	21.74
A lack of demand from clients	20.00
Other	18.26
BIM is not always relevant to our projects	9.57
The projects we work with are too small	6.96

5. Focus group findings

The findings of the three separate focus groups with respect to the selected FM topics are summarised in the subsequent three sections. These are followed by key issues raised during the whole group’s review of the findings and observations.

5.1 FM operational requirements for space management

Space reporting**:** FMs need information which allows the quick generation of tailored reports identifying all building and asset spaces by: name, type, size, volume, finishes and materials and where appropriate ownership. The space information should be delivered in a hierarchical manner with a unique and agreed "space naming system" specified by the customer. Space should be appropriately zoned to allow zoning for fire, security, rental and other purposes. Space flexibility information should be included for potential future change. The information should allow FMs to understand the quality level of the space and demands to be made on it. Ideally BIM models should link directly to CAFM tools to allow visualization of spaces and assets within the CAFM software. This will save on time in visiting spaces to address problems.

Space inventory and cost data**:** The information should include data/information on all assets within each space. Each asset should then have attached information detailing: asset/serial no, cost, life expectancy, warranty period, service costs, manufactures maintenance requirements etc. as well as who is responsible for each asset (in terms of purchase, replacement and servicing). This information should be available well ahead of building handover to allow transition planning and FMs to calculate detailed operational and replacement costs and the ability to benchmark costs and future performance, tenders and for managing projects.

Space concepts, logistics and use**:** FMs need to have a clear understanding of the design logistics planning concepts for the movement of people/equipment, access routes and space for changing pieces of plant and equipment at the point they need to be replaced. FMs need all relevant information for the planned use of buildings/assets/spaces at handover as well as how each space could be used in the future. This should include how easily spaces can be reconfigured to accommodate flexibility and change of use.

5.2 FM financial requirements

Asset and life cycle cost data**:** the BIM model should include all cost information for assets i.e. replacement and installation costs, life expectancy, service/maintenance costs etc. This will benefit FMs for both daily operational management as well as forward financial planning for asset replacement or refurbishment. This data should be available at the relevant data drops in the established design process (RIBA stages and COBie drops). Ideally this information should be migrated into the chosen CAFM tool by the construction contractor well before handover.

Commercial model data**:** It was acknowledged that there could be sensitivities around the issue of commercial information, but having full transparency of the builders procurement cost data will allow FMs to better understand and build their FM operational and asset replacement programmes faster and more accurately for clients.

Cost sensitivity and design efficiency**:** FMs should work closely with other stakeholders during the process as outlined in BS8536 from initial development of the EIR to identify information and concepts in the BIM process ensuring that site/building specific issues such as transport, logistics etc. are thought through from an FM operational perspective. This will help ensure cost accuracy, less change requests and provide regular feedback mechanism for more accurate sensitivity analysis with checks made as appropriate at every stage/phase.

5.3 FM personnel: training and skills requirements

***BIM training*:** The group reported most FMs have heard of BIM but have little or no practical experience. Members of the BIFM Soft Landings team reported that BIFM are currently working on guidance documents to help FMs develop an EIR and fully engage with the soft landings process. The FM staff should have training with respect to the BIM process and management of BIM models and associated data to ensure they can access, manage, amend and update data during the transition and operation phases. A key issue discussed was the need for FM to understand how the data will feed into CAFM / BEMS (BMS) and other FM systems. It was felt there was a risk that many of the potential benefits may not be realised due to poor training and a lack of understanding as to how the models can be used to FM advantage. If FMs are not able to interrogate BIM models there was concern about models being kept up to date.

***A FM handover training roadmap*:** should be a requirement in the EIR to ensure FM teams are fully involved with commissioning at the right time and receive appropriate pre-handover training. The group reported that adequate funding, resource and time for training are often lacking in projects and regularly squeezed into unrealistic timeframes at the last minute as D&C teams struggle to meet project deadlines. The FM team need to acquire BIM skills but also should have a different attitude and approach to embrace the possible benefits of using BIM models. The FM team should have adequate training and involvement during the design process whilst the models are being developed to allow them to give their clients feedback and suggested improvements as well as becoming familiar with the models and developing the skills to use them for visualisation and other uses.

***Post Occupancy Evaluations (POE)*:** FM staff should be included in the planning of POE for the Soft Landings process to ensure they understand how the BIM process and models will be used to help verify that the building is performing as per the design criteria and to understand any variations that may occur due to occupant behaviour or other factors.

5.4 Focus group discussion on the impact on the EIR

***Defining FM information needs/outputs*:** the whole group agreed it was difficult to tie down the required information needs/outputs and when they would be needed in the BIM process.

Guidance and templates: the whole group felt it would be beneficial to have specific guidance and templates to help clients/FMs draft and complete an FM/client-orientated EIR.

6. Discussion

With respect to research question (a) *How clients and FMs engagement with the BIM workflow process can be improved through the early contemplation of their requirements*?: the research confirmed a key issue impacting on both the D&C and FM industries is both are still not sure what BIM actually is. The research found that 57.45% of FMs and clients (somewhat) agree with this. This broadly aligns with the BIM4FM survey reporting that 63.2% of FMs were uncertain if their organisations had plans to use BIM. The 2015 NBS survey shows the D&C figure even higher at 67%. The research focus group feedback highlighted “most FMS have little or no practical experience of BIM”. This was backed up in the survey which indicated 41.2% have little or no practical experience of BIM. Other research from the D&C industry reports less than 4.05% use of BIM for FM operations with 54.05% never using it for FM (Eadie, et al., 2015). This is not surprising when we consider these figures together with the fact that most FMs have not yet had any significantly exposure to BIM projects and although many FMs have heard of the raft of Government BIM standards and guidelines, many have a poor understanding of the detailed content. This aligns with the focus group feedback that “as a community FM is on a sharp learning curve with respect to understanding how the BIM will impact on their FM operations”.

The NBS 2015 survey reports a general increase in D&C knowledge and adoption of BIM with 75% of respondents aware of the UK Government defined levels of BIM and 59% claiming to be already achieving level 2. Other research found this figure to be 53% (Eadie, et al., 2015). Not surprisingly the RIBA Plan of Work (RIBA, 2013) was noted as the most common BIM standard/publication used by D&C organisations. PAS1192-2 (BSi, 2013) is also well known. Other research (Eadie, et al., 2015) found the most common standard was BS 1192-7. However with respect to the support of FM in the operational phase the NBS figures did not look so good. Only 12% in the D&C industry have passed on “the model to those responsible for continued management of the building”. Also the use of COBie (which is essential for capturing data for FM CAFM systems) decreased slightly on the previous year with less than 1 in 5 respondents using COBie. The top 4 barriers to using BIM were (74%) lack of in-house expertise, (67%) lack of training, (63%) no client demand and (56%) cost. However “contrary to what the literature about the potential of BIM for FM, current state suggests it is rarely used with a very low figure (4.05%) (Eadie, et al., 2015). This all indicates FMs and clients need to educate themselves about the BIM process and understand how BIM standards and guidelines can be used to their own advantage in generating FM/client-orientated BIM strategies and EIRs.

With respect to research question (b) *what are the perceptions about BIM and its potential impact on the FM industry from an FM, user and client perspective?:* the time scale of 5 years seems to be a common figure. The research showed 55.4% of FMs feel BIM will have a significant impact on FM industry within 5 years. According to NBS, 95% of the D&C industry believe they will be using BIM on projects in 5 years. The figure of 5 years also ties in with other research indicating that “although BIM usage will have increased by 2016 it will not have reached the 100% level 2 stipulated by the Government” (Eadie, et al., 2015). With respect to the general perception and understanding of BIM, the focus groups and survey highlight that although a detailed knowledge of BIM guidelines and standards is lacking most FMs were general informed about BIM basics with (41.5%) somewhat agreeing BIM is about real time collaboration. Regarding software; (53.7%) somewhat disagreed that BIM is all about software and the majority of FMs agreed BIM is not only applicable to new buildings (54.6%) and also the majority (73.6%) believe BIM is not simply a synonym for 3D CAD drawings.

Concerning the main uses of BIM by FMs the research broadly aligns with the previous BIM4FM survey findings. Life cycle management was ranked top in both research surveys. Making cost savings was ranked 2nd in the research (3rd in BIM4FM survey) and increasing operational efficiency was 3rd in the research (2nd in the BIM4FM survey). Carbon reductions were in 4th place in both surveys. Regarding the key concerns there was some alignment with the cost of implementation ranking number 1 in both surveys. However the BIM4FM survey ranked integration with current technology and CAFM as 2nd whilst this was 6th in the research survey. Training and knowledge concerns were ranked 3rd in the BIM4FM survey and 4th in the research. Data management was ranked 2nd in the research and 3rd in the BIM4FM survey.

With respect to research question (c) *what data/information is required by FMs from the BIM workflow process to maximum optimisation of assets in the operation phase;* this was more difficult to address. A few FMs were aware of the Government EIR templates but most did not have a detailed understanding. Those that did commented that the templates are not FM/client-orientated. The individual and whole group feedback demonstrated how difficult it was to identify specific FM information/outputs in a clear way that would allow succinct wording for an EIR document. It was felt further research work is required in this area and it was hoped the development of new templates for BIM strategies and EIR documents by BIFM and Government bodies will help FMs in creating "client-orientated" EIR documents.

7. Conclusions

The research indicates that although BIM is rapidly becoming the norm in the D&C industry, the majority of FMs and clients do not yet have a thorough knowledge of the available BIM guidelines, standards and workflow processes and few have any practical experience of BIM. There is a need to further educate the FM industry to address the potential growing knowledge gap between the D&C and FM industries. To help achieve this further research should investigate the development of FM/client-focused BIM strategies and EIRs. FMs should engage early in the D&C process, and assume ownership of the EIR on behalf of their clients to ensure client and FM information needs are adequately addressed. This will help ensure the right information is delivered and structured in the right way to use in existing FM CAFM systems. There is a real danger that if these issues are not addressed many of the potential benefits of BIM may remain unrealised in the operational phase, especially if information from the BIM process ends up in a data cemetery due to a lack of BIM knowledge and skills in the FM industry.

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New Value Chains to Construction

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Abstract

Value chain analyses are utilized to study the value process production of companies. For the construction industry, several change agents are affecting the value chains in usage. To address this development, this article reviews what is considered to be the state of art in additive manufacturing methods and 3D measuring technology. Consequently, a new value chain is proposed for construction employing these technologies which is then compared to the current value chain in the construction industry. These emerging technologies may radically alter the construction industry and the way in which consumers procure construction services. Accordingly, disruptive technologies, digitalization, and servitization will likely have a profound impact on the business models and value networks in construction.

Keywords: value chain, additive manufacturing, 3D measuring, augmented reality, digitalization

1. Introduction

A value chain is a model of the corporate value forming process, first introduced by Professor Michael Porter (1985) in his book, “Competitive Advantage: Creating and Sustaining Superior Performance”. For the last 30 years, it has been applied to understand and analyze industries and has proven a useful mechanism for portraying the chained linkage of activities that exist within traditional industries, particularly that of manufacturing. It has also to a great extent framed modern thinking about value and value creation.

Accordingly, value chain analysis is a process whereby a firm identifies the primary and support activities that add value to its final product and then analyzes these activities to reduce costs or increase differentiation. The value chain represents the internal activities in which a firm engages when transforming inputs into outputs. In this chain, each step of the production process is identified and described for an individual product starting from its source materials, and each of these nodes in the value chain causes an incremental increase in the overall value. These nodes can be physical production steps, such as weaving cotton, or they can be intangible steps, such as associating the product with a brand. Until the 1990s, a central component in value creation for a company was the generation of economic benefit for its shareholders. However, during the previous two decades, the production of customer value has now become the core aspect in value creation. This has been coupled with the application of methods from design and the social sciences to branding and service development activities. This shift in focus has in turn led to the multidisciplinary study of intangible value creation wherein value is understood to be produced by all actions of a company, and formed on individual, social, and societal levels (Tikka & Gävert, 2014).

The concept of a value chain has assumed a dominant position in the strategic analysis of industries. However, the model is underpinned by a certain value-creating logic, and its application results in accordant strategic postures. As products and services have now become ever more dematerialized and the value is ever more created in networks and alliances, the value chain concept can no longer properly uncover all sources of value. As such, the focus of value creation and analyses has now shifted to value networks, meaning that value is co-created by a combination of players in the network. Adopting a network approach, organizations focus not on the company or the industry, but rather on the value-creating system itself. In contrast to the value chain logic, these functions are performed simultaneously rather than sequentially, and mutual adjustments are required with respect to network scope, capacity, and the technical properties of the concurrent services. The value network is a business analysis perspective that describes the social and technical resources within and between businesses. The nodes in a value network represent people (or roles). The nodes are connected by interactions that represent tangible and intangible deliverables. These deliverables take the form of knowledge or other intangibles and/or financial value. These value networks thus exhibit interdependence and account for the overall worth of products and services (Peppard & Rylander 2006; Allee 2000 & 2008; Santoni & Taglioni, 2015).

Beyond the value network approach, Porter has further expanded his value views to include shared value which means that value creation exists not only for companies and customers but to the larger society. He suggests that companies often remain trapped in an outdated, narrow approach to value creation. Focused on optimizing short-term financial performance, they overlook the greatest unmet needs in the market as well as the broader influences on their long-term success. Companies too often ignore the depletion of natural resources vital to their businesses, the viability of suppliers, and the economic distress of the communities in which they produce and sell (Porter & Kramer, 2011).

The construction industry has also faced challenges. Originally focused on industrial logistics, construction companies are transforming into service businesses. Following this transformation, a construction company becomes primarily a service provider from the point of view of its clients. Thus, the era of technical specifications and minimization of costs is rapidly coming to an end.

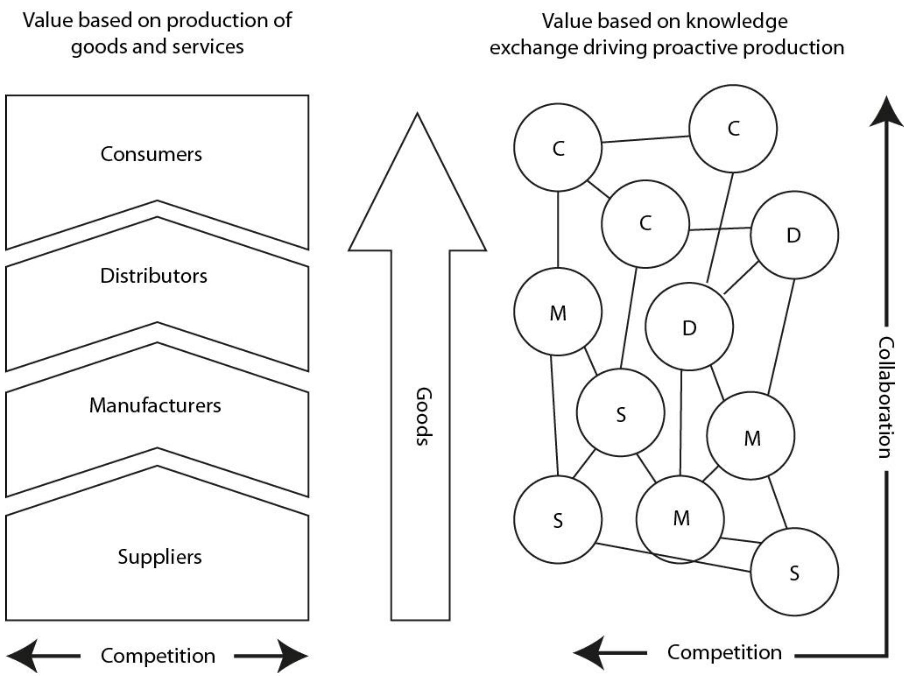

Figure 1: Difference between the value chain and the value network approaches (adapted from Kelly & Marchese, 2015)

Several possibilities exist for improving customer value creation in construction businesses. In addition to advances in brand definition and customer interaction, these possibilities are driven by technological development. The digitalization in general is changing value chains, with large online operators changing businesses. Some specific technologies that may affect construction are also emerging. Additive manufacturing, or as it is sometimes called, 3D printing, is changing the manufacturing industry. The development of construction applications is a topic of much interest. Secondly, the consumerized AR and VR technologies are attracting interest for developing applications also in construction. In addition, the applications of 3D technologies are being enabled by the 3D measuring equipment and UAV´s also being increasingly available for consumers. Together, these technologies may profoundly change the construction industry. In this article, we review these technologies, and present a scenario for future construction, utilizing them. We compare this scenario to the current dominant value chain in construction. Finally, the factors that may prevent the change in the industry are discussed.

2. Current value chain in construction

In order to map the current value chain, it is worth assessing the supply chain in the construction industry, as presented by Vrijhoef and Koskela (2000). Based on their observations of a typical construction supply chain (Figure 2), it is possible to map the corresponding value chain for the same parties (Figure 3).

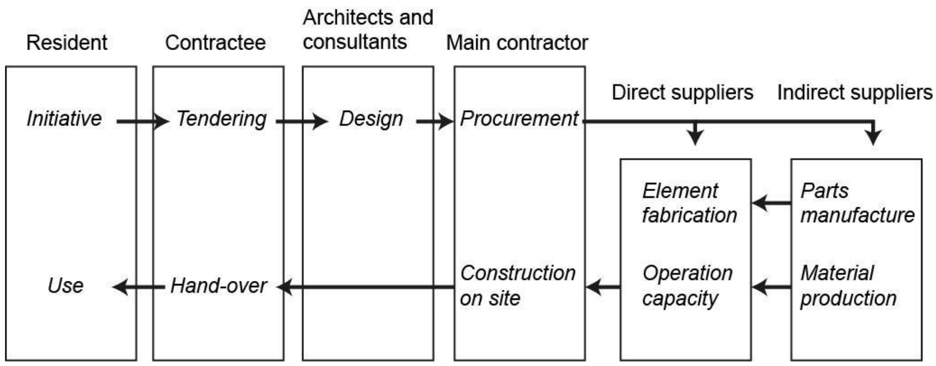

Figure 2: Typical construction supply chain (adapted from Vrijhoef and Koskela, 2000)

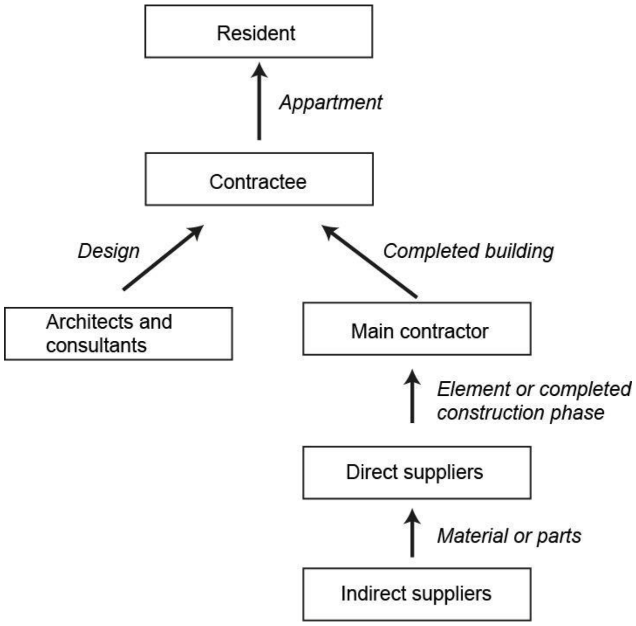

Figure 3: Construction value chain, with the product sold in each step shown in italics.

3. Change agents

3.1 Additive manufacturing technologies

Additive manufacturing (AM) techniques were originally developed as prototyping methods for product development in the manufacturing industry; one particular application being the prototyping of injection molded plastic components. Later on, they have become widely known as 3D printing methods and have spread to several new application areas with the emergence of affordable machinery. At the same time, the technology of 3D printing has advanced while the selection of 'printable' materials has grown (Schubert et al., 2013). In an editorial for the Rapid Prototyping Journal, Campbell, Bourell, and Gibson (2012) summarize the four benefits that are pursued with the adoption of AM technology: customization, improved functionality, reduction of total amount of parts, and aesthetics. As an example of improved functionality, they list a number of features from the aerospace industry that have been attained with AM: integrated mechanical functionality, reduction of required assembly features, and internal features of components (e.g. cooling ducts).

3D printing techniques have also been forecast to revolutionize the construction industry. Some research on this topic has already been conducted (Buswell et al., 2007), and some experimental projects have also been carried out (3DRS, 2015). For example, Lim et al. (2012) reviewed three different AM processes capable of achieving 3D printing with concrete-like materials. The authors estimated the potential advantages of these techniques for construction, and formulated a list of properties: increased freedom of design, reduction in mold costs, and integrated functionality of individual components (e.g. ducts). AM methods may, in future, enable the cost-efficient manufacturing of large, geometrically complex, unique components from materials applicable to construction (e.g. concrete). This could fundamentally change the way in which current buildings are designed using identical, geometrically relatively simple, concrete elements. Therefore, 3D printing technology is highly relevant for the construction industry as it is directly linked to logistics, customization, virtual models, and manufacturing.

3.2 3D measuring

One of the first consumerized 3D measuring methods was the utilization of depth cameras, such as Microsoft Kinect. Depth camera images can be turned into point clouds, and applied in 3D reconstruction (Izadi et al., 2011). Commercial devices intended for indoor measurement are already on market (Matterport, 2015). 3D scanning sensors based on depth camera technology have even been integrated into smart mobile devices (Google, 2015). However, typical issues when using depth cameras are the low measuring range as compared to laser scanning (Falie and Buzuloiu, 2008) and noise in the depth measurements resulting in a limited accuracy (Izadi et al., 2011).

Laser scanning technology has also developed quite rapidly. One of the key development directions is the miniaturization of measuring equipment, price reductions for sensors, and increased ease of use of the measuring instruments. For example, mobile laser scanning (MLS) has reached a point where the entire MLS system can be easily carried by a single person, or flown aboard an UAV (Kukko et al., 2012); currently, systems weighing only a few kilograms have been prototyped.

3D measuring can also be performed using photogrammetry. As computational capacity has increased, the automation of image analysis and 3D reconstruction has become possible. Image-based systems can even be built from quite affordable components (Straub et al., 2015). Applications of these algorithms from consumer camera data sets have also been presented. The process of 3D reconstruction from unordered sets of images consists of, firstly, an estimation of the camera orientations (e.g. Snavely et al., 2006) and, secondly, a dense 3D reconstruction from image pairs (e.g. Hirschmuller, 2008). To enable this, various algorithms exist for fast but dense stereo vision. They have been compared in different contexts, among others, by Sunyoto et al. (2004) and Ahmadabadian et al. (2013).

In addition, other sensor types can also be utilized. For instance, Rosser, Morley and Smith (2015) propose a solution where orientation sensors commonly found in current smart phones are used, together with the device camera acting as a sight, to obtain a coarse outline of a room footprint.

These footprints are then processed together with the house footprint (obtained from survey data) to produce a coarse 2.5D building model. Interestingly, although this solution was based entirely on consumer hardware and commonly available data, it was still able to reach an accuracy of some tens of centimeters.

3.3 Augmented reality

Another technological development with an approaching impact on the construction industry is the utilization of virtual reality (VR) and augmented reality (AR) in creating immersive visualizations of virtual environments. Several projects have already employed AR/VR technology in visualizing BIM models. In this fashion, AR technology will be employed both to visualize 3D models in their future installation site and to help guide the installation activities (Behzadar & Kamat, 2005). Consumer products enabling AR or VR have been released or announced by several companies during the last year, including Samsung Gear VR, Oculus Rift, Sony Morpheus, Google Cardboard, and HTC Vive.

3.4 Multi-sided platforms

The aforementioned value networks are becoming more and more dynamic due to the emergence of multi-sided platforms (MSPs) enabled by digitalization. These platforms typically connect two or more sides of the market via online services, benefiting from the network effects, i.e. the platform becomes more attractive the more it increases its users and complementary service providers. Different from supply chain platforms which feature, for example, mass customization, these platforms act as a foundation upon which external innovators can develop their own complementary products, technologies, or services (Gawer and Cusumano, 2014). Well-known examples of MSPs that have already disrupted traditional industries and their business models include among others, Uber for taxi services, AirBnB for accommodation services, Amazon for retailing, and Apple Pay for banking.

Such MSP operators thrive on data-driven customer intelligence and customer experience, enabled by faster innovation capabilities and greater profits than other industries in general. These ecosystem drivers provide a branded platform for a leading customer experience, offer seamless third-party products and services, and match customer needs with other service providers, extracting “rents” from the business transactions (Weill and Woerner, 2015).

These platforms also generate new end-user services difficult to envision beforehand, enabled by an open innovation ecosystem. Often the platform operators originate from outside the traditional industry players, bringing with them ecosystem business design and a complete customer understanding, thereby disrupting traditional production-oriented business models.

The tools empowering an individual consumer for interior design tasks are already emerging in the software market (Planner 5D, 2015), and it is arguably just a matter of time before these become integrated into the actual purchasing and manufacturing activities.

4. Scenario: future design and construction process

It is possible to combine the techniques of 3D measuring, such as terrestrial laser scanning (TLS) and 3D printing. In so doing, replicas of real world objects can be produced (Virtanen et al., 2014). The combination of 3D printing and 3D measuring opens up significant possibilities for mass customization in the construction industry. By utilizing the 3D measuring tools available in a smart phone, an individual consumer can produce a 3D data set of his or her apartment. The measured data can be further processed, automatically or semi-automatically to produce a 3D model of the measured space. Afterwards, the 3D model can be applied to design components. For example, a space divider can be planned using pre-made parametric models that are then semi-automatically adapted to each individual space, using the 3D model as a reference for measurements. This design process can be achieved by the consumer in an online service. The designed components could thus utilize the possibilities offered by AM. They can include the necessary mounting features, and their internal structure can be optimized to reduce material consumption and maximize strength. The components can then be manufactured using numerically controlled (NC) machines, such as 3D printers. After delivery, the parts would then be assembled on site. As the components are made to measure, the installation time is minimized. This process is illustrated in Figure 4.

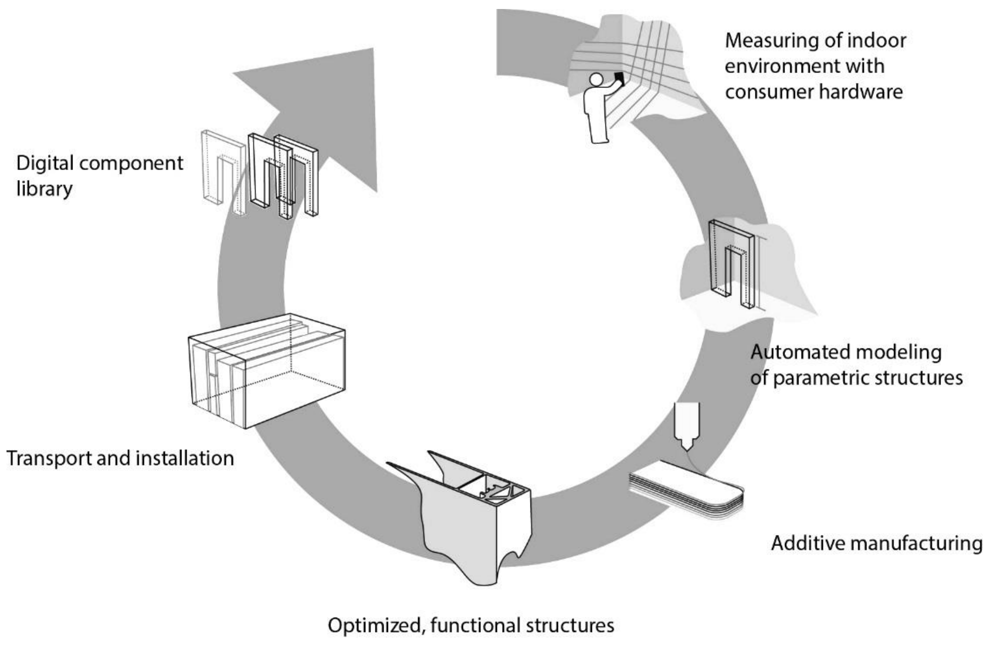

Figure 4: The future design and construction process

5. Discussion

The current value chain in construction is based on suppliers who manufacture individual parts from a single material (e.g. tiles, sheets, and beams) which are then used in manufacturing (e.g. furniture), or modified and installed on site (e.g. construction materials). As the manufacturing of these parts is a traditional industrial process, they are geometrically simple, and there can be a considerable number of these manufacturers. Furthermore, for more complex entities, such as furniture elements, there are direct suppliers (who manufacture furniture) and indirect suppliers (who manufacture materials). In contrast to this, additive manufacturing enables the production of varying, geometrically complex components. As the manufacturing process is tool free, unlike casting methods for example, and is not based on manufacturing the object by removing material from a starting piece as with milling for example, the geometrical variation of parts or complicated geometry does not increase production costs. Therefore, components of varying shapes can be manufactured by the same manufacturer, without using a large amount of pre-made parts. In the most minimalist of situations, the only indirect supplier would be the producer of the printing material. Thus, from a myriad of manufacturers producing geometrically simple objects in longer value chains, manufacturing shifts to a small number of key manufacturers producing complicated objects in a short value chain.

From an economic standpoint, the industry is moving from an incremental increase in value in small steps (manufacturing materials and parts, manufacturing components, and construction on site) to a rapid increase in value in one jump (AM manufacturing of components). The operator controlling the AM manufacturing step has subsequently more control in terms of scheduling and price determination. The amount of excess inventory, logistics, and warehousing are greatly reduced, freeing resources in the process. For the consumer and designer, this shift also increases the amount of customizability. In turn, fewer compromises must be made to adapt the final design to the limited offerings of manufacturers and available components.

An analysis of future value chains in the construction industry is subject to large uncertainties. Making predictions based on technical developments alone is not sufficient, as the construction industry is also affected by other factors, such as regulations that may also change. In addition, the large commercial operators in the field have an influence over the entire system. Finally, it is unrealistic to assume that a single value chain could serve all situations encountered in the construction industry. The supply chain presented in Figure 3 is originally drafted for the development of new projects. Retrofitting a single apartment and construction of a new residential area are inherently projects of a different scale and a different producer-customer relationship. While technological developments will affect both small and large scale construction projects, the resulting value chain configuration may be quite different. Moreover, the value chain presented in this article is clearly more oriented towards renovation operations than the construction of new buildings, which was the focus of Vrijhoef and Koskela (2000).

Like any new process, change takes time, especially in an industry as fragmented as construction. There are several barriers for quick adaptation of the new technologies and radical changes in the value chain. According to Edie et al (2014) the greatest barriers for BIM adoption (in order of importance) are the following: lack of flexibility of organizations, lack of supply chain buy-in, lack of vision of benefits, cost of software, cost of training and lack of technical expertise. Organizations are clearly unsure about their own capabilities and those in their supply chain. Hail et al (2012) highlight the importance of coordination given to the complex nature of construction. They point out the following key barriers of coordination: the nature of construction vary and the same technological methods cannot be used universally, traditional contractual arrangement can prevent to be open for new methods, construction participants may not have a common view, and the approach of construction management may vary between partners. Construction players do not need only new technological tools but also new mental models and management approaches to coordinate their projects towards a more innovative and cost-efficient implementation. Bernstein and Pittman posit - as early as in 2004 – three interrelated barriers for BIM adoption that are still relevant: the need for well-defined transactional business process models, the requirement that digital design data be computable, and the need for well-developed practical strategies for the purposeful exchange of information (Bernstein & Pittman 2004).

6. Conclusions

Additive manufacturing techniques suited for construction are beginning to emerge as commercialized tools. Concurrently, three dimensional (3D) measuring can be performed with laser scanning, scanners utilizing the triangulation principle, or photogrammetry. As these technologies have developed, 3D measuring has become increasingly available to consumers. By studying the current state and development direction of the technology, it becomes more feasible and more likely to forecast the possible value chains of future construction and estimate their impact on the industry.

By combining sensor technology, 3D measuring, AR, VR and 3D printing, the entire chain from planning, measuring to manufacturing and delivery can be digitalized, covering the entire life cycle of the built environment. In future construction, the user should be able to measure the to-be-altered environment with a mobile device, thus producing a digital model to be used in planning. In the planning phase, a new installation, such as fixed furniture, can be assembled from a set of pre-designed modules and individually produced 3D printed components. In this situation, design, visualization, cost estimation, and logistics planning are performed with online systems. After the order is placed, the pieces are manufactured, delivered, and finally installed. Digitalization will push the business models towards data-driven, multi-sided platforms where value-added services and servitization will change the current constellations of value networks.

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Smart Water – Intelligent Integration of Information Systems of a Water Utility

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Abstract

The largest water utility in Finland, Helsinki Region Environmental Services Authority (HSY) has started a Smart Water development program. Among many other objectives, this program aims at adopting and extending (1) a standardized data model for water and sewerage networks and (2) a data integration system to enable various ICT systems of HSY – such as the Network Information System (NIS), Customer Information System (CIS), Supervisory Control and Data Acquisition System (SCADA) and Network Investment Management (NIM) – to better interact with each other and also with ICT systems of external partners.

The part of the Smart Water program described here is implemented in cooperation with other large Nordic water utilities and Nordic water utility associations. The plan is to adopt and further develop the network data models developed in Denmark and currently owned by the Danish Water and Wastewater Association (DANVA). The Danish concept of Digital Water Company – Det Digitale Vandselskab (DDV) – has been established by DANVA in order to lift the digitalization and standardization work for water and wastewater networks to a more advanced level, making sure that the ICT strategies, system integrations, data exchanges, workflows etc. are in harmony with the common business processes of the Danish water companies. The aim of this joint Nordic effort is to adopt and further develop the DDV data model into a common Nordic data model applying open data source code and open data model. The ownership, maintenance and intellectual property rights of the Nordic data model should be with public non-profit organizations. The future benefits will be huge for the participating Nordic water utilities, but also for external business actors co-operating with water utilities. For instance, the possibility to share standardized water network data with planning and design consultants, contractors and authorities directly in the digital format can take the water utility sector to the modern Building Information Model (BIM) environment compatible with other infrastructure sectors. This will also open new and innovative business opportunities for commercial ICT service providers. In addition to the participating utilities, such as HSY, the results of the project give other water utilities encouraging examples of innovative developments in knowledge management towards smarter and more intelligent water and sewerage services.

Keywords: *data integration, ICT system, open data model, open source code, smart water, water networks*

1. Introduction

Water supply and sewerage services are invaluable for functioning of the society. Water services and systems are data and information intensive. Vast majority of the water infrastructure is in water and sewerage networks which are buried underground. The huge amount of networks, long life-cycle and a large number of potential information points makes availability and management of data and information related both to physical condition and actual operations of the networks challenging. Sophisticated supervisory control and automation systems are already used to manage network operations better. However, in general the holistic utilization of data related to network operations is not yet very advanced and smart in most water utilities. A common problem is that there is not enough measured data of adequate quality, to facilitate e.g. proper hydraulic or qualitative situation analysis of the network. Electricity utilities in Nordic countries are much more advanced in applying ICT systems in network management than water utilities, but electricity utilities have in most cases applied larger "all-in-one" ICT systems instead of integrating several decentralized systems.

The aim of this paper is to introduce recent and ongoing developments of intelligent ICT-applications of Helsinki Region Environmental Services Authority (HSY) in water and wastewater network management. HSY has started an ambitious Smart Water development program, which covers several key areas of its operations. Among many other objectives, this project aims at adopting and further expanding to Finnish utilities (1) a standardized data model for water and sewerage networks (location and properties, condition, hydraulic and quality data) based on the Danish experiences, and (2) a data integration system to enable various ICT systems of HSY – such as the Network Information System (NIS), Customer Information System (CIS), Supervisory Control and Data Acquisition System (SCADA) and Network Investment Management (NIM) – to interact better with each other and also with ICT systems of external partners such as consultants, contractors and authorities. The aim of this project is also to show examples and encourage other Finnish water utilities to advance and improve their water related ICT systems towards more intelligent and holistic management systems. HSY is in the Finnish context a very large water utility compared to all other utilities. On one hand its novel and innovative approaches would be important in paving the way for future utility management practices for other utilities, but on the other hand this "size polarization" is challenging for functioning markets. However, due to their size HSY and other largest Nordic water utilities together can also have a positive impact on the market behaviour within the ICT systems supplier market.

2. HSY's Smart Water program

2.1 HSY and its water and wastewater systems and their management

Helsinki Region Environmental Services Authority (HSY) is the largest water and wastewater operator utility in Finland and one of the largest in Nordic countries. HSY produces water and sewerage services to about 1 million people in Espoo, Helsinki, Kauniainen and Vantaa cities.

HSY's water and sewerage section has about 430 employees and its annual turnover is about 230 million euros.

The length of HSY's water distribution network is about 3 000 kilometres and wastewater sewerage network about 2 800 kilometres. In addition there are storm-water sewers for about 2 200 kilometres. There are altogether 12 elevated water towers, 32 booster pumping stations, about 520 wastewater pumping stations and 52 storm-water pumping stations, 3 water treatment plants and 2 wastewater treatment plants. Total value of the water infrastructure assets is at least 1.6 billion euros.

HSY uses Network Information System (NIS) to manage information related to its water distribution and sewerage networks. There is one master system in use, which is complemented by several other GIS systems for specific uses. In addition to Network Information System, HSY uses a number of other ICT applications in its operations. These include for instance Supervisory Control and Data Acquisition System (SCADA), Customer Information System (CIS), Financial Information System (FIS), Business Intelligence Software (BIS) and several authority level ICT systems. Most of these applications are currently operated more or less as isolated applications with not much compatibility or integration between each other. Knowing the enormous amount of data and information collected and utilised in a large water utility, this situation is definitely seen as a challenge and inefficient utilisation of resources.

2.2 Overall scope of the Smart Water program

HSY's Smart Water program consists of several sub-projects, such as:

1) HSY's open piloting platform for business-based product development
2) Intelligent measuring devices in water and wastewater networks
3) New condition assessment technologies for water and wastewater networks
4) Integration of water services related and other ICT systems (e.g. Financial Information System)

Business companies are given the opportunity in the Smart Water program to pilot their innovations and products in real-life situations in HSY's water services systems, including physical network infrastructure and data related to systems. The first sub-project aims at creating principles and opportunities for implementing these pilot projects. Pilot installations will be done in co-operation between HSY and the participating companies. Results will be available for both HSY and the companies.

The second sub-project aims at developing intelligent measuring devices or probes to measure key parameters available in water and wastewater networks, focusing on pressure, flow and acoustic parameters related to leakages. Measured data is used e.g. to establish real-time situational view of the network operations, thus supporting decision-making especially in exceptional situations. Data also helps in understanding the complex operation of water distribution and sewerage systems and in improving customer service. Initial findings suggest utilisation of probes based on membrane technologies (MEMS).

The third sub-project aims at developing methodologies and technologies to assess structural condition of water distribution network and for CCTV inspections of sewerage pipes. Knowing the huge total length (about 5 000 km) of HSY's wastewater and storm-water sewerage networks, the aim of establishing a holistic view of the network based on measured data sets rather challenging requirements for the assessment methods. The focus will be on developing interpretation methods for sewer inspections, based e.g. on machine vision interpretation of CCTV or laser scanning material.

The fourth sub-project on integration of HSY's water services related ICT systems is the main topic of this paper and is discussed in more details in the following chapters.

2.3 Integration of HSY's water services related ICT systems

The main objective of this sub-project is to develop an efficient, generic data integration system in order to facilitate data transfer and two-ways interaction between the existing ICT applications. The ICT systems in use by the water services are among others:

- Water distribution control system, SCADA
- Remote operation and control system for wastewater pumping stations
- Systems for customer information, customer relations and communication
- Systems for network information and network investment management
- Hydraulic modelling applications (water, wastewater and storm-water networks)
- Regional spatial data information system
- Financial Information System (FIS), Business Intelligence System (BIS)

The leading idea of the sub-project is to utilise the abundant, high quality measured and validated data from the utility's various processes and to integrate the ICT systems through well-functioning data exchange and integration between systems. Thus, the central element is the data integration system. Each data item should have one data storage location in the master data system. Copying data items to other satellite ICT systems and possible further data refinement is done in the master system, but updating can be done in satellite systems.

Figure 1 illustrates the basic concept of the data integration system in the water utility's ICT application system. ICT systems (System 1-n) are used e.g. to control water and wastewater networks, to manage network or customer information, to hydraulic modelling, to manage investments, or to create situation view for managers. Data to any ICT system from another system will be exchanged using a centralised data integration system. Additional systems can be added easily ("plug-and-play"). The concept also has a service interface for external ICT systems used e.g. by consultants, contractors, administrative bodies, etc. These will be controlled through access code systems. The concept as such is based on the principle of open data model.

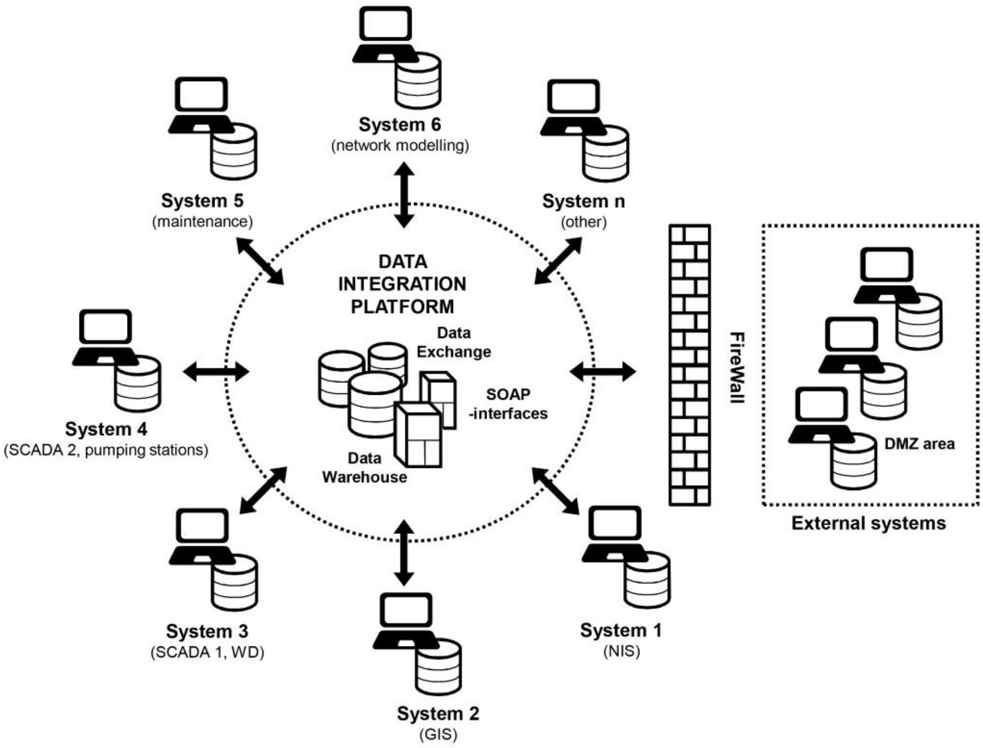

Figure 1: The principal idea of data integration system in HSY's water services related ICT architecture (Janhunen, 2015).

Benefits of integration of different ICT systems include:

- No need to manually transfer or feed data from one system to another, which reduces work, and errors and speeds up data management
- Makes it possible to choose for each purpose an ICT application which suits best from technological and functional point
- Makes it possible to develop applications flexibly and provides opportunities for software suppliers of different sizes. New (small) agile software suppliers can provide specific ICT programs for specific purposes.
- ICT programs can be renewed or procured flexibly by modules.
- Data can be updated to a master database from other applications.
- Data can be further refined during integration and transfer.
- Risks related to the use of only one software supplier ("vendor lock") can be minimised. Vendor lock easily increases total costs and makes product development too rigid.

3. Development of the network data models

HSY has started discussions and plans to adopt and further apply for its network management operations a data model developed in Denmark for the Danish water and wastewater sector. The

Danish Water and Wastewater Association (DANVA) has developed a concept called the Digital Water Company (in Danish Det Digitale Vandselskab, DDV). DDV as such was established in 2011 in order to lift the digitalisation and standardisation work in the Danish water industry to an advanced level, ensuring that e.g. ICT-strategies, system integration, data exchange, workflow etc. in in harmony with the common business processes in the Danish water companies (Asmussen, 2012). This is in line with the Danish government's strategy together with the local authorities for enhancement of digitalisation 2011-2015.

The Digital Water Company (DDV) is a co-operation project between Danish water companies and the Danish Water and Wastewater Association (DANVA). DDV focuses on guidelines and best practices for increased alignment between business processes and data. The four main tracks of DDV are: (1) digitalisation and change management, (2) standardisation in the water industry, (3) external standardisation and co-ordination, and (4) customer focus and customer trends. Standardisation within DDV includes e.g. terminology and data models, data quality, accessibility and reuse, interface descriptions and data exchange. In external standardisation e.g. the requirements coming from the INSPIRE directive are taken into account.

Already in 2004 DANVA developed a data model for registration of wastewater pipes called DANDAS, followed in 2005 by a data model for registration of water pipes (DANVAND). In 2008 a model was added for data model maintenance purposes (D&V). The principles of data models concur with Service Oriented Architecture (SOA) and are in line with the requirements of the INSPIRE directive. Figure 2 shows the linkage between different data models within DANVA's DDV concept.

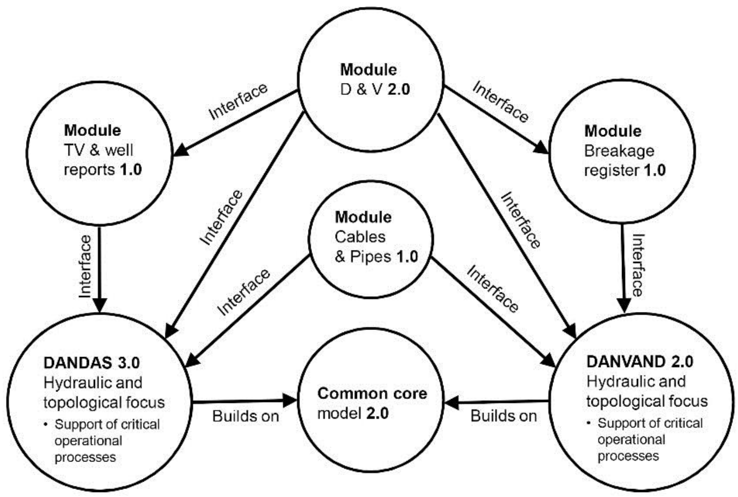

Figure 2: DANVA's data models and their interconnections (Gadegaard 2015).

Network data models (DANVAND and DANDAS) include a standardised description for water and wastewater networks and their components. Example of the structure of the data models is shown in Figure 3.

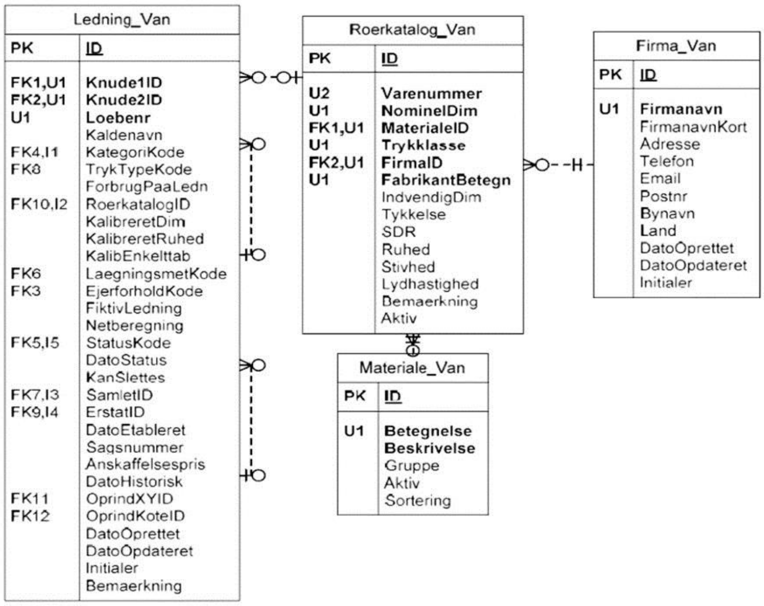

Figure 3: Example of a partial structure of DANVA's data model (Asmussen 2012).

In 2015 some of the largest water and wastewater utilities and national water and wastewater utility associations in Denmark, Sweden and Finland commenced negotiations and plans for adopting and applying the Danish DDV-concept also in Sweden and Finland. All the Nordic so-called “6-city water utilities” are involved in these negotiations.

One of the main reasons for HSY in applying the DDV-concept in Finland is the need to adopt a data integration system to enable compatible and integrated use of data and information in a standardised format between the various ICT-applications in use. The basic model needs to be extended for this purpose. Extending the Danish open data models to other Nordic countries also requires that in each country a competent and neutral body will be identified and engaged to administer and coordinate the use and maintenance of data models. Water utilities adopting data models in their operations should be prepared to finance the costs of administration and coordination.

There are several commercial data integration ICT-applications available on the market, for instance those developed by Oracle, Microsoft, Napcon and others (Seppälä 2015). There are, however, some concerns in HSY for using fully commercial data integration applications. Adoption and development of such fully commercial data integration software would lead to a continuous and deep market dependence from the software supplier. Another important point is that a non-commercial data integration system could easily be replicated to other water utilities in a much more affordable manner than a fully commercial system. Examples of non-commercial data integration systems include e.g. Mule, Geoserver, and PostGIS database. An ideal situation would be a combination of non-commercial and commercial systems for instance on a 50/50 basis. An illustration of a commercial generic data integration system is shown in Figure 4.

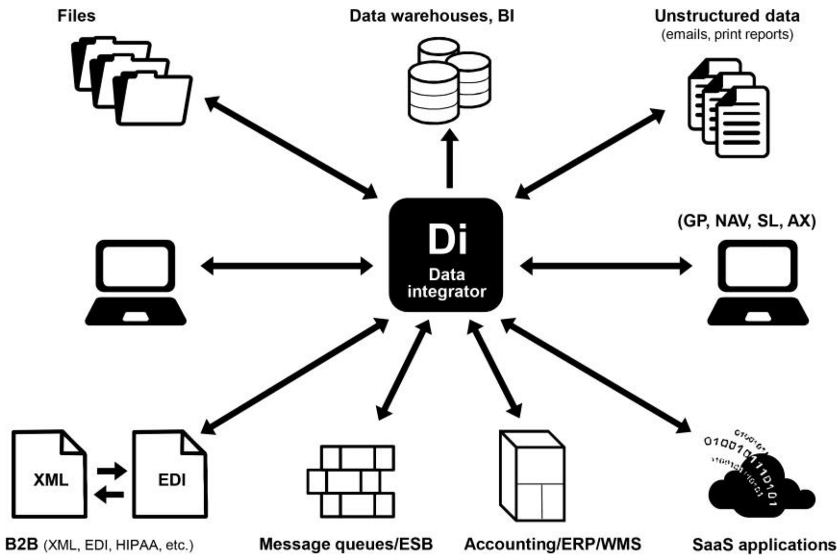

Figure 4: Schematic example of a commercial generic data integration system (Seppälä 2015).

HSY has good and practical reasons for its policy of finding a balance between non-commercial and commercial ICT systems. HSY has already fallen into a vendor lock situation regarding some of its ICT systems, which has caused excessive development and maintenance costs and inadequate interest from the supplier's side for further product development.

The trend towards open data systems and advanced data exchange between systems is in the long run a win-win situation for both system end-users and system suppliers. For end-users the main benefits are faster product development and improved quality when data is exchanged easier and without errors between data systems. ICT system suppliers need to review their revenue logic in future, because customers will increasingly shift from one-supplier closed systems more towards open data source and open data exchange systems. The new paradigm benefits more new and innovative system suppliers, but also traditional closed system suppliers may expand their business if they are agile enough to renew their business strategy.

4. Discussion and Conclusions

HSY as a large water and wastewater utility has a dire need to establish smart and well-coordinated system of collecting and utilising data from its operational and managerial data systems. As part of a larger Smart Water development program, HSY intends to improve its utilisation of high quality measured data from its water and sewerage systems through extensive and advanced ICT system development.

Instead of entering into a massive one-supplier system, HSY wishes to build its system on the existing decentralised ICT systems which are integrated through a data integration system. Moreover, the plan is to develop a non-commercial data integrator instead of using generic commercial data integrators. However, as a whole HSY intends to apply a balanced combination of non-commercial and commercial ICT systems for its operations. This will also ensure a healthier market situation and avoid the one-supplier vendor lock situation.

Adoption and local tailoring of data models developed in Denmark for the water industry has been identified in HSY as a priority solution to achieve functioning integration of ICT systems, being essential part of HSY's Smart Water project. HSY works in co-operation with the Nordic 6-city group water utilities to develop national applications of the Danish DDV model. Discussions between the Nordic water utilities and associations are ongoing, but the actual implementation of the Nordic expansion of the Danish DDV model has not yet been started. Besides the participating Nordic water utilities, there is need to organise administration and maintenance of locally tailored data models in each participating country.

HSY's aim is also to show examples and encourage other smaller Finnish water utilities to advance and improve their water related ICT systems towards more intelligent and holistic management systems. This is one reason why a non-commercial data model and data integration system has been chosen as the basis for development. This makes it easier for other Finnish and other Nordic water utilities to affordably start using the data models and integration system compared to fully commercial systems. Wider deployment of these non-commercial systems could also have a positive impact on the ICT supplier market in the Nordic countries.

In addition to HSY's internal benefits of integrating its own ICT systems, another key result is the possibility to share standardized water network data with planning and design consultants, contractors and authorities directly in the digital format can take the water utility sector to the modern Building Information Model (BIM) environment compatible with other infrastructure sectors. This will also open new and innovative business opportunities for commercial ICT service providers.

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Digitising UK Construction: Closing the Gap between UK Government Aspirations and Industry's Ability to Deliver

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Abstract

While the UK Government's 2016 BIM mandate could filter through construction supply chains and touch even the smallest organisations, respondents to recent surveys have questioned the ability of industry to upskill and respond to the challenges encapsulated in digitisation (Knutt, 2015). As Small and Medium Enterprises (SME) and micro-firms form the majority of UK construction organisations, the adoption of BIM by SMEs is a vitally important factor in delivering on aspirations to digitise the UK construction sector. Implementing innovation within SMEs is complex and a non-linear process, suffering from scarce resources, lack of skills and systematic measurements, which can result in implementation failure and frustration for SME managers. (McAdam et al., 2010) Based on literature review and data gathering from industry experience, this paper will scope out and identify key challenges faced by BIM 4SME in reaching out to a fragmented construction sector. Driven by strategic objectives, UK construction is faced with embedding digital working into whole life supply chain activities. Perceived barriers may include cultural issues, the embodiment of industry step change, engagement with disruptive technologies and the ability of SMEs/micro SMEs to embed innovation into status quo work practices and forward planning. (Christensen, 2000; Vanheverbeke, 2012). The purpose of the research is to develop an evidence based and representative perspective on where UK construction SME/micro SMEs sit as a key industry group in responding to UK Government's mandate for digitisation.

Keywords: BIM, SMEs/micro-SMEs, reach, knowledge transfer, assimilation

1. BIM 4SME; genesis and paradigms for change

According to Government figures, construction contributes almost £90 billion gross value (GVA) added to the UK economy representing almost 6.7% of total output and sustaining 280,000 companies. (Anon., 2008) It has been argued that the UK construction industry is highly fragmented, (Egan, 1998) (Pringle, 2012), both by international standards and in comparison with other domestic sectors. Over 90% of organisations in the built environment sector employ less than 10 workers, and almost 72,000 firms are one-person operations. Fewer than 130 construction organisations have a workforce of 600 or more. It has been noted that these large firms generate only around 25% of the industry's output by value. Supporting professional and technical services are similarly diverse. Even the largest UK construction company commands only a 3.5% share of the market; this would not even place it within the world's top 20 construction organisations.

During 2011, the UK Government's Construction Strategy was published. (Cabinet Office, 2011). The report announced the Government's intention to require collaborative 3D BIM (with all project and asset information, documentation and data being digital) on its centrally funded projects by 2016. In effect, UK Government embarked on a four year programme for sector modernisation with the key objectives of: reducing capital cost and the carbon burden from built environment construction/operation by 20%. Pivotal to realising these ambitions was the adoption of information rich Building Information Modelling (BIM) technologies and processes which it was perceived would unlock new more efficient ways of working for construction to facilitate realisation of strategic industry targets.

The BIM Task Group established a number of working groups (including the so called "BIM4s") to take its message to UK construction. BIM 4SME is a pan-discipline industry group with a specific remit to interact with the UK's SME and micro-SME construction communities. Membership draws from a range of professional and industry representative interests. Since 2012 BIM 4SME has developed its remit to:

- Raise awareness of BIM within the SME marketplace
- Ensure SMEs understand the requirements of Level 2 BIM relevant to their role in the supply chain
- Demonstrate the value proposition / business benefits to the SME: better efficiency, better information and better decision making
- Make sure the SMEs understand the risks of doing nothing with regards BIM implementation
- Help SMEs get ready for the Level 2 switch over: where they are and what next?
- Produce simple guidance around the BIM process in simple English and to match business needs

While realisation of UK Government objectives for digital working is predicated on wholescale buy-in by the construction sector, at November 2015, there were no reliable indicators in place to record industry's state of readiness to deliver on the 2016 BIM mandate. The authors would argue that without appropriate indicators, it is impossible to predict whether or not the Government's ambitions for digitisation of construction are deliverable.

To date, BIM 4SME has relied on volunteer effort to disseminate its messages framed around perceived benefits of adopting open and collaborative BIM. The group hosts a website specifically targeted towards SME/micro organisations and BIM 4SME's Linkedin page has stimulated online discussion and debate. (For example, in a recent post, the UK Government's 20% cost saving target has been challenged) In addition to the framing and application of BIM standards, protocols and the like, the authors would argue that upskilling of the construction sector needs to be informed by evidence based critique from stakeholders.

Since 2014, BIM 4SME has run a series of BIM clinics for practitioners, contractors, sub-contractors and suppliers. Although BIM 4SME could be described as a "push" organisation, its developing knowledge base relies primarily on interactions with SME practitioners and industry organisations. In that context, BIM 4SMEs mission could be interpreted as bridging between *evangelical* (UK Government protocols) and *evolutionary* (developmental industry models) approaches to BIM uptake (Kouider and Paterson, 2014).

2. Research Methodology

2.1 Research Aim and Objectives

The authors' hypothesis suggests that as we approach the end of 2015, UK Government's aspirations for the digitisation of the construction sector may not be matched by industry's ability to deliver. The aim of this research is to benchmark the state of readiness among SMEs/micro-SMEs in addressing UK Government's 2016 BIM mandate. Following a literature review, data gathering will take a representative slice through construction supply chain organisations to identify skill/knowledge gaps. The investigation will also attempt to determine how the challenges of BIM adoption by SMEs could best be addressed at strategic industry level to facilitate delivery on key targets such as cost saving and carbon reduction.

The objectives of the research are:

1. Review construction SME statistics from the literature and identify perceived challenges to engagement with BIM in the UK.
2. Scope out perceived barriers to BIM adoption within SMEs.
3. Identify key challenges for the BIM 4SME group in reaching out to a fragmented industry struggling to address the need to embed digital working into design, construction and supporting supply chain activities.
4. Make evidence based recommendations to strategic UK construction organisations on how challenges inhibiting the digitisation of construction could be overcome.
5. To enhance the capability of BIM4SME as an industry organisation in providing effective support to facilitate SME engagement with BIM.

2.2 Research Strategy

The phenomenon of this research is contemporary, socially constructed and may change over time. Thus, epistemologically subjective with presupposed interpretive approach of the social phenomena, focusing on the details of situation and the subjective meaning of the motivation of the social actors, aligned with the interpretivism and in opposition with positivism theoretical perspective of research (Saunders, 2012).

The research adopts a multimethod qualitative methodology, investigating in depth small samples to obtain rich and deep data to be analysed. Themes and patterns will be identified using an inductive approach ranging from the specific to the general. The objective is to create a conceptual framework for analysis through cross-sectional sampling of SME/micro built environment organisations.

The methods adopted are literature review, data gathering from case studies provided by BIM 4SME organisations, interviews of BIM4SME experts, and observations from BIM Clinics. BIM Clinics involve SME firms approaching industry experts to discuss company experiences and concerns with BIM; a significant opportunity to observe interactions between the BIM 4SME organisation and SME practitioners. Finally, in broadening the sample from BIM 4SME contacts, the research will capture data from interviews with SMEs practitioners to increase the scope of perceived barriers and key challenges with BIM adoption.

All data trawled from the research will be systematically reviewed using content analyses: describing, connecting and classifying data through the identification of patterns emerged from the data (Gray,2004).

3. Literature Review

3.1 SMEs in the UK Construction Industry

More than 90% of the UK construction sector comprises the small, medium sized and micro organisations (SMEs) described by the European Commission as the “engine room of the European economy” (EC, 2013). Small and Medium Enterprises (SME) is usually defined by companies with less than 250 employees. In addition, for capital allowance purposes in the UK, SMEs would have turnover of less than £22.8 million and a balance sheet of less than £11.4 million pounds (HMRC, 2011). In 2015, there were 5.4 million SMEs in the UK, accounting for 99% of the UK business and 48% of the country turnover {Rhodes, 2015, Business Statistics}. Moreover, SMEs can be divided into 3 groups:

- Micro companies – 0-9 employees
- Small Companies – 10-49 employees
- Medium Companies – 50-249 employees

The construction sector enterprises accounts for 18% of the UK all business, but only 8% of employment and 7% of turnover. The reason for that is the large amount of micro companies in construction, boost the overall number of companies, but not the number of employed in the construction sector (Rhodes, 2015).

Although the official construction statistics cannot offer exact figures for SME numbers and turnover, they do highlight the importance of SMEs to the UK construction industry. Due to the classification adopted in the Official Construction Statistics (2015), if considering firms within the range from 0-114 number of employees, (therefore excluding medium sized companies with 115-249 employees) SMEs represent 96% of all firms in the construction sector, accounting for 61% of total value of work in the UK construction. These figures would be likely to rise if medium sized enterprises in the range of 115-249 employees were included in the overall range.

3.2 SME BIM adoption

BIM awareness is growing in the UK, according to recent survey published at NBS National BIM Report (2015), 95% of respondents were aware of BIM, and 48% are currently using BIM in their organisations. That is a significant increase in the use of BIM from 2010, which was a small 13% of respondents using BIM, but it also demonstrate that despite evidence of awareness, the majority of construction enterprises have not yet engaged with BIM. In the authors' view, lack of clear definition as to what "BIM" means, could be a significant qualification to meaningful interpretation of the statistics.

International surveys demonstrate that large companies are leading the way into the uptake of BIM. For example, the Smart Market Report (2014) stated that 34% of the large firms reported more than 5 years' experience with BIM, while half of this amount (16%) of small firms would have the same experience. However, it is not clear how the report categorised company sizes labelled as "large" and/or "small". NBS (2014) survey reported awareness and use of BIM by size of firm, comparing firms with 1-5 employees and firms with more than 6 employees, as Figure 1 shows. This survey confirms that small companies are behind large companies in the engagement with BIM. "large" and/or "small". NBS (2014) survey reported awareness and use of BIM by size of firm, comparing firms with 1-5 employees and firms with more than 6 employees, as Figure 1 shows. This survey confirms that small companies are behind large companies in the engagement with BIM.

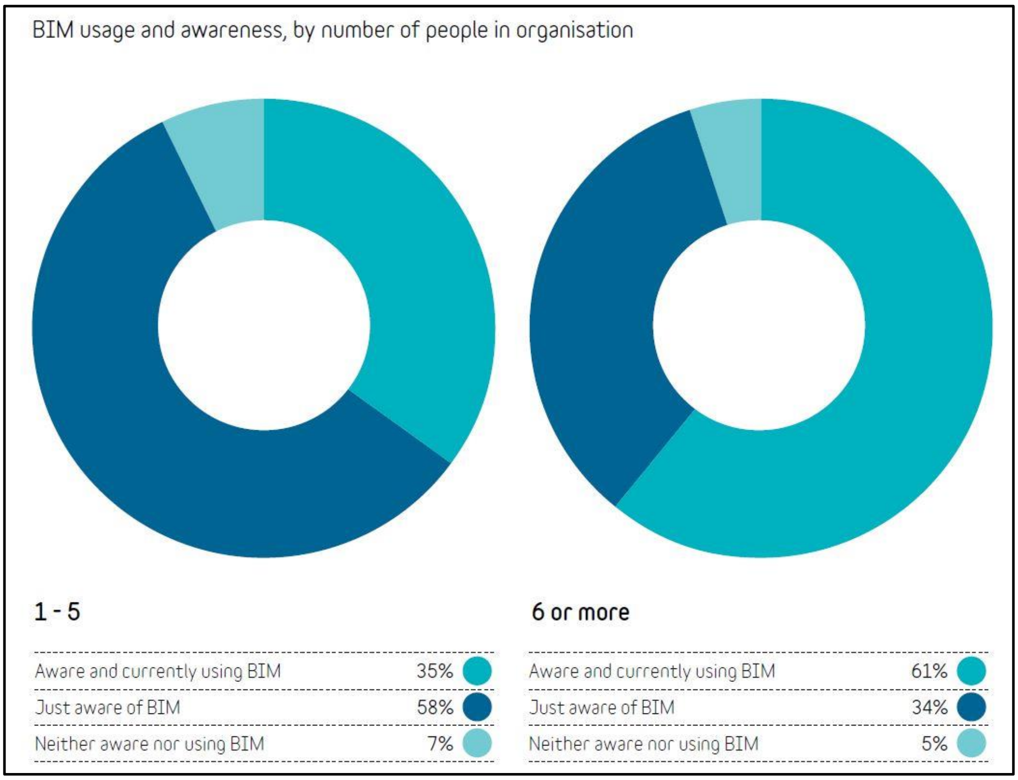

Figure 1: BIM Usage and awareness, by number of people in organisation. Extract from NBS National BIM Report, after NBS (2014)

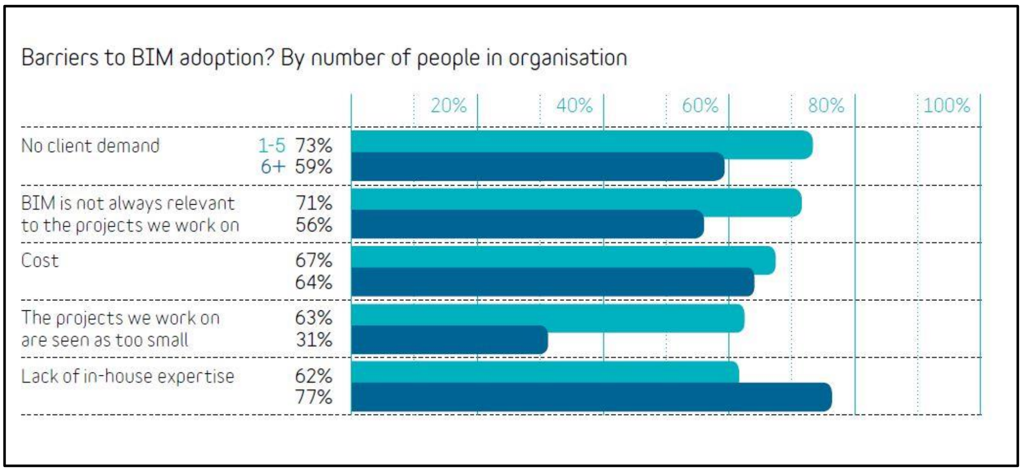

Figure 2: Barriers for BIM adoption, by number of people in organization. Extract from NBS National BIM Report, after NBS (2014)

When asked about the barriers for BIM adoption the lack of client demand is the most important reason for companies with 1-5 employees, while for companies with more than 6 employees the lack of in-house expertise is highlighted as the principal barrier, as Fig.2 above demonstrates.

Because collectively SMEs represent a majority stakeholder in the UK construction sector, their engagement with BIM is crucial for the realisation of UK Government's 2016 mandate. This preliminary research suggests that there is a lack of detailed information about micro, small and medium companies BIM adoption in the UK and a lack of evidence based data about the challenges and barriers which SMEs face when migrating to digital working; specifically BIM adoption.

3.3 Challenges and Opportunities

The authors would argue that embodying BIM into construction SME business models is likely to involve disruption to status quo work practices and workflows. Unlike manufacturing industry, the construction sector faces the challenge that every building is different, "a unique prototype, developed by a team of consultants, contractors and other suppliers that may never have worked together before and may never work together again." (Anon., 2015)

Also BIM involves engagement with new technologies, step change because of the ways in which information is embedded in data rich models and the use of unfamiliar protocols, for example the IFC format for file exchange. Harvard Business School professor Clayton M. Christensen coined the term *disruptive technology*. Christensen (1997) separated new technology into two categories: sustaining and disruptive. Sustaining technology relies on incremental improvements to an already established technology. Disruptive technology lacks refinement, often has performance problems because it is new, appeals to a limited audience, and may not yet have a proven fit with some organisations' business models.

Christensen pointed out that large organisations are designed to work with sustaining technologies. They excel at knowing their market, staying close to their customers, and having a mechanism in place to develop existing technology. Conversely, they have trouble capitalising on the potential efficiencies, cost-savings, or new marketing opportunities created by low-margin disruptive technologies. Christensen noted that it was not unusual for a large organisation to dismiss the value of a disruptive technology because it does not reinforce existing company goals. On the other hand, due to their adaptability and structure flexibility, SMEs are more likely to engage with radical innovations, which have the potential to generate high financial returns (Adegoke et al, 2007).

In the UK, there is a commercial pressure to implement BIM with the Government mandating BIM use on public project and non-public clients demanding BIM at tender stages. In some large organisations as Skanska, Laing O'Rourke, Arup, and HOK, BIM may be part of a company's strategy for innovation and engineering excellence. Across large industry organisations, CEOs and strategists have acknowledged BIM as a potential driver to improve efficiency and increase profits. BIM may be mandated for all new company contracts and services (Jordan and Jeffrey, 2013) Considering that large organisations rely on supply chains (including SMEs) to deliver their projects, these companies could be pushing the uptake of BIM by small and medium sized firms.

It has been argued that, in the future, engagement with BIM may influence the awarding of contracts/sub-contracts and consequently a significant opportunity for SMEs to win business. As highlighted by UK Government spokesperson Chloe Smith, during her 2013 presentation to the BIM4SME group: "As an SME, no matter what your role in the built environment is, it is highly likely your business will or should be involved in the BIM process whether through supplying or managing data." Smith argued that SME BIM engagement could be either be via a publicly funded project, or as part of contractual requirements from a supply chain partner (Platts and Eynon, 2013).

SMEs with appropriate BIM expertise could have a commercial advantage when engaging with projects managed by BIM enabled main contractors. In addition to single contract relationships, SMEs could also benefit from repeated business and long-term relationship with established and new supply chain partners. Another opportunity for SMEs is the possibility to tailor their input to a "just-in-time" methodology to reduce risks of abortive work, re-work and errors. For example, by using a main contractor's digital site model, a steel sub-contractor could design and detail assemblies to fit with site constraints and/or simulate site handling logistics. Historically, sub-contractors may engage late in the design/construction processes with heightened risk of abortive work and on-costs. BIM can potentially offer unseen benefits for a range of supply chain partners, particularly sub-contractors and suppliers.

A further opportunity is for SMEs to develop new BIM related products and services for commercialisation in national/international AECO markets. While BIM transforms the way the industry works, new products and process are going to be demanded by the industry. Being at the forefront of innovation can bring a competitive advantage. Innovation is essential for firms' competitiveness, survival and growth. It can drive competitive advantage, improve productivity and enable companies to capture higher value components of the value chain.

The construction contracting industry in particular is perceived to have low levels of innovation, (measured by research and development) compared with other sectors. Although expenditure on wider innovation such as design and organisational innovation is between two to three times larger than industry's expenditure on tangible assets such as machinery and tools, (£7.42 billion versus £3.15 billion in 2007) the proportion of firms innovating still ranks low relative to other sectors. A literature review carried by UK Government Department of Business Information and Skills highlighted several reasons for the apparent low levels of innovation in construction: (i) high level of industry fragmentation and limited collaboration; (ii) procurement impacting on the level of collaboration; (iii) sub-optimal knowledge transfer and lost learning points; (iv) issues around market uptake and awareness of benefits from innovation; and (v) access to finance and risk-averse attitude to innovation (BIS, 2013).

The literature suggests that SMEs are receptive to engagement with disruptive technologies. SME and micro organisations tend to be structurally lean, agile and potentially adaptable to innovation. However, industry surveys suggest that large companies are leading the way on BIM adoption. This research found that some large contractors may have reached significant levels of BIM maturity in the UK and internationally. Paradoxically, it is small and medium companies which constitute the majority by numbers of the UK's construction sector. In fact, in terms of construction supply chain characteristics, main contractors may manage the projects but sub-contractors/suppliers, (mostly SMEs), which actually do the work. For example, the literature has suggested that, for example, on a £25 million contract, the smallest sub-contract could be as little as £10k. Therefore, it is crucial to understand factors which impact on SME engagement with BIM. As a strategic issue, the adoption of BIM by SMEs is critical for the UK construction industry to achieve high levels of expertise and engagement with digital working. Also at operational level, to achieve alignment with short/medium term Government targets.

4. Preliminary Findings

4.1 Drawing from the BIM4SME Experience

Tables 1.2 outlines a range of perceived challenges to step change in work practices based on industry/practitioner data gathered and collated by BIM 4SME team between September 2012 and March 2013. These parameters were factored into BIM 4SME's launch in London in April 2013. In articulating possible challenges/barriers, the intention was to stimulate discussion among focus groups at the launch event. Also to scope out priority areas for forward planning and testing by data gathering, analysis and the framing of appropriate recommendations as outlined earlier in the paper. Perceived challenges were structured at strategic (industry) and operational (organisation) levels. There may well be interdependencies between factors identified at strategic/operational levels. That premise will be tested during Phase 2 of the research between January and March 2016 through further data gathering from SME organisations.

Strategic challenges
• Lack of objective advice and critique within the industry
• BIMUK forward plan for education/training, FE/HE, industry etc
• Are national BIM surveys carried out to date representative
• Lack of R+D culture in UK construction. (historical + contemporary)
• Fiercely competitive market situation suggests favours those with knowledge
• Fast moving pace of technological change
• Downstream dissemination of UK Government strategy is a volunteer effort
• Lack of clear and achievable protocols, eg common templates for construction of BIM models
• Unclear legal framework (are risks perceived or real)
• Parallel information flows on BIM from professional, regulatory, statutory bodies (PSRBs)

Table 1: BIM and strategic industry challenges

Operational challenges
• Cost of tooling up and risks of redundancy of software/hardware
• Training costs
• BIM wash blurs consistency of message
• BIM overload syndrome. Associated anti-BIM backlash particularly from micro-
• Lack of familiarity with BIM language/concepts eg "soft landings"
• Weakest link in the chain eg only one project team actor BIM compliant
• Variable levels of client engagement with BIM. Do clients perceive added value
• How robust is data embedded in and exchanged between models, eg thermal modelling, cost data etc
• Risks of uncertainty/abortive work related to organisations engaging with BIM on live projects while still way down the learning curve
• Lack of exemplars from BIM users on small projects,. Little evidence to back up claims of collaborative working in 3D environment other than on large projects.

Table 2: BIM and operational challenges for SMEs/microSMEs

5. Conclusions

Following the publication of the 2011 UK Government Construction Strategy, the industry has witnessed an increase in the awareness and use of BIM. In addition, industry groups became established to offer support and guidance to construction enterprises. BIM 4 SME is part of the BIM Task Group which aims to facilitate the transition from conventional to digital working in micro, small and medium enterprises.

The literature has demonstrated that most construction sector employment comes from SMEs, which are companies with up to 250 employees and up to £ 11.4 million turnover. In the UK construction, Industry SMEs represents the hugely majority of construction firms, accounting for more than 61% of the total value of work in the sector. Despite the recognised adaptability of SMEs with respect to innovation, the paradigm shift to digital working in construction is currently being led by large organisations. Preliminary findings from BIM 4SME industry workshops held between September 2012 and April 2013 identified a number of challenges to BIM uptake; these were classified at strategic and operational levels. The next phase of the research will test perceived challenges by sampling from a representative cross-section of construction SMEs. The summative part of the study (Phase 2) aims to make recommendations to the industry groups that are supporting SMEs in their BIM journeys. To date, the research has highlighted not only challenges, but market opportunities for SMEs and BIM.

Traditionally, the UK construction sector is risk averse. Construction's fragmented morphology combined with the unique nature of building projects tends to mitigate against change. Even when collaborative approaches to working prove successful, it is difficult to maintain significant levels of continuity over time. On the other hand, BIM technologies and digital processes are seen as motivational factors which could bring improvements to industry performance. The next stage of the research will also expand on the analyses of key challenges for BIM 4SME in reaching out to SMEs faced with embedding digital working into design, construction and supporting supply chain activities. Drawing from industry data gathered and taking an evidence based approached, the concluding phase of the study will propose ways to overcome perceived challenges and provide continuing support to SMEs in engaging with BIM. Realising high level objectives for digitising UK construction (cost and carbon reduction) must take account of industry's capability to deliver.

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The Potential of 4D Modelling Software Systems for Risk Management in Construction Projects

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Abstract

Any construction project is full of risks, which if not minimized or eliminated can jeopardise its outcome. The sources of risks vary from project to project. With refurbishment projects, information is scarce leading to making assumptions about them, which generally entail risks. On the other hand, very new and very large projects are complex involving many disciplines and generating too much information in the different phases of construction life cycle. Actions by stakeholders in the different phases related to the project information have implications on quality, cost and schedule-related risks. Building Information Modelling (BIM) has been hailed as a solution to many challenges in construction including risk management. Applications of BIM in quantity surveying, project planning, facilities management and sustainability have been extensively researched and now common in the scientific literature. However, research about risk management in a BIM-enabled environment is still very sketchy. This is compounded by the plethora of BIM software systems which overwhelm end-users to be able to make informed decisions about their uses in risk management. The work presented in this paper is the first step of a more comprehensive research aimed at improving the understanding of risk management in a BIM environment. The focus of the investigation is about the potential of and limitations of 4D BIM software systems in managing construction risks. A purely desk-top study has been adopted to achieve the aim of this study.

Keywords: BIM, construction, efficiency, nD modelling, risk

1. Introduction

Similar to most projects, construction projects are highly subjected to risks. This is further exacerbated by their complexities, dynamism and peculiar nature (Rostami *et al.*, 2015; Taillandier *et al.*, 2015). Rostami *et al.* (2015) argued that construction projects are subjected to more risks and uncertainties because of the varying range of activities and transformation involved from the planning stage to completion. Such activities include complex planning procedure, regularly bespoke and time-consuming design as well as costly production processes. Furthermore, construction projects are becoming increasingly larger and more complex in physical size and cost. If not effectively managed, the risk associated to this huge size can lead to losses (Chen *et al*, 2012). Also, projects are based on teamwork with different interested stakeholders, and the co-operation among them is formed around extensive, disparate and interrelated processes. People are very unpredictable in behaviour, compounded by unpredictable external environmental risk factors in delivering projects can be very high. Construction projects involve a lot of decision-making with consequences on the project's success or failure (in terms of cost, time and quality) and on its environment (Taillandier *et al.* 2015). Sawhney *et al.* (2014) argued that construction is confronted by challenges such as time and cost overruns, wastage, low levels of standardisation, fragmentation, inconsistent procurement practices and low use of technology. Studies by Abderisak and Lindahl (2015) revealed that cost and time overruns are quite common with increases in the range of 50-100% being more regular and an increase of over 100% is not an unusual case. The risk associated with cost and time overruns will have immense effects on the outcome of any project if not properly managed.

Digitization of construction using BIM offers innovative ways to effectively manage construction risks (Hartmann *et al*, 2012; Tomek and Petr, 2014). Mott MacDonald, a management, engineering and development consultancy, defines BIM as "a coordinated set of processes, supported by technology that adds value through creating, managing and sharing the properties of an asset throughout its lifecycle (Mott MacDonald, 2015)." In order to support BIM workflow of processes, a market for BIM technologies has significantly grown in recent years. Although the growth of BIM software is great, its huge number and other technical issues have posed challenges for end-users. Lee and Sexton (2007) argued that there is a lack of holistic information for relevant construction parties regarding the characteristics of the various software packages and their appropriate uses. Furthermore, issues of non-compatibility (interoperability) among software packages are still too common. Day (2011) argued that depending on the software put to use, BIM models get very large in file size as the level of detail increases and this poses problems to computers with limited memory sizes. Fazli *et al* (2014) claimed that one of the major weaknesses is getting different file formats to function properly when creating a combined building information model. When data is taken from the original BIM model, a certain value is attained and when converted into another file format, a different value can be generated. A recent study by Abanda *et al.* (2015) led to the identification of/and differences between 122 BIM software systems across different construction domains. However, the study was top level with lack of details on specific domains. Building on Abanda *et al.* (2015), this study aims to conduct a detail investigation of BIM risk management software systems with focus on interoperability amongst the different software systems. Three main objectives employed to achieve the objectives of this study are: an Investigation into why construction risk management is required; the identification of the various commonly used scheduling and 4D BIM software for construction risk management; an investigation into the interoperability amongst the scheduling and 4D BIM software systems.

To facilitate understanding, the remainder of this paper is divided into 4 sections. In section 2, the methods used to achieve the aim of this study are examined. To provide the context of this study, in section 3, risk management in construction is explored. This is followed by an assessment of the traditional scheduling and 4D BIM software systems, where emphases was placed on the type of operating systems supporting the software, the import/export file formats of the software and whether risk has been integrated into the software. In section 4, the key findings and how the study objectives have been achieved are discussed. The paper concludes by a way of summary in section 5.

2. Research methods

Given that the core of this study is based on interoperability, its definition is important to provide a context for the adopted research method. Generally four types of interoperability exist in the literature. These are syntactic, technical, semantic and organisation interoperability (Rezaei *et al*., 2014). For purposes of this study, the focus is on syntactic interoperability which refers to the ability of two (or more) separate systems or software programmes to communicate and exchange data (or information) with each other and use the data (or information) that has been exchanged (Rezaei *et al.*, 2014; Bahar *et al.*, 2013). With this definition in mind, four criteria for the different software to be reviewed were established. The first criterion considers whether the software can be installed on two most popular operating systems, i.e. Mac and Windows. The second was based on how legacy scheduling/risk management tools were integrated into 4D BIM tools. By integration we mean the ease with which 4D BIM can read into legacy scheduling and/or risk management tools. The third criterion is about the file exchange formats inbuilt into the software system. The last criterion is about whether risk is integrated as part of the scheduling or 4D BIM software systems. These criteria are captured in the framework shown by Figure 1.

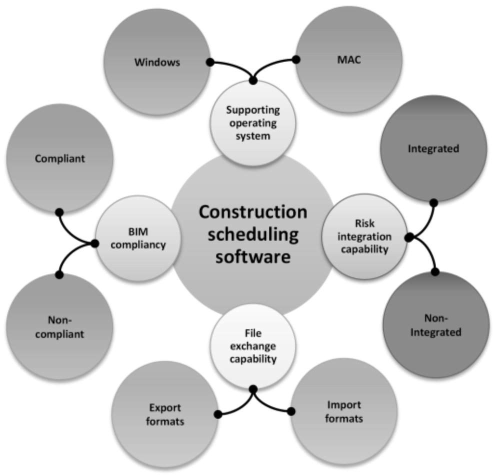

Figure 1: Factors qualifying the potential of construction scheduling software

Based on Figure 1, an extensive literature review from peer-reviewed sources and vendors' websites was conducted. Giving the emerging nature of BIM, peer-reviewed studies about BIM software are scarce and the few existing studies have tapped information from vendors' websites (e.g. Crawley et al. (2008) and Abanda et al. (2015)). In examining the vendors' websites, the specification documents were explored to identify the different operating systems, file exchange formats supported by the different software systems, whether scheduling and/or risk software was integrated in 4D BIM software systems and finally, whether risk has been integrated in the software. To further gain clarity about the set criteria for this investigation, some of the software were installed and explored. That led to the identification and inclusion of 34 project scheduling, 3 legacy risk management software and 20 4D BIM software systems.

3. Risk management and its digitization in construction

Risk management involves creating uncertainty awareness, qualifying the risks, managing the controllable risks and curtailing uncontrollable risks impact by risk allocation/appointment (Liu *et al*, 2007). There are many definitions of risk management, all portraying the fundamental goal of minimizing the impact of risk. According to Irimia-Dieguez *et al.* (2014), risk management is the systematic process of identifying, analysing and responding to project risk. Also, Tohidi (2011) defined risk management as the process of identifying and assessing risk, and applying methods to reduce it to an acceptable extent. Hence, risk management involves the process of determining the likelihood of risk to occur, taking necessary steps to examine its effects and fashioning out ways to prevent or lessen the effects, in the event that it occurs. Generally, managing projects revolves around the proper management of the delivery of project objectives in terms of time (scheduling), cost, quality and safety as most risks emanate from them. The focus of this study is on risk associated with construction project scheduling. In emerging BIM paradigm, 4D stands for scheduling in a BIM tool. As such the discussion ensuing in this section concerns the applications of risk management in traditional software systems and contemporary risk management approaches in BIM enabled environments.

3.1 Risk management in traditional scheduling software

Project scheduling is important for construction project managers as it facilitates their task of tracking and managing the triple constraints of time, cost and quality of projects (Faghihi *et al.*, 2014). Planning and scheduling in construction normally involves activity sequencing in space and time, taking into account other construction processes like procurement, resources, spatial constraints, etc. Traditionally, bar charts (Gantt charts) are used to schedule construction activities but these methods have been unable to show how or why certain activities are linked in a given sequence (Eastman *et al.,* 2011). Once these schedules are created, there appears to be no direct link between the computer-aided-design (CAD) drawings and the construction schedule. As the design progresses in typical project scenarios, the construction manager reviews any updated drawings, then updates the schedule to reflect these design changes where such clarification depends on the accuracy of the construction manager (Hardin, 2009). Eastman *et al.* (2011) further argued that the spatial components aren't adequately captured by the traditional methods and nor are they linked to the building model. Further claims were that scheduling (using the traditional methods) is manually intensive and often at times does not concur with the design thereby creating complications for project stakeholders to understand the schedule and its impacts on site logistics. Two most common software systems used in traditional scheduling are MS Project and Primavera. It is important to note that traditional software has been in existence for ages even before the advent of BIM and/or 4D BIM modelling. While some traditional scheduling software systems have compatible plug-ins with 4D BIM, others do not. Also some have integrated BIM while others have not. A summary of the different project scheduling software uncovered are presented in Table 1.

Table 1: An overview of construction scheduling software systems

Software	*BIM compliant*	*Export file format*	*Import file format*	*Risk analysis integration*	*Operating system*
Asta Powerproject	*Yes*	*HTML, CSV, MPX, XML, XER*	*PDB, MPX, XML, XER, DIR, STX*	*Yes*	*Windows/Mac*
ConceptDraw PROJECT	*No*	*XML, MMAP CDPZ, CDPX, CDPTZ, CDMZ, TXT,*	*CDPZ, CDPX, CDPTZ, CDMZ, TXT, MMAP, XML, MPP, MPT, MPX, XLSX*	*No*	*Windows/Mac*
Deltek Open Plan	*No*	*XML, CSV*	*XER*	*Yes*	*Windows/Mac*
Express Project	*No*	*Express Project files*	*Express Project files, CSV*	*No*	*Windows/Mac*
Fast Track Schedule	*No*	*HTML, MPX, XML, ICS, MMAP*	*MPP, MPT, XML, MPX*	*No*	*Windows/Mac*
Gantt Project	*No*	*CSV, MPX, XML, HTML, PDF, GAN,*	*CSV, ICS, TXT, XML, GAN*	*No*	*Windows/Mac*
MicroPlanner X-Pert	*No*	*TXT, DIF, CSV, XML*	*TXT, DIF, CSV, XML, MPX*	*No*	*Windows/Mac*
MS Project	*Yes*	*XML, MPT, MPP, CSV, TXT, XLS*	*MPP, MPX, XML, MPT, XLS, XLSX, XLSB, XLSM, CSV, TXT*	*Yes (2010 and later versions)*	*Windows/Mac*
Milestones Professional	*No*	*XML, PDF, MPX, CSV, TXT*	*XML, MPX, CSV, TXT, MPP, MPD*	*No*	*Windows/Mac*
Organiser	*No*	*ORG, HTML*	*ORG*	*No*	*Windows/Mac*
Phoenix Project Manager	*No*	*MPX, XML, XER, XLS, XLSX, SDEF, CSV*	*MPX, XML, XER, XLS, XLSX, CSV, P3*	*No*	*Windows/Mac*
PMA Netpoint	*Yes*	*XML, XER*	*XML*	*Yes*	*Windows/Mac*
Primavera	*Yes*	*XML, XLS, XER*	*XER, XML, XLS*	*Yes*	*Windows/Mac*
Project Commander	*No*	*XLS, MPX, TXT, CSV, WMF, DOC, PPT*	*MPX, TXT, CSV, XLS*	*Yes*	*Windows/Mac*
Project KickStart	*No*	*PRX, MPX*	*PRX, PRJ, MPX, CSV*	*No*	*Windows/Mac*
ProjectLibre	*No*	*POD, XML*	*MPP, MPX, XML, POD, PLANNER*	*No*	*Windows/Mac*
P2ware Project Manager	*No*	*PDF, HTML, XLSX, CSV, TXT, RTF, MHT, MPP, XML*	*XLSX, PLAN, MPP, XML, MPX*	*Yes*	*Windows/Mac*
Project Xpert	*No*	*MPX, XML, ICS, CSP, PRJ*	*CSP, MPP, MPX, XML, ICS*	*No*	*Windows/Mac*

Rational Plan Professional	*No*	*SRP, XRP, XML, XLS, MRP*	*SRP, MRP, XRP, MPP, XML, MPX, MPT*	*No*	*Windows/Mac*
Risky Project	*No*	*MPX, Decision Tree*	*MPP, XML*	*Yes*	*Windows/Mac*
Safran Project	*No*	*SP, MPD, MPX, XML, XER, DBF, P3*	*SP, SPP, ART, MPX, MPD, XML, XER, P3, PM, XML*	*Yes*	*Windows/Mac*
Sure Track Project Management Software	*Yes*	*MPX, P3, HTML*	*MPX, P3*	*No*	*Windows/Mac*
Turbo Project	*No*	*MPD, PEP, MPX*	*MPD, PEP, MPX*	*No*	*Windows/Mac*
Altiproject	*No*	*XLS, BusinessObjects*	*XLS, BusinessObjects*	*No*	*Mac*
Curio	*No*	*ICS, HTML, PDF, RTF, TXT, CSV*	*RTF, ICS*	*No*	*Mac*
iTaskX	*No*	*iTaskX (Project), iTaskX (Template), XML, MPX, OPML, TXT/CSV, MPP, ICS*	*OPML, TXT/CSV, ICS, MPP, XML, MPX, TXT, CSV*	*No*	*Mac*
iMindQ	*No*	*XLS, XML, PDF, HTML, CSV*	*XLS, XML*	*No*	*Mac*
Invoax Plan it	*No*	*HTML, CSV, ICS, XML*	*XML*	*No*	*Mac*
Merlin Project	*No*	*XML, MPX, MMAP, NovaMind, TXT/CSV, HTML, OPML, XLS*	*MPP, XML, MPX, XLS, MMAP, NovaMind, OmniOutliner*	*No*	*Mac*
OmniPlan	*No*	*ICS, CSV, MPX, XML, HTML, OmniOutliner, OmniGraffle*	*XML, MPX, MPP*	*No*	*Mac*
Project X	*No*	*ICS*	*ICS*	*No*	*Mac*
SG Project Pro	*No*	*PDF, XML, SGP*	*XML, SGP*	*Yes*	*Mac*
X Plan	*No*	*XML, ICS, xView, XList5*	*XML*	*No*	*Mac*
@RISK	*No*	*XLS, DOC, PPT,*	*MPX/MPP, XML, XLS*	*Yes*	*Windows/Mac*
Crystal Ball	*No*	*XLS, CSV, TXT, DIF, PDF, XPS, XML*	*XLS, XML, TXT, DIF, dBase*	*Yes*	*Windows*
Risk Solver	*No*	*XLS, PDF, TXT, XML*	*XLS, XML*	*Yes*	*Windows*

3.2 Risk management in 4D BIM software systems

Sebastian (2011) argued that BIM is not the same as the widely known computer aided design (CAD) because it goes beyond generating the traditional digital (2D or 3D) drawings. It is an integrated model in which all process and product information is combined, stored, elaborated and interactively distributed to all relevant project actors. Also, the proposed design and engineering solutions can be assessed against the client's requirements and expected building performance using BIM. The use of BIM during the construction phase can support good communication network between the building site, the factory and the design office (Sebastian, 2011). Fazli *et al.* (2014) also argued that communication processes that exist between stakeholders in a project can be enhanced massively through BIM. This is in contrast to traditional projects in which building visualizations (views) are made from scratch while BIM-based projects, the visualizations can be made from previously created models and can be monitored real-time. The schedule of construction is directly linked to the 3D model, enhancing visualization of the sequential construction or sequence activities of the building, thus allowing schedulers to visually plan and communicate activities in the context of space and time (Eastman *et al.*, 2011). Furthermore, Hartmann *et al.* (2012) discussed that project risks are communicated as a risk inventory using Gantt charts and sketches that however, do not allow project managers to completely visualize and understand risks, their location on site and their implications on project deliverables making it hard to collaboratively examine and mitigate project risks. The argument was that 4D models capture both the temporal and spatial aspects of schedules and communicate schedules more effectively than Gantt charts. In the experimental study carried out by Reizgevičius *et al.* (2013), they argued that 4D models can shorten construction time by 1/3. Furthermore, they claimed that the use of 4D CAD model can reduce mistakes to a greater extent (twice as much) in construction processes and help in detecting and removing them more quickly. In Hartmann *et al.* (2012), a case study showed that if time schedule is aligned well with existing risk management processes, design teams can use 4D models to visualize project risks in time and space. Mahalingam *et al.* (2010) discussed that 4D CAD are beneficial in the planning and construction stage where in the former, it will be useful in communicating the construction plans and processes to clients who can then visualize the project and convey their suggestions, approval or disapproval. In the construction stage, it will be particularly useful in comparing the constructability of work methods visually in order to detect conflicts or clashes. It also serves as a visual tool for contractors, clients, subcontractors and vendors to review and plan projects' progress. The summary of the 4D BIM software uncovered in this study are presented in Table 2. Even if many 4D software deal implicitly with many aspect of risk management (logistics, space, etc.), the risk analysis integration considered here is the explicit feature included in the software. It is important to note that some of the software systems are also 5D BIM systems, i.e. 3D plus cost dimension.

Table 2: An overview of 4D BIM software systems

Software	*Export formats*	*Import formats*	*Risk analysis*	*Operating*
Autodesk Navisworks	*3D DWF, DWFx, FBX, KML, NWD, NWF*	*TXT, ASC, DGN, PRP, PRW, DWF, DWFx, W2D, DWG, DXF, FBX, IFC, RVT, SKP, NWD, NWF, NWC*	*No*	*Windows*
AVEVA NET Player	*XML, PDF, PPT, HTML, SVG, DOC*	*HTML, XLS, XML, SVG*	*No*	*Windows*

Bentley ConstructSim	*XLS, IFC*	*ISO, XLS, DGN, DWG, PDS, PDMS, IGES, IFC*	*Yes*	*Windows*
Bentley Navigator	*IFC, PDF*	*IFC, DGN, DWG, DXF, SKP, PDF, IGES, KML,XML, XER*		*Windows*
Dassault Systemes CATIA	*3D XML, DWG, DXF, PDF, IGS*	*3D XML, DXF, CATProduct, IG2, IGS*	*No*	*Windows/Linux/Unix*
Dassault Systemes Civil Design for Fabrication	*IFC*	*IFC*	*No*	*Windows*
Dassault Systemes Delmia	*IFC*	*XML, XER, IFC*	*No*	*Windows/Unix*
Dassault Systemes Optimized Planning	*IFC*	*IFC*	*No*	*Windows*
Digital Project Extensions	*IFC, XML, HTML*	*IFC, XER, XML, DWG, DXF, IGES, SDNF*	*No*	*Windows*
D-Studio 4D Virtual Builder	*4D PPT, IFC*	*XML, MPP, MDP, PP, IFC*	*No*	*Windows*
DESTINI Profiler (Beck Technologies)	*DWG, DXF, eQUEST, IFC, IGES, KML/KMZ, STL, XLS*	*PDF, DWG, DXF, XLS, RVT, PEE, MC2*	*No*	*Windows*
Innovaya 4D/5D Simulation and Estimating	*INV, HTML, DOC,*	*XML, INV, XER, XLS, RVT, MPX, DWG*	*Yes*	*Windows*
Intergraph SmartPlant Construction	*XER, IFC*	*XER, XML, IFC, DWG, DXF, DGN, PDS, PDMS, CAESAR II, SAT, XMpLant, CADWorx*	*No*	*Windows*
Onuma Planning System	*GBXML, IFC, COBie, KML, BIMXML, CityGML*	*IFC, OGC, OSCRE, COBie, XLS, KML, CSV, GBXML, XML, BIMXML, CityGML*	*No*	*Windows/Mac/Linux*
Solibri Model Checker	*IFC, PDF, RTF, XLS, SMC*	*IFC, DWG, DXF, DGN, SKP, SMC*	*No*	*Windows/Mac*
Synchro Software	*SP, XML, XER, IFC, XLS, P3*	*XML, P3, XER, IFC, SP, NP4*	*Yes*	*Windows*
Tekla Structures	*PDS, XML, PML, SCIA, HLI, DWG, DXF, DGN, IFC, SDNF, SKP, PDMS*	*IFC, DWG, DXF, DGN, XML, HLI, SDNF*	*No*	*Windows*
Vico Virtual Construction	*XML, XLS, DOC, PDF*	*IFC, SKP, DWG, sbXML, XLSx, XML, CAD-DUCT*	*Yes*	*Windows*
RIB iTWO	*IFC, XML, XER, MPX, RPA, RPD*	*IFC, XML, XER, MPX, XLS, RPA, RPD*	*No*	*Windows/Mac*
Visual 5D	*Avi, mpeg*	*Cinema 4d, Blender, 3ds max, .RVT*	*No*	*Windows*

4. Findings and discussion

Tables 1 and 2 provide an overview of some scheduling and 4D BIM software systems and how they integrate with BIM. The software systems were classified according to the different criteria set in section 2. A summary of how the research objectives were achieved will be discussed.

Table 3: How the research objectives were achieved

To investigate why construction risk management is required;
This was achieved through a literature review and discussed in sections 1 and 3. In section 1, the rationale for risk management in construction projects was examined. Then in section 3, the rationale and benefits for digitising risk management were discussed.
To identify the various commonly used scheduling and 4D BIM software for construction risk management;
This was achieved through an extensive literature review. Peer-reviewed and vendors' websites served as source of information. The findings from this review were presented in Tables 1 and 2.
To investigate the interoperability amongst the scheduling and 4D BIM software systems;
Once the software systems were identified, the specification manuals were read to determine the software characteristics (e.g. file import and export format). Furthermore, in some cases some of the software had to be installed and explored to determine whether it is compliant with BIM, types of file exchange formats and whether it contains risk components.

By achieving the objectives, four main findings were uncovered. Firstly, some traditional construction scheduling software are BIM compliant and also contain a risk analysis component. For example, Asta PowerProject has a risk component, and its project can be read by 4D BIM software system (e.g. Synchro). Secondly, most traditional scheduling software are not yet integrated in BIM and do not contain a component for analysing risk in construction (e.g. Project Xpert and Rational Plan Professional). Thirdly, some 4D BIM software systems have a risk analysis component (e.g. Synchro and Vico) while others do not (e.g. Navisworks). The last is that some scheduling and 4D BIM software systems can be installed on Mac and/or Windows operating systems. The findings from this study can be modelled using a Venn diagramme (Figure 2) which reveals the relationship between the different software systems.

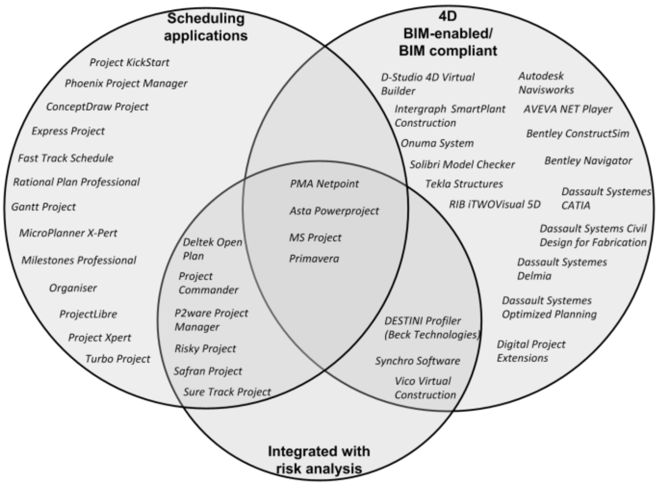

Figure 2: Software category summary

5. Conclusions

With construction projects increasingly becoming larger and more complex, there is the need for efficiency in the way construction activities are carried out. The construction industry is known for its inefficiencies, and amongst many, scheduling (time) risk is not left out. This study has explored the domain of risk management through which an understanding of the various problems that give rise to risks in construction projects was achieved. Consequently, some of the available traditional scheduling software systems were examined based on their compliance with BIM. However, it was clear that these software systems are not quite efficient in specifically managing scheduling risk. With the global advancement in technology, BIM has emerged as a technology capable of bringing more efficiency in the way the industry operates. It is in this regard that a critical appraisal of 4D BIM software systems was carried out. Although, BIM is still in its early phases, one of the benefits of BIM is that it can further enhance better risk management through 4D modelling. Through 4D modelling, project managers can be able to visualize the virtual construction of any project, identify any risk associated and make more subjective decisions rather than objective decisions. The traditional software systems are not capable of doing so but with 4D software systems, this is possible. This has been illustrated through the different literatures in this paper as well as the critical appraisal of some of the 4D software systems presented. Nonetheless, this study has not investigated how schedule risk management can be performed in a BIM environment. Future studies will focus on the processes of undertaking schedule risk management in a BIM environment for proper understanding of how to manage risk using BIM.

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SECTION

7

Facilities management

Visualization of Facilities Management KPIs during Early Design Using BIM

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Abstract

The use of building information modelling (BIM) in Facilities Management (FM) is a central topic of study in the construction industry at the moment. Most of the current research in the subject is focused on using BIM to efficiently deliver handover building information, support maintenance activities and close the loop in the building lifecycle. However, the use of BIM opens another set of opportunities for FM professionals that can help them to be part of a more integrated design process. This paper studies the involvement of FM professionals during the early design phase supported by the use of BIM tools. BIM tools are capable of simulating and predicting different parameters that can be utilized by FM professionals and later be used as FM key performance indicators (KPIs) to support their decision making process. In addition, the paper presents the Multi KPI visualization tool that enables the compilation of simulation results related to energy, cost and sustainability. By using the Multi KPI tool, a facility manager is able to influence in an integrated design process which opens a new set of innovative opportunities for the FM field that can positively impact the building lifecycle.

Keywords: facility management, building information modelling, key performance indicators, early design, KPI visualization

1. Introduction

During the last decade building information modelling (BIM), lean practices and integrated project delivery methods have been the major drivers of innovation in the architecture, engineering and construction (AEC) industry. With the increasing complexity of building projects and increasing number of unknowns, the combined use of these three methods has allowed for making more accurate predictions that can meet the client requirements, cost, schedule and quality of the project (Khanzode et al., 2007). After experiencing the benefits during design and construction, the project owners are also interested in extending the benefits of BIM in facilities management (FM) and possibly cover the building lifecycle. BIM for FM has been a topic of discussion for several decades, but in practice the implementation in FM is still in an early phase without yet being as successful as in design and construction. A range of potential applications of BIM in different areas of FM have been proposed in the literature such as for operation and maintenance (O&M), asset management, space management, performance management and as a building information database (Forns-Samso et. al., 2015). However, the implementation in these areas bring along organizational, technological and process issues that need further investigation. In addition, research in this area is predicated on the premise that facility managers are only involved in the operational phase limiting different approaches on how BIM can be a useful tool for facility managers. Additionally, a thorough description of the FM industry has been constantly overlooked or mainly focused on operational activities and neglecting the value input facility managers can bring in supporting strategic level decisions in the design phase.

2. Literature Review

2.1 Facilities Management

Facilities management is said to cover all aspects of property, space, environmental control, health and safety, and support services, and it requires that appropriate control points are established in the organizations (Alexander, 2013). As a young discipline, the FM business field developing rapidly and continuously (Elmualin et al., 2010). In the past FM was often regarded as merely a sub-profession such as maintenance, caretaking, or cleaning of buildings or it was considered as a secondary discipline of principal professions in the categories of real estate, engineering, architecture and construction (Atkin, 2009). The current trends indicate that FM will be moving from operational to strategic because of its potential to in creating value for business activities (Meng and Warren, 2015). As such, the participation of FM professionals is growing, evolving and not only active in the post construction phases but also in the early phases of design.

Barrett and Owen (1993) divide FM into operational and management functions as two broad categories by function analysis. *Operational* functions are the daily or routine support functions involving workers. Activities at this level have a regularly short-term scope, and involve specific processes, simple and straightforward, such as repairing, replacing, cleaning, refurbishing, etc. Traditionally, operational functions were performed by in-house departments in educational and healthcare facilities but they had to be multifunctional and the personnel had to be multi skilled. Currently, it is more common that non-core business activities are outsourced to external specialists who can provide effective and efficient services (Meng and Warren, 2015).

Management functions can be distinguished at tactical and strategic levels. Tactics are action plans involving managerial operations for specific and routine activities (Johnson et al., 2008). Such activities are for example, safety procedures for prevention or proper use, maintenance plans and care of maintenance resources. Activities on this level support responsible behaviour in the workplace and the continuity of working conditions. At the strategic level there is consultation and non-routine planning aimed at making the best, long-term use of the organization’s physical resources and overall facilities. Johnson et al. (2008) see management strategy as dealing with the complexities of ambiguous, non-routine situations which can affect the direction and future of the whole organization. Strategic decisions demand an integrated approach since the entire organization should move in the same development direction. Strategy is needed to cope with the prospect of an unknown and changing future. Although long term forecasting can only hypothesize about the future, strategic planning aims to reduce uncertainty by choosing a preferred path and a reasonable long term direction for the development of the organization.

2.2 BIM for FM

The research in the area of BIM for FM has increased rapidly in the last years. A recent literature reviews by Forns-Samso et al., (2015) summarizes the potential BIM uses in different functions of facilities management. The area with stronger focus is in supporting maintenance activities in building operations. Such potential uses include visualization and location of building components with access to real time information concerning attribute data and historical maintenance information. It also facilitates the scheduling of maintenance tasks and the ability to virtually develop a maintenance program without need of making a site visit. However, all of such uses depend on the accuracy, consistency and reliability of the data.

The second category with stronger focus is information management. Information management deals with improving data management during the lifecycle, handover information, as-built/as-maintained model used for the operational phase. Articles in this category investigate about interoperability, information exchange standards such COBie, IFC, FMie etc. and data management procedures. The vision in this research area is geared towards a lifecycle information management approach by capturing information from initial phases of the project through demolition. Major concerns with this implementation are towards the processes and roles for data capturing and data maintenance during the building lifecycle. Supportive concepts are used from industries such as manufacturing, automobile, and shipping with a strong focus on product lifecycle management (PLM). In addition, the literature considers emerging requirements for the capture of Building Performance Attribute Data.

The third category is the use of BIM for building performance which is mostly concerned with tracking and monitoring energy consumption, thermal performance, and components performance. Based on the literature building performance can be measured by integrating other systems such as requirements management, energy simulations tools and building automation systems.

The fourth category is in the area of asset management which is strongly related to maintenance activities but are more closely related to tactical decisions such as assessing the service life of components, maintenance programs, historical data and predictions about equipment failures and replacements. The area of asset management seems to have wider publications from Australia and UK.

The fifth area is space management which is concerned with activities related to real estate functions and cost. Publication numbers in this area are the lowest but it could be because already sophisticated systems such as Computer Aided Facility Management (CAFM) or

Integrated Workplace Management Systems (IWMS) have been widely used in the area of space management and BIM has not found a distinctive application from what already exists.

As described BIM for FM has many potential applications. However, there are only a few studies that show potential uses of BIM for FM in the early phases of design and how to support strategic level decision in FM. With that premise the current study gives a perspective how BIM can be utilized by FM professional in the early phases of design.

2.3 Early involvement of FM expertise during design

The involvement of FM professionals during early design phases is perceived of high value for entire facility lifecycle. Jaunzens et al., (2001) produced a guide that includes the participation of the facilities management team that is part of a client organisation in the design of future facilities and how the FM team´s position within the client organisation, its level of expertise and relationship with the design team affect this participation. In this study, they were able to identify issues relevant to facilities management which should be stated in the design brief, namely maintenance, flexibility and adaptability and the environmental policy.

Jensen (2009) proposed a typology of four mechanisms for knowledge transfer, to establish an integration of building operation considerations in building design. Jensen's mechanisms of knowledge transfer are the following: (1) Utilizing building operation experiences to create codified knowledge, increasing designers' awareness as a result, (2) Boosting the skills and capabilities of facilities managers, increasing designers' awareness as a result; (3) Using power to guarantee that designers seriously take into consideration building operation issues through facilities management participation; (4) Using power to guarantee that design teams seriously utilize codified knowledge.

Wang et al (2013) proposed a framework with the use of BIM to engage facility managers in the early design stages. The main activities improved were in space planning, energy analysis and maintenance planning. Using BIM as a source of information proved to be valuable for collaboration and reduction of life cycle costs. Enoma (2005) states that FM involvement at the design stage will add value to the facility by "ensuring less 'rework', emphasising value for money, efficient control of the supply chain and team work". However, the main barriers of FM involvement are the increased cost in with their participation and when the client is not the end-user of the building.

2.4 Key Performance Indicators

KPIs have become progressively more established within several industries as a performance measurement system. The advantages of using KPIs in facilities management is to direct the managerial effort towards more important areas of performance, and can be embedded in the FM services contract to clearly present the required outcomes and their relevant monitoring and control. It is important that KPIs are relevant, measurable or quantifiable in order to make appropriate comparisons (Lavy et al., 2014). The majority of KPIs generated in FM are the ones related to the cost of maintenance and operation, revenue, space management, and environmental and safety issues.

KPIs have become a part of growing area of analytics, a field that deals with prescriptive analysis. Prescriptive means that decisions regarding how to improve the performance of a facility are made based on data analysis. It utilizes the process of optimization to identify the best solution. In other words, it prescribes how to achieve the best outcome considering the effects of variability. This is recommendation phase where decision and support are coupled with expert opinions to create tactical and strategic guidance for the organization. The process of data analysis may be performed using actual or simulated data that is based on reasonable assumptions. In summary, the process of analytics can be effectively used with simulated data to analyse the relationships and impacts of KPIs.

Within this context the analysis of different KPIs using simulated data can be beneficial for facility managers during the early design phases to support their strategic level decisions. Different BIM platforms are able to assess the facilities lifecycle performance using simulations such as ECOTECT, TRNSYS, RIUSKA etc. However, they are not extensively used by facility managers because, as explained previously, relevant FM KPIs contain a wide range of parameters that cannot be interpreted by a single simulation platform. Therefore, it is needed a platform that can visualize a different set of parameters derived from different applications. This research try to cover that gap by presenting the Multi KPI tool described in the next section.

3. Research Goals and Objectives

To widen the scope in the use of BIM for FM, its implementation should not only focus in facility managers supporting operational activities but also involve them actively in early design phases where FM professionals can provide valuable input in the decision making process, add value in the facility design and lead to a more integrated design process.

The goal of this study is to propose a platform that compiles dynamic simulation results from different BIM platforms and present the simulation outputs as Key Performance Indicators (KPIs). KPIs can be visualized and analysed by facility managers to improve the decision making process. KPIs can be for instance, total energy consumption, CO_2 emissions, total cost of energy consumption, investment cost, maintenance cost. The following are the specific objectives for this study:

(1) Widen the scope of BIM for FM to be used in the early phases of design

(2) Employ different simulated KPI outputs useful for Facilities Management

(3) Visualize and analyse the relationship between input variables and KPIs using a sensitivity analysis and uncertainty analysis

(4) Demonstrate using visualization techniques the generations of different scenarios and supported decision making

4. Research Methodology

This project uses design science methodology. The use of BIM for FM has been widely discussed in the last years without achieving tangible benefits. Within this context, design science research is an accepted problem-solution finding method that it is suitable for this study. Design science would mean designing a framework/tool as an artefact that would help the construction industry but essentially facility managers make use of BIM and support their decision making process. Vaishnavi and Kuechler (2004) described a model of the general process followed by design science research and its multiplicity of as practice variants.

The process for design science research contains different steps and the expected outcomes from each step: (i) *Awareness of the problem* which uses different sources to find an interesting problem in an industry or a reference discipline. The outcome is the proposal, formal or informal, for new research effort. (ii) *Suggestion* is the following step from the proposal, it is an essential creative step where a new functionality is envisioned or enhanced from an existing one. (iii) *Development* which focuses on the novelty of the artefact being developed and does not necessarily be construction of an artefact but design of it. (iv) *Evaluation* is where the artefact is evaluated according to the criteria explicitly explained in the proposal. Deviations from expectation, both qualitative and quantitate, are carefully noted and must be explained. It also contains an analytic sub-phase where hypothesis are made about the behaviour of the artefact. (v) *Conclusion* is the end of the research cycle and final stage of the research effort. The result concludes with the deviations of the behaviour of the artefact from the revised hypothetical revisions. It places a great emphasis on the knowledge contribution in the area of research.

In this project we focus on the suggestion-development phase where the artefact is envisioned or partially created as part of the development phase.

5. Multi KPI Decision Support Tool

The development of Multi-KP is intended to support multidisciplinary work and enhance collaboration between projects teams. Also, it should support the facility manager, owner, decision maker, in analyzing the impacts of key performance indicators. The Multi-KPI tool helps teams to work in a more structured way but enabling flexibility and interaction in the analysis of alternatives facilitating the decision making process. Multi KPI tool uses concepts in the development of decision support systems (DDS) tools in information systems. As such, the Multi-KPI should function as a critical tool for the rapid comparison of different evaluation criteria that could support facility managers. Therefore, Multi KPI should help the complex decision making process, assist in evaluating alternative options or scenarios, deal with complexity and have a clear, reproducible procedure. The Multi-KPI is developed as a web-based decision making application that uses a graphical multi-attribute utility analysis to evaluate and compare alternatives based on key performance indicators.

5.1 Energy Simulation

Simulation modelling has been usually used for the facility´s energy performance. Augenbroe (2002) stated simulation modelling is now being more widely applied in post-construction phases such as commissioning and facility management. In fact, simulation has become an integral part of the whole building design, engineering and operation process. In this project we use energy simulation platform RIUSKA to obtain the different Key Performance Indicators related to energy consumption and CO2 emissions.

5.2 Cost Simulation

Lifecycle cost analysis is used to evaluate the economic feasibility based on the calculation of the equivalent values of all the important costs that occur within the life span, with particular focus on buildings or the major components of buildings. An LCCA is conducted using the following four steps. (i) The analysis target is identified, which is the first step toward making a cost-effective decision by creating and evaluating the alternatives that can meet the minimum performance standards. (ii) The basic assumptions are established for the LCCA, including the analysis period and discount rate. In addition, the initial investment cost, operating cost, alteration/replacement cost, and other associated costs are confirmed, and the time of occurrence of each cost is verified. Because these cost items occur at different points in time, it is important to convert each cost to the value at a single point in time. (iii) The LCC is calculated for each alternative by adding up the costs according to the type for each alternative. (iv) The related indices are calculated to evaluate the economic feasibility (the LCCA) including the net savings, savings-to-investment ratio, and payback period. In addition, a sensitivity analysis can be implemented to complement the LCCA methodology, which will provide reliability to the LCCA results.

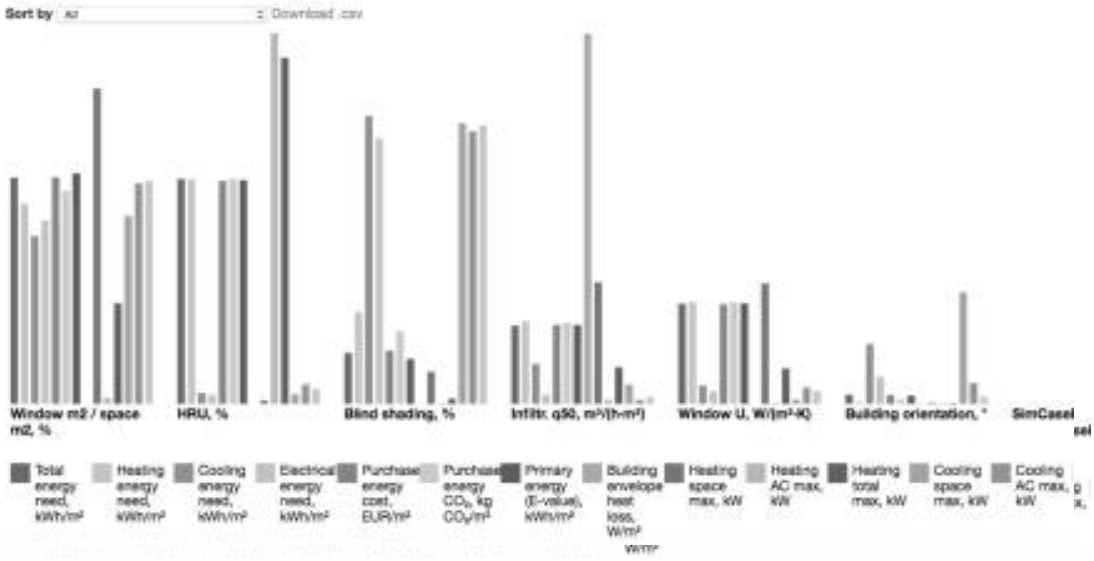

Figure 1: Visualization of the of key variables through a sensitivity analysis

5.3 Sensitivity Analysis

The subject of sensitive analysis (SA) is to learn about the influence each design variable has on the studied KPIs. This knowledge is needed to perform educated design changes to improve the design in exactly the desired way. The aim of the sensitivity analysis step is to find a design with optimised KPIs. Figure 1 illustrates a sensitivity analysis example.

5.4 KPI Visualization

Applying analytics to conceptual design has proven difficult because a problem typically has multiple targets and is imprecise with respect to one or more of these objectives (Shaw, Miles et al. 2008). The interaction of professional expertise and computer-based exploration therefore is essential for the process to be successful. Facility managers need to be able to understand general performance trends as well as variable sensitivities in order to make informed decisions in guiding the optimization process. Advanced plotting tools that enable multi-dimensional data visualization have proven useful for this purpose. such as pareto graphics (Khajehpour and Grierson 2003), hyper radial visualization, parallel coordinate (Parmee 2005; Parmee, Abraham et al. 2008) plots and radar charts have proven useful for this purpose.

Parallel Coordinate Plot (PCP) is a simple way to visualize multi-dimensional data in two dimensions as shown in Figure 2. PCP shows each of the desired variable and the KPIs are presented in parallel to the coordinate axes. Each axis can have its own value range and can either be continuous or discrete variables. Discrete variable axis enables the use of non-numerical values. The visualization shows the result obtained or the results of the values of the variables depending on the approach taken, and combined these with a certain result of all the values of the line between the axes.

Although the number of variables and the objective function that can be presented in this type of visualization can be infinite, the large amount of variables will make the visualization difficult to read and find correlations of the variables may be difficult. Appropriate use of the quantitative objective function variables and visualization strategies facilitate the use and understanding.

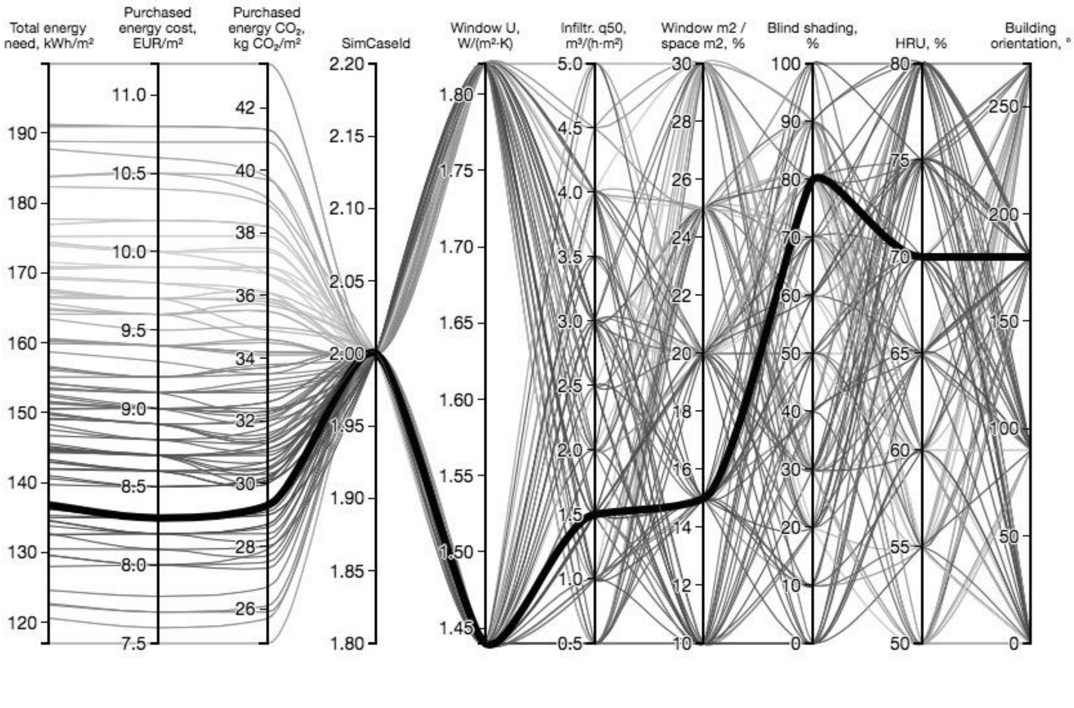

Figure 2: Parallel coordinate plot for the decision-making using the developed multi- KPI analysis prototype tool.

The value of the variable ranges can be adjusted so it facilitates the selection of the best solutions within a desired number of parameters and therefore achieve the best desired result. It is also easy to visualize by assigning to each result and its constituent variables on the line that falls within the desired ranges. The color visualization also helps to determine the most appropriate solution. By utilizing interactive visualization options to restrict the values of the parameters and their results, so that solutions that not fall within those parameters will change colors to for example, gray, therefore we can better focus on a limited number of solutions.

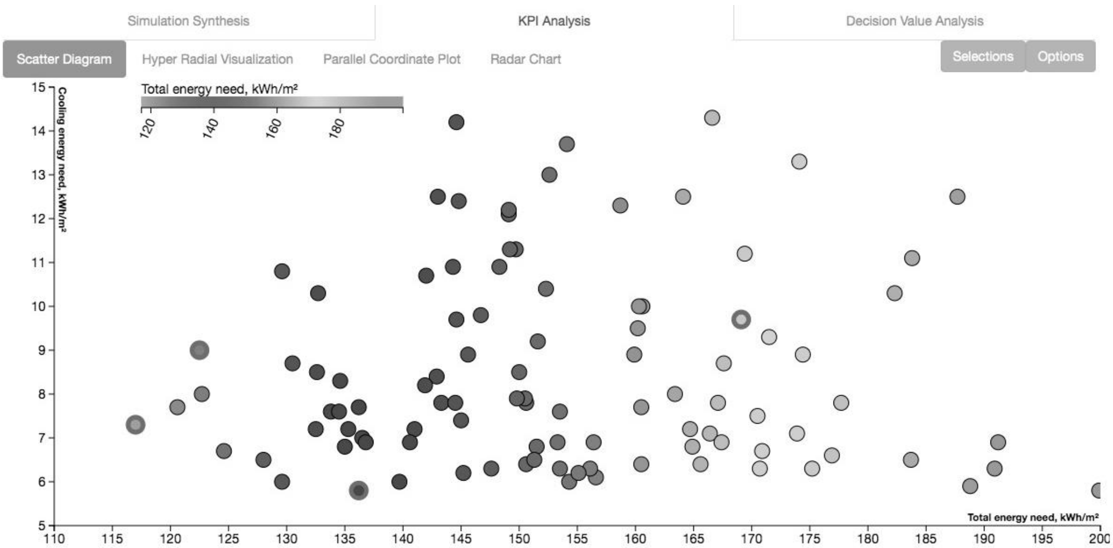

Figure 3: Decision making analysis via scatter diagram.

The scatter diagram is usually used to analyze the relationship between two variables. The pattern of the intersecting points can graphically show the relationship of the variables and usually validate or invalidate cause-and-effect relationships. Scatter diagram graph can be represented in two variables of the objective function, however a third variable is also possible but projection a three-dimensional visualization could be difficult to read and interpret in practice. A more intuitive way to use the third dimension is the coloring of the points of the third objective function value and the color legend, graphs, presentation as shown in figure 3.

6. Conclusions

As described above, FM is a complex and fast growing business that responds to the demands and economic pressures of the built environment. Latest trends indicate that FM, which traditionally focuses on technical issues, is having stronger impact on a strategic level. In other words it is developing from purely technical to more market driven service. The role of facility managers in early design should become more prominent. The use of different BIM tools enables FM professionals to make various long term predictions. The Multi-KPI which gathers different simulation results could be a powerful tool to be used by facility mangers to visualize different KPIs related to FM that can improve can their decision making process.

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Identifying the Inefficiency and Poor Performance of the Delivery of Services

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Abstract

The construction industry has had a history of non-performance in the delivery of services [in terms of on time and on budget]. Other industries such as IT and professional services have also experienced non-performance. The problem seems complex, as there are many participants who are involved in the project non-performance including the owner, the buyer, the vendor, sub vendors, manufacturers, designers, and project managers. An industry structure analysis proposes that the problem is caused by parties managing, directing, and controlling (MDC) another party. This could happen anywhere in the supply chain. This paper proposes that a major source of the non-performance in projects is caused by project managers who are managing the projects from the different construction supply chain participants including the owner, the designer, the vendors, and procurement. This has been identified in numerous project tests where the objectives of the test was to minimize the MDC in the projects and the major difficulty was the resistance from project managers. The paper also proposes that the project managers are educated to manage, direct, and control in their education and training, including their professional certifications from the Project Management Institute (PMI) and the International Project Management Association (IPMA).

Key words: project management, risk management, low performance, resistance to change, delivery of service

1. Introduction

Organizations in the construction industry have had problems with delivering services on time, on budget, with high customer satisfaction. This problem has been seen in multiple industries, particularly highly technical ones, such as construction and information technology. The poor delivery of services has been documented in the construction industry worldwide for over 30 years (Latham, 1994; Egan, 1998). However, after many years and billions of dollars invested in research, the solution remains elusive (Goff, 2014). Similar to the construction industry, the information technology (IT) industry has had similar documented performance information of poor delivery of services, and has struggled to efficiently and effectively complete projects since its origins. A literature search has identified the source of the problem is still unknown to industry in consistently and efficiently delivering high performance services. Very few in industry and academia have created a successful hypothesis, run cycles of tests, which resulted in the changing of industry practices (Kashiwagi, et al., 2008). The most impactful research identified, has led to conclusions that pre-planning is critical, hiring contractors who have expertise will result in better performance, and risk is mitigated when the supply chain partners work together, and expertise is utilized at the beginning of projects. One of the issues making it difficult to identify the problem of the poor delivery of services is the number of parties involved in the supply chain. The supply chain parties are segmented into various silos of communication. Each silo communicates using technical jargon. The technical communication increases complexity and make it more difficult to identify the source of inefficiencies. Research has also shown that the continued education of industry participants maintain the status quo and are perceived to be ineffective in driving positive change (Goff, 2014).

2. Problem

Due to the current reactive environment of delivering services, the result has been ineffective (Lepatner, 2007; PWC, 2009; Yun, 2013). Research has shown the following poor performance metrics:

- 2.5% of projects defined as successful (in terms of completing the full scope, on time and on budget).
- 30% of projects are completed within 10% of original planned cost & schedule.
- 25 to 50% of projects do not efficiently align labor on projects.
- Management inefficiency costs owners between $15.6 and $36 billion per year in the world.
- Rework by contractors is estimated to add 2-20% of expenses to a contractor's bottom line.
- An estimated $4 billion to $12 billion per year is spent to resolve disputes and claims.

The industry has struggled with overcoming poor delivery of services, and has not seen any significant improvement in the last 3-6 decades. The fact remains that the industry as a whole does not understand the source of its own problem and has not done anything effective enough to fix it. The problem is also being proliferated by multiple parties: manufacturers of systems and materials, owners, buyers, owner project managers, procurement personnel, general contractors (GC), subcontractors (SC), and GC/SC project managers. Literature research has shown that both the construction and information technology industries having significant documentation of the performance of the delivery of services. Both industries have had similar results. In the United States, construction performance has been low (Kashiwagi, 2013):

- Productivity has decreased by .8% annually.
- Construction companies have the second highest failure and bankruptcy rate (95%).
- Over 90% of transportation construction jobs are over budget.
- Almost 50% of time is wasted on job site.

According to numerous reports in information technology, the poor delivery of services has been similarly documented (Kashiwagi and Kashiwagi, 2014):

- US Accountability office identified 413 IT projects--totaling at least $25.2 billion in expenditures for the fiscal year of 2008 as being poorly planned, poorly performing, or both. With just under half being re-baselined at least once.

- European Services Strategy Unity reported 105 outsourced public sector ICT projects with 57% of contracts, which experienced cost overruns with an average cost overrun of 30.5% and 30% of contracts which were terminated.
- McKinsey & Company analyzed over 5,400 projects and reported 50% of IT projects on average are 45% over budget, 7% over time, 56% less value than predicted, and 17% of projects end so badly they can threaten the life of the company.

In a recent study to better understand why the performance of the delivery of services was poor, it was identified that the current delivery systems and management theories have been based on management, direction, and control. The study reviewed 780 publications in five major databases [EI Compendex, Emerald Journals, ABI/Inform, Google Scholar, and ASCE Library]. From the 780 publications reviewed, 103 delivery systems were analyzed and compared. Additionally, 10 company management models were assessed. Lastly, the top 22 major buyer/supplier theories were identified including: Lean Construction, Supply Chain Management, Total Quality Management (TQM), Just in Time (JIT), Project Management Body of Knowledge (PMBOK), and Conflict Management (Kashiwagi, 2013). In the study, the authors identified some management experts (e.g. Marcus Buckingham, Jim Collins, Edward Deming, Peter Drucker, W.L. Gore, and Ricardo Semler) that proposed that the management, direction, and control methodology is not an effective or efficient approach. Though repeatedly implemented by the management experts over the past seven decades, the non-traditional idea has not been recognized as a valid solution by current delivery methods or management theories. According to the management experts identified, MDC may be the cause of project nonperformance. Additionally, they identified the following as more accurate alternative concepts of practice to improve performance:

- Adjust structure to fit the constraints of the people.
- Select the right people and put into right position.
- Formulate team philosophy, draft people to fit into the philosophy, then change the philosophy to match the constraints of the people you drafted.
- Use the strengths of people.
- Take the path of least resistance; let nature take its course.
- Shift management model to an alignment model, which sets the environment and the course of the organization.
- Remove management, and create transparency, resulting in increased accountability of all stakeholders.
- Set up alignment model that empowers employees to choose their own work and who they will become accountable to until completion of work.

3. Proposal

The researchers propose to look into the traditional idea of management, direction, and control (MDC) to identify if the concept increases performance. The researchers propose to identify the results. If the results identify MDC does not improve performance then to create a new project management model that is not based on MDC and see if it can help resolve issues occurring in the industry.

4. Methodology

The researchers propose a mixed methods approach to carrying out the proposal, involving two types of research: Literature and Case Study research. To identify if MDC improves performance the following will be performed:

1. Identify the success of MDC in solving major social issues
2. Identify if construction has experienced the same results.
3. Confirm the potential source through testing.
4. Identify key components in the industry who can test out the solution.
5. Identify how to document, and proliferate the solution in the key components.

5. Success of MDC in Solving Social Issues

A literature search was performed to identify if the idea of management, direction, and control is a viable option to improve performance. In order to better understand this idea, and if it parallels what the management experts have identified, the researchers looked outside of the delivery of services area. The researchers identified dominant examples in society, where the principles of control were implemented. The goal was to potentially gain additional insights for the entire professional services community, to either strengthen the argument for or against the use of control principles. Some of the most dominant examples of societal issues were identified such as Prohibition, Drug War, Gun War, Prison System, and Immigration.

5.1 Prohibition

Prohibition will forever be one of the most dominant examples of one entity failing to control another. The United States just finished World War I and due to the progressive era [widespread social activism and political reform] in the U.S. in the late 1800's and early 1900's, alcohol consumption and politics were perceived to go hand in hand causing government corruption. In fact, many factions, including religious organizations were at the heart of the discussion. It was not until January 1917 that Congress first convened and began discussion and partial implementation of the removal of alcohol distribution to restrict access. On October 28, 1919, Congress officially passed the Volstead Act, overruling President Woodrow Wilson's veto, to enforce the eighteenth amendment (prohibition). Prohibition went into full effect January 1920; until it was repealed, December 1933 by the ratification of the twenty-first amendment signed into law as the Cullen-Harrison Act by President Franklin Roosevelt. The devastation that the era of prohibition left in U.S. history has been extraordinary. In total, the prohibition lasted nearly 14 years, and started with great intentions to decrease crime through the removal of alcohol distribution and access to consumption (Burns, et al., 2011; Tracy and Acker, 2004). What actually occurred was the following:

- Increased law enforcement.
- Increased funding.
- Increased access to alcohol.
- Increased alcohol consumption.
- Increased criminal activity.
- Decreased taxes collected through alcohol.

The government's attempt to control the American people attempting to restrict access and consumption did not work and only increased costs without decreasing access or consumption. People will always do what they want. Some additional dominant statistics are the following (Blocker, 2006; Peck, 2011; United States, 2008; US Treasury Department Bureau of Industrial Alcohol, 1932; Warburton, 1932):

- Prohibition law violations increased 102%.
- Drunkenness and disorderly conduct increased 41%.
- Drunk driving increased 81%.
- Theft and burglary increased 9%.
- Federal convicts increased 561%.
- Total federal expenditures increased 1000%.

5.2 Drug War

Popularized by President Richard Nixon in 1971 with his public declaration "America's public enemy number one in the United States is drug abuse," the drug war has its roots starting in the 1800s. Opium was beginning its popularity in the American Civil War, and cocaine was just as popular. Drugs like cocaine, heroin, and morphine were readily accessible for medicinal purposes in both health drinks and remedies. Due to an increase in addiction to these drugs, the first set of regulations to control it and restrict access was in 1906 when the Pure Food and Drug Act began requiring doctors to label their medicines. Shortly after, a number of increasingly more serious regulatory statutes took effect, such as the Harrison Narcotics ACT in 1914 (first federal drug policy), down to the creation of the Federal Bureau of Narcotics in 1930 (Sharp, 1994; Rosenberger, 1996). Though many attempts to restrict access and consumption through regulation was good intentioned, it found its match during the flower revolution of the 1960's. Access to drugs and its consumption was at an all-time high during this decade, to the point that it caused the newly elected President Nixon to make an address against drugs that has lasted over 40 years. Not using hindsight and learning from Prohibition regarding restriction of access and consumption of substances, the war on drugs has utilized more resources and seen less improvement than the Prohibition of 1920.

Interestingly, the U.S.'s second attempt to use MDC to restrict access and consumption of substances has resulted in the following (Drug War Facts, 2014):

- Increased funding from less than $100M to over $25B.
- Increased law enforcement.
- Increased arrests from 1M to as high as 2.5M.
- Increased prison population over other arrests by over 50%.
- Maintained or increased drug use.

5.2.1 Portugal/Netherlands/Canada/Uruguay

Realizing the drug war has increased cost without decreasing consumption or criminal activity, four countries (Portugal, Netherlands, Canada and Uruguay) have all decided to decriminalize the use of drugs in some way. The Netherlands decriminalized drugs in the 1970's, Portugal in 2001, Canada in 2003, and

Uruguay in 2013. The Netherlands and Portugal governments created committees of the smartest minds to study the effects of drugs and the cost to continue enforcing rules and regulations. What is interesting though is in the Netherlands, all drugs are illegal, but the government recognizes any form to control it only causes greater issues. Instead, they have tolerated the use of drugs at a certain limit sold in coffee shops, which has resulted in drug use levels no greater than other countries and drug related deaths (2.4M) being the lowest in Europe (Mayer, 2014; Hari, 2015). According to the latest performance information published on Portugal's decriminalization of all drug use, the numbers show similar results (Aleem, 2015):

- Continued drug use decreased from nearly 45% to less than 30%.
- Drug induced deaths decreased from nearly 80% to less than 20%.
- HIV infections decreased from nearly 45% to less than 10%.
- Increase in drug treatment by nearly 50%.

What each of these countries realized, was the prevention of drug use by increasing control does not work, and it is better to help align the people then punish them.

5.3 Additional Dominant Control Examples

There are many other examples documenting the inefficiency of control, and how the use of no control, has increased production and reduced cost and time:

1. Gun Laws – the U.S. "removal of guns" activists have attempted to have laws passed as a form of control to decrease access to guns and deaths of violent gun users. This attempt to prevent the access to guns and prevent death has only increased cost of the ATF (Bureau of Alcohol, Tobacco, Firearms and Explosives), without a significant decrease in deaths or access (U.S. Department of Justice, 2010).
2. Prison Systems – The U.S. thought that it could control the people they incarcerated to educate and rehabilitate them to prevent them from committing further crimes. The U.S. in general has been unable to reduce the number of law breaking individuals through incarceration, and has been one of the largest failures of control (ProCon, 2010).
3. War on Poverty – In the 1960's the U.S. declared "war on poverty." It has tried to use control to level the poverty in the U.S. through multiple government-controlled programs. The reduction of poverty has not been successful (National Poverty, 2014).

History has identified that one entity cannot control another entity; therefore, any attempt to manage, direct, and control someone should produce consistent predictable results of low performance. Similar to the findings of the management experts that any attempt to use management, direction, and control are not effective and efficient, has become evident in the social case studies presented. The pattern identified seems to be that when one entity attempts to manage, direct, and control others, the opposite desired outcome occurs instead. Whenever control is exercised, the following occurs:

- Cost increases.
- Time and resources increase.
- Increase in stress and decision-making.
- Risk increases.
- Overall performance diminishes.

Based on observation and deductive logic, the practice of MDC is inaccurate and increases risk. In the whole history of man, many people have attempted to control others with no success. The delivery of services is no different. The industry has been plagued with MDC, and it is the leading cause for all poor project performance (Kashiwagi, 2013).

6. Longitudinal Case Studies: Minnesota and MEDCOM

In order to better understand if MDC was a viable option to improve performance in industry, a two six-year longitudinal study [users in the state of Minnesota and the U.S. Army Medical Command (Table 4 and 5)] was conducted. Each user used a best value (BV) system called the Performance Information Procurement System (PIPS). PIPS is a revolutionary approach to improving the delivery of services. PIPS proposes the replacement of management, direction, and control with the utilization of expertise. The system was first conceived in 1991 as part of Dean Kashiwagi's dissertation (1991). PIPS was originally, strictly a selection process. The first test of the process was performed in 1994, used to select roofing systems and contractors for private organizations including Intel, IBM, and McDonald Douglas. The system was documented and performed so well for the roofing industry, the system spread to other construction areas. PIPS has since been tested in the entire supply chain (construction and non-construction services). Its developments have been researched and developed, by the Performance Based Studies Research Group (PBSRG) out of Arizona State University (ASU), in support of professional groups like the International Council for Research and Innovations in Building and Construction (CIB) and the International Facility Management Association (IFMA) for the last 23 years, and has been identified as a more efficient approach to the delivery of professional services. It has identified that the main cause of non-performance in delivering services is due to management, direction, and control. The two studies identified the following similar issues:

- Inefficient internal management structure.
- Poor performance in the delivery of services.
- Did not know how to identify the performance of their services.
- Looking for an approach to help them improve their project performance.
- Needed a way to improve the management structure.

The BV system identified the following observations:

1. BV application has been a total success by providing transparency.
2. Expertise lowers costs and increases performance.
3. An expert vendor can accurately identify a projects scope and cost.
4. Measurement brings transparency and minimizes decision-making and MDC.
5. A visionary core team must be organized that is optimal in terms of a high-ranking visionary leader, and visionary project management and procurement components.

Table 4: U.S. Army Medical Command Best Value Performance

Completed Projects	*NTP 2007*	*NTP 2008*	*NTP 2009*	*NTP 2010*	*NTP 2011*
# of Projects	*110.00*	*129.00*	*122.00*	*92.00*	*27.00*
Original Awarded Cost ($$)	*$181,945,282*	*$177,275,551*	*$183,989,041*	*$107,091,486*	*$16,278,439*
Final Awarded Cost ($$)	*$193,881,007*	*$187,844,708*	*$192,602,961*	*$110,952,677*	*$16,352,909*

Total Over Budget ($$)	*$11,935,725*	*$10,569,156*	*$8,613,920*	*$3,861,190*	*$74,470*
Total % Over Budget	*6.56%*	*5.96%*	*4.68%*	*3.61%*	*0.46%*
% due to owner	*4.58%*	*5.59%*	*3.61%*	*2.36%*	*0.46%*
% due to designer	*0.00%*	*0.14%*	*0.00%*	*0.21%*	*0.00%*
% due to contractor	*0.11%*	*-0.17%*	*-0.01%*	*0.08%*	*0.00%*
% due to unforeseen	*1.88%*	*0.40%*	*1.09%*	*0.96%*	*0.00%*
Total % Delayed	*51.56%*	*48.43%*	*36.77%*	*28.53%*	*3.31%*
% due to owner	*41.38%*	*39.96%*	*28.51%*	*16.53%*	*9.20%*
% due to designer	*0.00%*	*0.49%*	*0.00%*	*1.32%*	*0.00%*
% due to contractor	*1.86%*	*-0.02%*	*1.29%*	*0.12%*	*-6.40%*
% due to unforeseen	*8.32%*	*8.01%*	*6.97%*	*10.56%*	*0.51%*

Table 5: State of Minnesota Best Value Performance

General Overview	*Overall*	*Group A*	*Group B*	*Group C*	*Group D*	*Group E*	*Group F*	*Group G*
Total Number of Projects	*399*	*1*	*8*	*21*	*10*	*3*	*355*	*1*
Total Awarded Cost ($M)	*$434.88*	*$0.19*	*$37.81*	*$17.24*	*$5.07*	*$29.50*	*$332.70*	*$12.36*
% where BV was lowest cost	*54%*	*0%*	*83%*	*42%*	*33%*	*33%*	*55%*	*0%*
Overall $$ Change Order Rate	*8.83%*	-	*3.73%*	*4.04%*	*1.27%*	*2.54%*	*10.16%*	*4.53%*
Owner/Client	*7.61%*	-	*2.15%*	*1.08%*	*0.33%*	*0.34%*	*8.83%*	*1.16%*
Designer	*0.69%*	-	*1.68%*	*2.07%*	*0.63%*	*1.57%*	*0.33%*	*2.55%*
Contractor	*0.01%*	-	*-0.21%*	*-0.17%*	*0.00%*	*0.00%*	*0.01%*	*0.21%*
Unforeseen	*0.52%*	-	*0.12%*	*1.06%*	*0.31%*	*0.63%*	*0.51%*	*0.62%*
Overall Schedule Delay Rate	*47.17%*	-	*35.31%*	*1.59%*	*16.38%*	*7.44%*	*51.68%*	*12.73%*
Owner/Client	*21.92%*	-	*15.26%*	*0.00%*	*7.41%*	*3.93%*	*24.13%*	*5.45%*
Designer	*4.47%*	-	*5.69%*	*1.59%*	*8.97%*	*0.00%*	*4.48%*	*7.27%*
Contractor	*2.65%*	-	*10.93%*	*0.00%*	*0.00%*	*3.51%*	*2.42%*	*0.00%*
Unforeseen	*4.54%*	-	*3.42%*	*0.00%*	*0.00%*	*0.00%*	*5.04%*	*0.00%*
Number of Satisfaction Surveys	*233*	*0*	*2*	*18*	*0*	*0*	*212*	*1*
Vendor	*9.5*	-	*9.0*	*9.9*	-	-	*9.5*	*8.8*
Selection Process	*9.7*	-	*8.5*	*10.0*	-	-	*9.6*	*10.0*

Table 4 and 5 both identify the results of both studies. The following conclusions were made:

- The owner/client and their representatives were the biggest source of project deviations.
- The BV PIPS minimized the cost and time deviations.
- The vendor performance was outstanding when the owner/client minimized MDC.
- Cost was minimized and within the budgets.

7. Analysis

The research conducted by PBSRG identified the solution to the inefficiency of delivering services was in the overall structure of the industries and not a technical issue in any of the industries. It also showed the potential of the BV PIPS [utilizing expertise] to improving industry performance. Each BV case study shows a dominant improvement in performance of delivering services, simultaneously decreasing owner/client MDC. The case studies support the following concepts of the BV approach:

- The replacement of MDC with the utilization of expertise may be the most needed change required to improve industry performance.
- The utilization of expertise leads to lower costs, higher performance, and value. This is despite some industry perception that expertise is too costly. Then, when faced with massive failure due to the utilization of vendors without adequate expertise, they blame the complexity of the projects.
- If the expert must be managed, directed, and controlled, they are defined as a non-expert.
- Transparency minimizes the level of complexity and increases the value of experts and their expertise.

8. Proliferating the BV Solution

The very successful BV approach has been researched and developed for 22 years in construction and non-construction industries, and has been shown as an alternative to delivering services with documented performance information. It has been identified as a complete procurement/risk management system. The same technology has been taken into the classroom of the ASU Barrett's Honors program, and has had the following results:

1. Most popular Honors class at ASU [Rate my professor rating of 4.9 (out of 5.0), 150 slots fill up in less than an hour, ASU engineering class ratings of 4.7 (out of 5.0), led to identification of Dr. Kashiwagi being one of the top teachers in 2013].
2. Students with problems have made drastic improvement in their personal lives to stop taking pharmaceuticals, stop drinking, implementing a life makeover, becoming transparent, and having an increase in accountability and responsibility.
3. Students learn complex concepts four to five times as quickly using natural laws, simplicity and common sense.

The Barrett's Honors College has exposed the innovative solution to 7th and 8th graders in summer programs. The results have been outstanding. The high school education effort has paved the way for additional BV endeavors. The curriculum from the course has been compiled into a single class package that can be incorporated into any educational program. The results of the BV college and high school courses has led to additional key partnerships:

- St. Louis High School, a prominent school in Honolulu, Hawaii, has adopted a semester-long curriculum in the fall of 2015. A second private school in Honolulu is also interested in the education program
- A successful summer 2015 program was tested on 116 undergraduate Brazilian engineering students. This effort was carried out to identify if the BV-FM education could be taught quickly (in two months) and could attract students with limited English capability to the methodology.
- Tempe High School has initiate a semester long leadership academy at the first high school in the Tempe School District. The program is being pushed by an ASU coordinator who has watched the ASU honors program, the Barrett Summer Scholars program, and the 2015 successful Brazil undergraduate engineering program

Many other entities in the supply chain can benefit from the testing and implementation of the BV solution to include PMI, IFMA, IPMA, NIGP, Union organizations, Owners, Contractors, Manufactures, K-12 institutions, and Universities. The future of delivering services is to educate professionals to become someone who can utilize expertise and not manage, direct, and control. They must be able to escape their silo to increase value to the company by utilizing expertise to minimize cost.

9. Conclusion

Organizations have struggled for decades to deliver services efficiently and effectively. Due to increasing numbers of parties in a supply chain, projects have become more complex and less transparent. Due to the complexity of projects, management, direction, and control has become a staple practice in attempt to increase performance. Many project management models and delivery systems have not moved from the practice of management, direction, and control, and it has been identified as the leading cause for non-performance. Management experts such as Deming, Buckingham and others, along with dominant societal case studies such as the Prohibition and the Drug War have clearly identified that any attempt to manage, direct, and control others will result in low performance. A new approach called BV PIPS, which shifts the use of management, direction, and control to utilizing expertise, has been significantly documented to improve the performance of delivering services, and closely relates to the principles of no control identified by such management experts. The researchers further identified that the same solution, BV PIPS, is applicable to all supply chain participants in all industries, and the most important participant is the “project manager” who is doing the integration between silos in the supply chain. Lastly, the BV approach education program has been shown to successfully increase the number of highly qualified entrants into the professional industry. In testing the education curriculum on college and high school students, it has been found that students of varying ages, backgrounds, and degrees of study can learn proven high-performing industry management techniques. Students can begin learning these concepts at a young age, thus creating a pipeline of competent students entering industry. The researchers recommend future research to take project managers and propose a methodology to educate, apply, and document the results of their efforts, as well as create a pipeline of qualified and competent young students entering industry.

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Lean Collaboration Services One Click Away – Should We Stay or Should We Go?

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Abstract

Ability of individuals to work independent of time and place alter the optimal way of supporting core tasks of mobile workers in physical and virtual environments. Information resources are increasingly accessible to individuals, decision making power is shifting from organizations to individuals, sizes of organizations shrink, number of organizations increases and value is increasingly generated by smaller collaborating actors in networks rather than massive individual organizations. These shifts make collaboration facilitation more complex: partnering organizations and their employees are more and more scattered which creates demand for services that connect people to collaborate physically and virtually.

Collaborative practices, such as meetings and workshops, are being arranged and managed in both physical and virtual environments. Collaboration that takes place in virtual platforms is usually considered less time-taking and more sustainable in terms of carbon footprint but often include major technical nuisances. On the other hand, face-to-face collaboration can be considered more straight forward and fruitful but getting everyone in the same meeting room at the same time can be a challenge.

Therefore, this paper explores the service potential of facilitating collaborative practices by supportive services that are manifested in virtual and physical dimensions of space. It aims to increase understanding on the literature gap between virtual and physical work environments and reflect it to literature on collaborative knowledge work. It does so by first introducing lean management approach and knowledge worker typologies. Second, it discusses results of fourteen interviews and three workshops on collaborative knowledge work practices. Third, it synthesizes the results. Fourth, it discusses the implications and limitations of the study.

Keywords: Collaborative practice facilitation, Facilities management, ICT management

1. Introduction

Knowledge workers can increasingly work independent of location and time (Laing 2014). Technology enables flexible working opportunities providing more freedom of choice regarding where, when, with whom and how each individual works. At the same time, the ability to dictate work habits from the top of the organisation down to individual employee decreases. Organizations are becoming flatter, boundaries between organizational silos are blurring, and increased flexibility allows more agility and change responsiveness (GSA 2009). The new setting requires more proactivity from both the organizations and the employees.

At the same time, According to a study with 578 respondents on national meeting habits in Finland (Kokousbarometri 2015), an average employee attends seven meetings in a week, spends nine and a half hours attending meetings and over six hours to other meeting-related tasks weekly. With the average of six persons attending each meeting, one meeting is worth an individual work day, eighteen per cent of the meetings are arranged from a distance, a fourth of the meetings were considered to be possible to arrange without a meeting and 42% of the meetings are considered inefficient. Three fourths of all the meetings were reported to be internal. 56 % of the informants of the study thought that there are always or seldom too many meetings.

But the dilemma is that an increasing amount of value and knowledge is co-created 1) through internal collaboration interactions in groups rather than by any single employee alone, and 2) through external collaboration together with the partners and the customers. The increased freedom causes a variety of manners of conducting tasks which does not come without its implications. It is increasingly difficult to match times, locations and activities with peers, colleagues, clients and partners. Need for collaboration exists but an increasing amount of time is wasted in trying to collaborate rather than collaborating both in physical and virtual spheres. Collaboration activities require thus more effective facilitation and services to support them.

To understand the collaboration dynamics in physical and virtual spheres, this paper outlines the opportunities and challenges in arranging collaboration activities face-to-face and from a distance. It aims to increase understanding on service potential regarding support for collaborative knowledge work.

It does so by first introducing lean management approach and knowledge worker typologies. Second, it makes an overview of novel collaboration tools available on the market. Third, it discusses results of fourteen interviews and three workshops on collaborative knowledge work practices. Fourth, it synthesizes the results. Fourth, it discusses the implications and limitations of the study.

1.1 Literature overview

1.1.1 Lean approach to physical and virtual collaboration

Lean thinking is a business management approach which aims to capture customer value in value creation phase (Koskela 2000). Lean can be approached through three main concepts:

customer value, waste and continuous improvement (Jylhä 2013). Increasingly, as the value is co-created with the customers (Grönroos and Ravald 2011), customer value refers to the subjective perception of a service or a product for the customer. Waste refers to the types of activities that are conducted but that do not create any value for the customer (Jylhä 2013). Continuous improvement refers to the requirement of constantly improving processes and operations to minimize waste and to stay competitive in customer value creation (Jylhä 2013).

Two valid measurement concepts in lean especially in regards to collaborative activities are resource efficiency and flow efficiency. Resource efficiency is about optimizing at the level of an expert individual. Flow efficiency is about optimizing as a team for a feature. (Rothman 2015). In terms of lean for collaboration, the latter is more valid.

Lean concept originates from Japanese car industry and has been largely used in product development practice (Rothman 2015). It has also been introduced in the field of construction management (Koskela 2000) and more recently in real estate management (Jylhä 2013). In addition, scholars in IT production have discussed lean (Plenert 2012). Lean has also been discussed in the context of team effectiveness between teams that regularly meet face-to-face (Van Dun and Wilderon 2012) and those that are globally virtual (Maznevski and Chubova 2000).

Van Dun and Wilderon (2012) outline five fundamental rules in literature of Lean orientation to management:

1. Specify the value-creating and non-value creating activities from customer perspective.
2. Identify all the necessary steps to produce the service across the whole value stream.
3. Ensure that value-creating actions flow without interruption.
4. Only make what the customer requests.
5. Continually remove waste at work as it is uncovered.

They furthermore identify four main enablers for effective lean team collaboration: Higher level leadership Support, Strategic and Structural clarity, HR policy, Resource Abundance.

However, there are no studies looking at lean as an overarching approach to compare physical, virtual and hybrid ways of collaborating in teams. Therefore, this piece of research aims to build bridges over the disciplinary silos by focusing on identifying the customer and the waste types in collaboration activities in knowledge work.

1.1.2 Knowledge worker as a customer in physical, social and virtual spheres

So if the organisations consist of individuals and the aim of workplace infrastructure is to support organisations, let us assume that a lean team is an ideal way of removing waste from organizational knowledge practices. The question for the managers of the supporting infrastructure then is: What does it take to facilitate these knowledge workers in the future?

To identify what actually creates value for the customer, we need to first identify the customer. In the context of providing services for collaborating knowledge workers, the demands are heterogeneous. The dilemma is that not all the knowledge workers are the same, not all their activities are the same, and not all their demands are the same. The most suitable working styles for each individual depend on the relative tasks, abilities, personal preferences and relationships with other members in relation to the organization, the team and the projects underway. Then again, not all the individual wishes can be fulfilled as individuals tend to be selfish and might not see a greater good. An interesting example is that of Yahoo's back to office campaign some years ago.

There are various approaches to categorizing knowledge workers. We hereby briefly review some of the most recent shifts and typologies from social, virtual and physical knowledge facilitation aspects. The most relevant points are listed in Table 1.

Table 1. Literature insights on knowledge worker types and supportive services from different branches

	Approach	Conclusion	Field of research
Van Dun and Wilderon (2012)	Enablers for effective lean team collaboration	Higher level leadership Support, Strategic and Structural clarity, HR policy, Resource Abundance	Lean for knowledge management
Reinhardt et al. (2011)	Knowledge worker roles and actions	Personas of controller, helper, learner, linker, networker, organizer, retriever, sharer, solver and tracker.	Knowledge management
Morgan (2015)	Shift from knowledge workers to learning workers	Learning overcomes knowing.	Knowledge management
Bennett et al. (2012)	Four generations at workplaces	Facilitation of knowledge exchange between generations through mentoring millennials, teamwork, collaborative working and virtual workplace.	Physical workplace management
Lake (2014)	Smart flexibility	Flexibility means the same work with different tools at different times in various locations.	Physical workplace management
Matthews et al. (2011)	Collaboration personas	Collaboration personas for Community of practice, Project team and Task team.	Virtual workplace management
Miller and Marsh (2014)	Digital renaissance	Technology is most effective when invisible.	Virtual workplace management

From the social knowledge facilitation point of view, Reinhardt et al. (2011) outlined nine roles and action types of knowledge workers that all contribute to the overall organisation: Controller, helper, learner, linker, networker, organizer, retriever, sharer, solver and tracker. Morgan (2015) suggests that the whole concept of a knowledge worker is challenged by that of learning workers as knowing is not useful anymore when all the knowledge is available but rather ability to learn.

On the other hand, from the physical knowledge facilitation side, Bennett et al. (2012) discuss the tricky situation of facilitating four different generations at workplaces at the same time and approaches the problem from a merely demographic aspect. In general, the technical capabilities and attitudes towards working between the generations are different and in addition, the heterogeneity among each generation is huge. Bennet et al. (2012) suggest four workstyle criteria to overcome these problems: Mentoring Millenials, Teamwork, Collaborative working and the Virtual workplace.

Lake (2013) introduces the idea of flexible working. In his view, flexible working is not about doing a radically different kind of work. It is about doing basically the same work with different tools at different times in various locations. Both of these dynamic ideas increase individuals' autonomity, proactivity and demand for education and common rules for collaboration.

Matthews and her peers (2011) propose collaboration personas as a design tool for workplace collaboration in the virtual sphere to unleash collective intelligence. They outline two main problems in virtual collaboration tools: the adoption problem and the use of inappropriate tools for collaboration. They argue that the end user segments in digital tool planning tend to focus on individual rather than collaboration needs. Thus, they outlined three types of teams: A *community of practice,* A *project team, a task team.* They also identified four phases of collaboration: Starting, Planning, Executing and Reporting. Miller and Marsh (2014) discuss the role of digital renaissance in the workplace, arguing that technology is most effective when it is invisible.

A proposal for the interrelations of the different dimensions are shown in Figure 1.

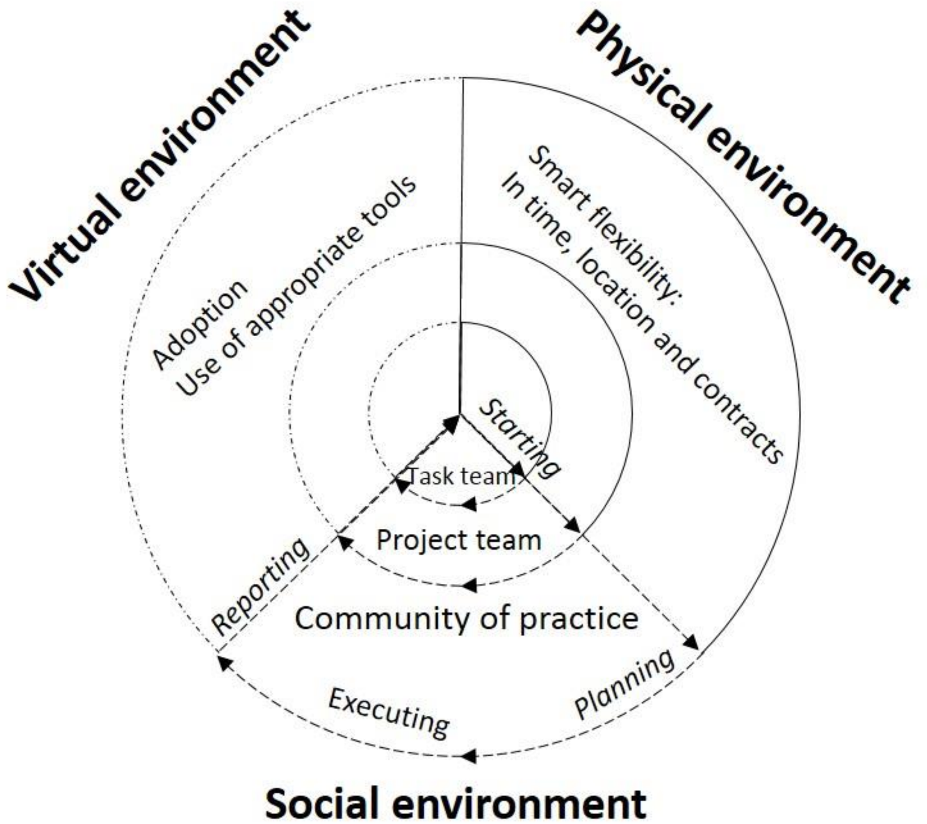

Figure 1. Interrelations of social, virtual and physical workplace environments.

Figure 1 pinpoints the demands of meeting more face-to-face in the beginning of any project and then again the ability of collaborating virtually in order to execute and report the collaborative tasks.

1.1.3 Waste from collaborating knowledge worker point of view

The actual value of any supporting service for a collaborating team of knowledge workers is getting their job done, i.e. creating value to a customer or various customers. In reality, much time is wasted in non-value creating tasks that could be automatized or totally neglected such as searching for an appropriate meeting place, ordering appropriate food, searching for a parking place, searching for emails, colleagues arriving late to meetings, connections not functioning, and so on.

So in terms of the outlined research problem, the customer is a team of collaborative mobile knowledge workers. The most simple collaboration activity, such as a meeting, can include multiple potential added values and waste flows from the knowledge worker point of view. This section explores literature on types of collaboration wastes in three scales of real estate service, office and meeting.

Jylhä (2013) identified six sources of waste in real estate services: price minimisation over cost minimisation, poorly managed information, inability to improve, unmatch between process and customer value, sub process optimization over value creation process optimization, and constantly overemployed employees.

Taylor (2014) claims that as much as 90 % of all the work in the office can be considered waste. Taylor suggests that waste in an office can be seen to include at least process, physical environment, information and people waste. In the physical sphere, the largest nuisance in an office is interruption which can happen as frequently as every three minutes (Taylor 2014). Furthermore, Taylor (2014) claims, that it takes 20 minutes to get focused again on the task one was conducting before interruption.

According to a national query in Finland, on average two hours per person per week is waste in meetings (Kokousbarometri 2015). The main nuisance was considered to be not sticking to agenda, the second largest issues was someone being late from the meeting, the third getting to the actual agenda, the fourth the decision making and the fifth the unfunctioning meeting tools and equipment (Kokousbarometri 2015). It was concluded that on average in an organization of a hundred employees, the potential savings that could be achieved by removing waste from meeting practices reach up to 1,5 million € annually and save 5 hours 22 minutes from an employee's average week.

On the other hand, offices facilitate informal encounters that can help in proceeding with projects without heavy meetings. In comparison to offices, working from home increases solitude and the amount of information waste which is the largest nuisance in the virtual sphere. One can easily get carried away by overflowing email boxes and endless social media and link jungles. Working from third places can potentially increase interaction outside the home organization but requires more proactivity from the knowledge workers.

1.1.4 State-of-the-art of available collaboration services

What kind of services are there on the market to remove the outlined wastes? There are plenty of applications to help multinational corporations in collaboration such as Trello, Fingertips, Slack, Dropbox, Microsoft OneNote, Outlook, Skype for Business, Adobe Connect, Sharepoint, Google Drive, Doodle, etc. To get an idea, this chapter outlines examples of these kinds of services that could help in removing the waste types identified in literature.

For unfunctional equipment, there tends to be helpdesks and centers but physical help is rarely available. However, some office space providers such as Technopolis offer a service where the virtual meetings begin and end automatically whenever wanted and support is available during the office hours.

For sticking to agenda, there are various types of tools that help in focusing on relevant topics. One example is Trello that provides a visual tool for organizing and following project execution. Another software is called Fingertip which helps before, during and after the decision making with various integrated tools. In physical sphere, there are various small and medium sized consultancies that provide professional – usually thematic - facilitation services such as Fira Verstas.

For the waste theme of unfunctional tools for information processing, there is a vast variety of softwares and applications available. The softwares tend to focus on a specific task of organizing, sharing, reporting or executing a task. The problem is, however, that they are not always integrated, meaning that the application may not discuss with each other. That is why for example a company called Apped mainly provides mobile applications that are always integrated to the business softwares.

To overcome the waste of getting to the agenda, applications such as Trello, Fingertip and Onenote help by visualizing tasks, responsibilities and following the decision making. Fingertip also provides a larger tool box for planning before, executing during and analyzing after decision making.

For motivating latecomers to be on time, there are not as many solutions on the market, but Latejar is an example of a gamelike app where people are motivated to come early because otherwise they would need to pay to the Latejar based on the time they are late.

Table 2. Examples of waste types in different scales and dimensions

Waste in real estate services (Jylhä 2013) for community of practice (Matthews et al 2011)	Waste in office (Taylor 2015) for project team (Matthews et al 2011)	Waste in meetings (Kokousbarometri 2015) for task team (Matthews et al 2011)	Mainly manifested in dimension	Existing services
Price minimisation over cost minimisation	Physical	Unfunctional equipment	Physical	ie. Technopolis help center, Sharepoint
Poorly managed information	Information	Not sticking to agenda	Virtual	ie. Trello, Fingertip, Facilitation consultancy services such as Fira Verstas.
Inability to improve		Unfunctional tools to process information		ie. Trello, Slack, Fingertips, Outlook, OneNote, Yammer, Twitter, Facebook, Whatsapp, Silverbucket, Apped, Sharepoint, Doodle, Google Drive, Dropbox, QlikID, Salesforce.
No match between process and customer value	Process	Getting to the agenda	Social	ie. Trello, Fingertip, Onenote, Facilitation consultancy services
Sub process optimization		Decision making		ie. Fingertip
Employees are constantly overemployed	People	Latecomers		ie. Latejar

This literature and market overview outlined a proposal for approaching collaboration in physical, virtual and social dimensions of space. The proposal is utilized by reflecting the empirical analyses to it in the next section.

2. Method

This paper combines literature overview and service analyses with empirical data using the approach of building propositions based on case study evidence as suggested by Eisenhardt (1989). First, it looked into the types of collaboration activities in the network era by introducing recent modern knowledge worker persona types that scholars have identified in literature in fields of knowledge, workspace and ICT management. Second, it focuses on analyzing data from 15 interviews and 3 workshops on collaborational activities in physical, social and virtual dimensions of space.

The interviews were semi-structured and they aimed to identify the typical wastes and potential sources of improvement for collaborating activities in physical, social and virtual sphere. The interviews were conducted, transcribed and analyzed by the research team consisting of four researchers from November 2014 to November 2015. The analyses were done in a two day workshop with a sensemaking technique where three of the researchers who had conducted the interviews together read and discussed each interview based on which they synthesized the results.

The analyses structured the data in three waste and improvement clusters from front-end and back-end aspects of a service organization. Accordingly, the waste types can be approached through social, physical and virtual lenses. The potential for improvement in these dimensions is introduced in Table 3.

Table 3. Potential for improvement in collaboration services in social, physical and virtual spheres

	Front-end improvement potential	Back-end improvement potential
Social	Clear package, one click away	Easily accessible services, one touch point
Physical	Location and equipment	Big data and tracking
Virtual	Education for applications	Connectivity and analyses of big data

First, it is noteworthy, that the users are individuals in a hurry who try to reach each other and be effective. Thus, simple clarity of any collaboration service is crucial in collaboration services. From the end-user perspective, it is increasingly relevant to have a clear unique package the content of which is clear, to have one touch point and be one click away from whatever is needed for the collaboration activity– so whatever one needs, there has to be one clear instance responsible for it and it has to be easily accessible. From the service provider aspect, the services must be made easily accessible and clear eventhough there would be multiple providers. The user must know one place one click and one package that is relevant for him / her.

Second, the location of collaboration activities is crucial. The informants found it irritating to be always changing places and to be searching for the optimal solution where to work in depending on whom to meet. From the service provider aspect, this means that big data usage is crucial for improving services for collaboration. So tracking collaboration activities based on which services can be directed to the right places. The same technological solutions must be available everywhere, so that users from different locations can do the same things.

Third, the management of overflowing information was considered tricky. The lack of education for new applications was seen as a major reason why technology is not in as good use as it could be and digital detox was considered a way of exiting the constant information flow. Connectivity issues were considered frustrating which must be taken care of by the collaboration service provider whether it is access to files or connecting a video conference call. Also the analyses of the real time big data has to be taken care of in order to direct services better proactively rather than reactively.

3. Results

The results propose collaboration activity guidelines that can be clustered in physical, virtual and social clusters. The improvement and waste types of these clusters can be approached from front-end (end user) and back end (service provider) aspects.

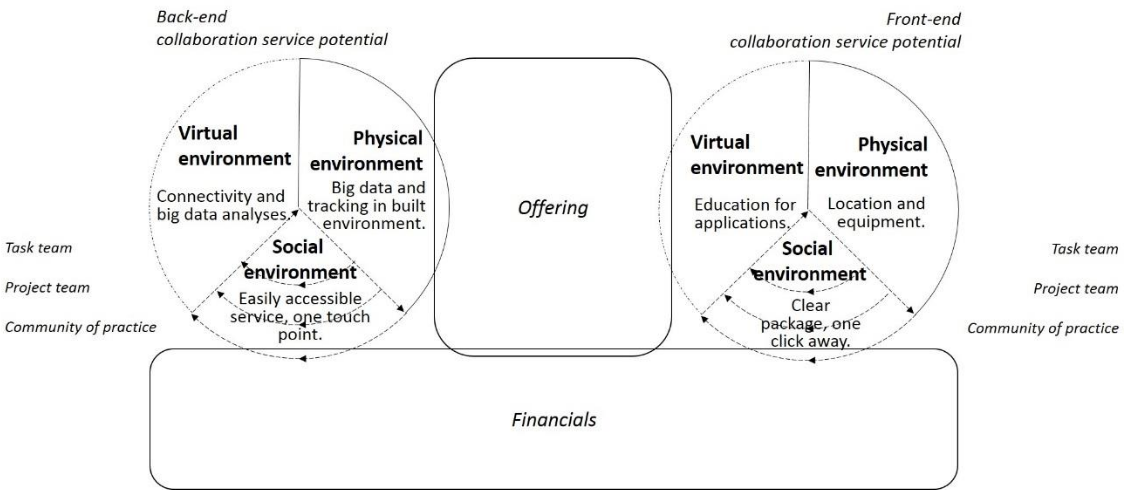

Figure 2. Proposal for collaboration service potential

It is noteworthy that different scales of teams can be supported by the collaboration infrastructure services and probably the demands are different as are the lifecycles of the scales of teams. In the beginning of any project, more collaboration that connects people physically together is required whereas execution and reporting can be more easily done without face to face meetings and usually even more effectively delivered via virtual collaboration channels. The largest service potential in the back end seems to lie in easily accessible, easy to use big data tracking, collection and analyses whereas the front-end is suggested to hold largest potential in education, relevant locations and up-to-date equipment and clear packaging with easily accessible services.

4. Discussion

There seems to be a demand for services that would support clear structures and offer collaboration as a holistic service through one touch point, one click away. Regarding the front-end, this would require effective education for the end users of the potential service in the virtual sphere, focal locations and equipment in all the locations of the physical sphere and clear packaging one click away for the end users regarding the social dimension. Regarding the back-end, this type of service would require access to multiple data sources in order to track the people and their locations and match that with the relevant collaboration space locations that would be connected without boundaries. The service should be however offered from one touch point and should be easily accessible.

The described types of services that offer some part of the components exist in the market such as Facebook, LinkedIn, Tinder, Yammer, Skype, Foursquare, Yelp, Worksnug, Venuu, Fingertip, Trello, Onenote, Silverbucket, Google Drive, Sharepoint, Dropbox and Slack among others. A competitive business idea could be to collaboratively produce and integrate the most relevant data in the back end by following big data flows in order to be able to offer a one-click away collaboration service for the end users.

5. Conclusions

This paper aimed to outline service potential of collaboration services in physical and virtual dimensions of space. It outlines a conceptual framework for developing services that would support collaboration in physical and virtual spheres. In order to develop it further, specific requirements of the collaboration personas could be explored and a prototype should be made to test its components in the market. Extensive future research is thus required in order to make the collaboration clash happen.

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Changing Societal Expectations and the Need for Dynamic Asset Lifecycling and Obsolescence Management

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Abstract

Current revolutions within the consumer electronics market are having dramatic effects upon how businesses are able to deliver their services with the continued embedding of technology within our lives. Conversely, this is currently having a direct impact upon long life assets with life expectancy in the region of 15+ years, an impact, which is believed to only increase. The term asset in this context refers to systems and their internal components, for example security systems and their orthogonal components i.e. intruder detector components, CCTV cameras, recording equipment, automated security doors, controls etc. This is a rather middle to top-level view upon the term asset and components; you will find literature referring to components as the individual electrical and material elements of a product. The mismatching of lifecycles due to contrasting market conditions is driving unforeseen obsolescence investments across the Built Environment, highlighting the current neglect of obsolescence within static asset lifecycle planning. As society changes, so do the expectations of service delivery from the Built Environment. The pressures imposed by these changes upon Facilities Managers will demand resultant changes in how services are delivered, maintained and supported throughout their useful lives. It is the combination of societal demands for a greater connected, interactive and smarter Built Environment and the effects of technological change upon obsolescence that will be covered in this paper. This paper will build upon a current Engineering Doctorate project into obsolescence and asset management to speculate both the importance of developing a dynamic approach to planning asset lifecycles and possibly how this would materialise in the future. Evidence will be provided in the form of a case study, reviewed literature and current live trends, supporting the title of this paper. The main conclusions include the growing evidence that what is being witnessed across the Built Environment will likely increase and also that more advanced industries have experienced the same problems previously. It is therefore seen as a growth area for the Built Environment to reduce the impact of obsolescence and ensure that service delivery continues to meet societal expectations.

Keywords: *Asset Management, Lifecycle, Obsolescence, Service Delivery, Facilities Management*

1. Introduction

Since 1965 when Gordon Moore first speculated about the future trend of computational power, Moore’s Law, technology has continued to support this original foresight (Mack 2011). Regardless of the readers’ views upon privacy, data, statistics and the like, there is a wealth of literature both within the main stream circles and academic journals, illustrating the dramatic change we are all experiencing and the plethora of change to come. Every day in 2015 over 75% of UK adults use the Internet, for a variety of needs, with almost 100% of them using it ‘on the go' (Office for National Statistics 2015). These two statistics are more than double the uptake of 2006. Similarly, an independent report produced by the World Economic Forum in 2015 identified from a survey of 800 executives and experts, from the ICT sector, that by 2025 the first 3D printed production car would be on the road and the Built Environment would encapsulate 1 trillion sensors connected to the internet (World Economic Forum 2015). Much of the above can be found within literature associated with the term the ‘Internet of Things (IoT)’. IoT is founded upon the increasing computational power and reduction of cost and size of sensor technology (Moore’s Law), making the embedment of such technology financially viable on a large scale. In addition to the trends and developments made within industry, there are social implications of such change, Michael Felton of the New York Times created the diagram in Figure 1, which demonstrates the rapid increase of technology adoption in American households. This powerful illustration shows not only how technology is quickly finding itself within the home, but also how once a new form of technology has become accepted it quickly saturates. Technology trends such as the IoT offers a wide variety of benefits for both building occupants, through service delivery, and Facility Managers through data collection and analysis (please see Big Data, Predictive Analytics and Machine Learning).

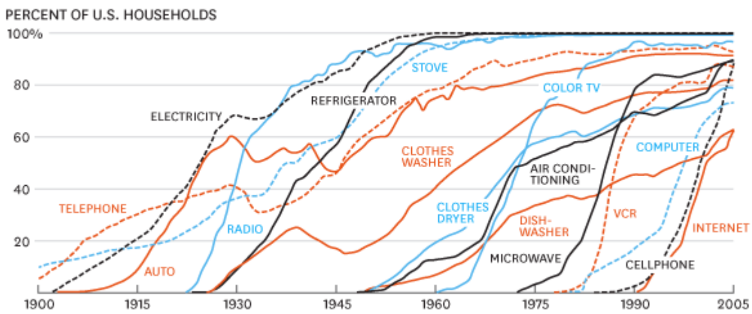

Figure 1 Technology Adoption within American Households, adopted from Felton (2008)

Gravier & Swartz (2009) described another side to the above trends and coined it ‘the dark side of the technology curve’, within which it was highlighted that obsolescence and lifecycle mismatches would carry significant operational and financial costs. Obsolescence occurs when a component or asset is no longer suitable for current demands or is no longer manufactured or supported. Obsolescence is not a new term, phenomena or problem, however in light of the above trends it is tipped to greatly effect the Built Environment in the same way it challenges the Oil & Gas, Avionics, Aerospace and Defence industries. This paper will draw upon new findings from a case study experiment, illustrating the cost of ‘the dark side of the technology curve’ within the Built Environment.

2. Literature Review

The following section will cover two key themes; recent trends around the IoT and the changing expectation of service delivery within the Built Environment, regarding asset obsolescence. The purpose being to capture the future changes that will effect our buildings and how we deliver services, and also the wider implications/demands upon lifecycling techniques and standards.

Depending on whether you reference MIT Technology Review, International Data Corporation (IDC) or business consultancy firm Gartner, forecasted projections of 28, 32 or 33 billion connected devices will exist by 2020 (SIEMENS 2014). Such an expansion of devices, both producing and collecting data, will become inevitably wide reaching. Google trends currently illustrate distinct search patterns, telling a story of how large sections of society are becoming actively aware of the IoT, shown in Figure 2.

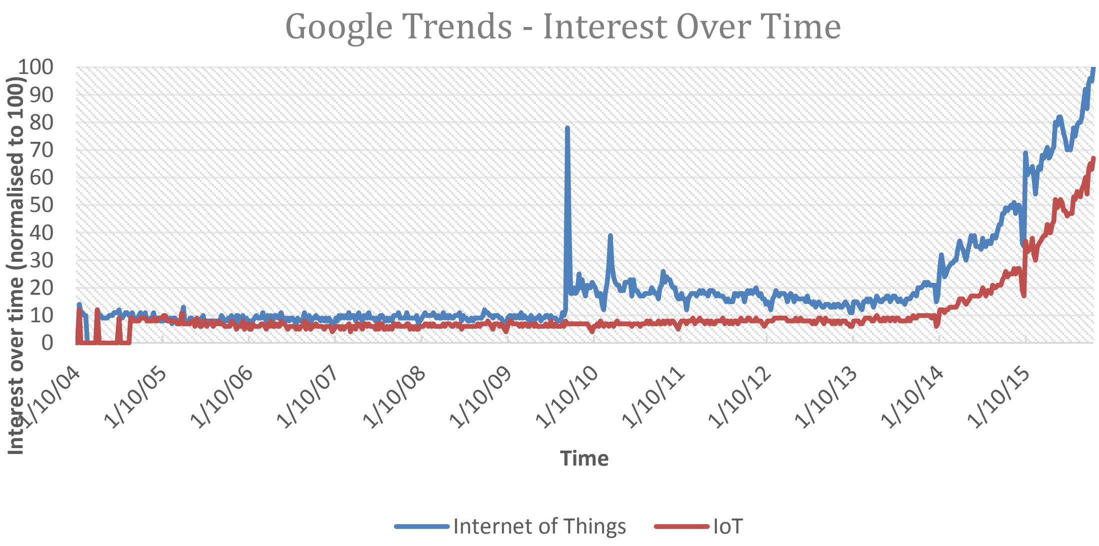

Figure 2 Google Trends for the terms 'IoT' and 'Internet of Things', publically available data from www.google.co.uk/trends/

In light of the above figure, it is felt by this author that such trends will effect society in both an active and passive way. Meaning, we as members of society will either actively adopt new services, now possible through big data analysis and the medium of smart phone applications for example. Alternatively, lives of some sections of society, will passively be effected by efficiencies, now possible through discrete optimisation modelling and data driven decision making, traffic flow for example. Ultimately however, as we have witnessed with the adoption of smart phone technology, once the concept has been accepted, it quickly becomes expected. Therefore, whether you actively or passively partake in the trends outlined within this paper, subconscious acceptance of new performance levels of service delivery is likely.

The above theory, aligns with the views of 'mutual shaping' with regards to 'social shaping of technology (SST)', where society and technology development are not independent of each other but rather influence and shape each other mutually (Williams & Edge 1996; MacKenzie &

Wajcman 1985). This is a contrasting view to the previously followed technology determinism views upon technology development, heavily associated with Karl Marx. SST directly tackles the conflict between technology development, in this context relating to the IoT, against societal values and expectation, in this context relating to privacy and service delivery expectations. Does technology development shape society? Or conversely will society shape the development of technology? Interestingly, Williams & Edge (1996) explain how the concept of SST involves the idea of 'choices' (though not necessarily conscious choices), meaning in a 'mutual shaping' context, society will consciously and subconsciously effect and be affected by technological change within the Built Environment.

In 2014, SIEMENS as part of their 'pictures of the future' magazine, reported that the Asia Pacific region were investing more into the IoT than Europe or North America, shown in Figure 4 (SIEMENS 2014). This mirrors the analysis undertaken by Google, in Figure 3, showing that six of the top seven countries searching for information regarding the IoT are from the Asia Pacific region. The result of such activity has led to these areas also holding both the largest number of and fastest growth rate of patents related to the IoT, typically linked with organisations such as LG Electronics and Samsung (LexInnova 2014).

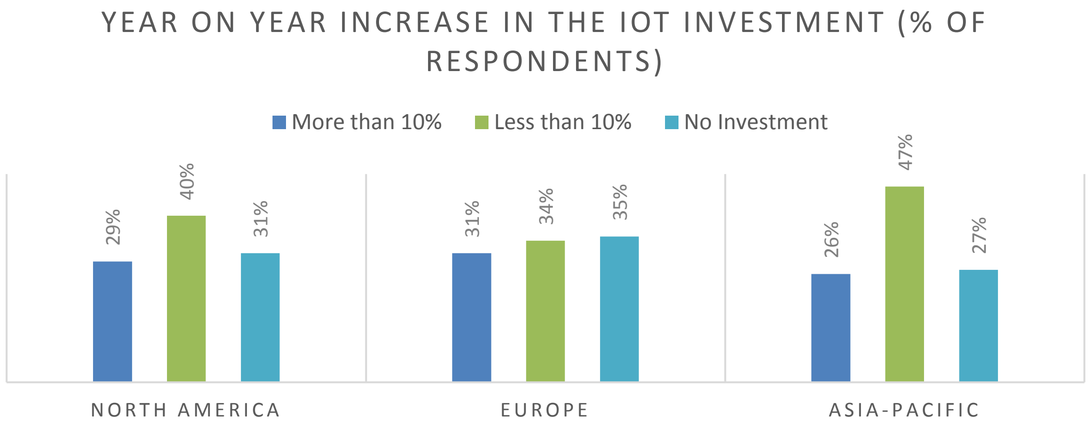

Figure 4 Year on year increase in IoT investment, percentage of respondents within report, adapted from SIEMENS (2014)

Figure 3 Google Trends of the terms 'IoT' and 'Internet of Things', publically available data from www.google.co.uk/trends/

The IoT is on course to disrupt and revolutionise the performance of FM service delivery, currently being capitalised by organisations located from the Asia Pacific region. This will inevitably effect society in both our professional and personal lives, potentially changing our expectations of service delivery within the Built Environment. There is academic and industrial evidence supporting the above relationships, however whether they are causal is yet to be clearly understood, therefore the real impact of such change upon both service delivery and society, is not well defined. This paper will now draw the readers' attention to the other side of the above trends covered within this literature review, focussing on obsolescence and the life sustainment issues created by lifecycle mismatches.

Obsolescence occurs within assets when they are no longer manufactured or supported, this occurs in both software and hardware, recently exacerbated by the explosion of the consumer electronics market and the resultant shortening of lifecycles (Feng et al. 2007; Solomon et al. 2000; BSI 2007). Solomon et al. (2000) produced Figure 5, which conceptually introduces how both obsolescence is inevitable and also time related. A single asset, or collection of assets within a system, will contain hundreds and often thousands of components, which will contain their own lifecycles. The length and profile of these respective lifecycles are dictated by market forces and manufacturers. This unknown characteristic of assets within the Built Environment, creates lifecycle mismatches, causing supportability issues for FM and building users. This predominantly unrecorded, side effect of technological advances was coined as 'the dark side of innovation' by Gravier & Swartz (2009). The case study featured within this report begins to quantify the scale of the impact of the aforementioned dark side. A bibliometric analysis, shown in Figure 6, illustrates the rising research attention towards obsolescence. However, following gap analysis it was identified that consideration for the assets found within the Built Environment, and end users as opposed to manufacturers receive little attention.

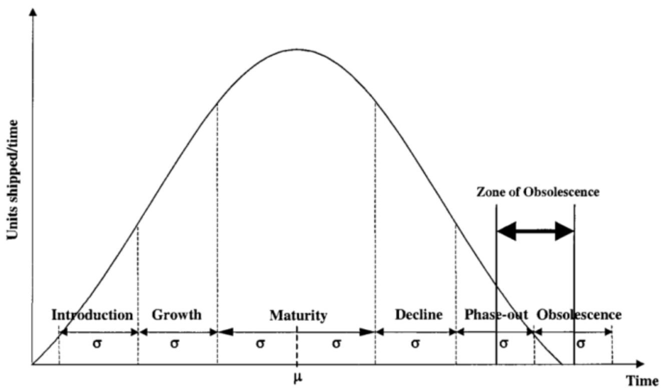

Figure 5 Obsolescence lifecycle stage, from Solomon et al. (2000)

The crux of obsolescence within assets, is the dependence upon life expectancy of assets and their components and the need to lifecycle cost the projected intended life the asset. This is further complicated by the BS ISO 15686-2:2012 for Service Life Planning of Buildings and Constructed Assets containing the following caveat:

"[Lifecycle Planning] ... does not cover limitation of service life due to obsolescence or other non- measurable or unpredictable performance states." - (BSI 2012) Service Life Planning

It is common practice to provide a nominal figure in years for the expected useful life of assets and major components, this prescriptive approach and has proven to be sufficient. This paper will challenge the applicability of such stationary methods for assets and asset systems that now experience dynamic variations of lifecycles and life expectancy as markets change at a faster rate.

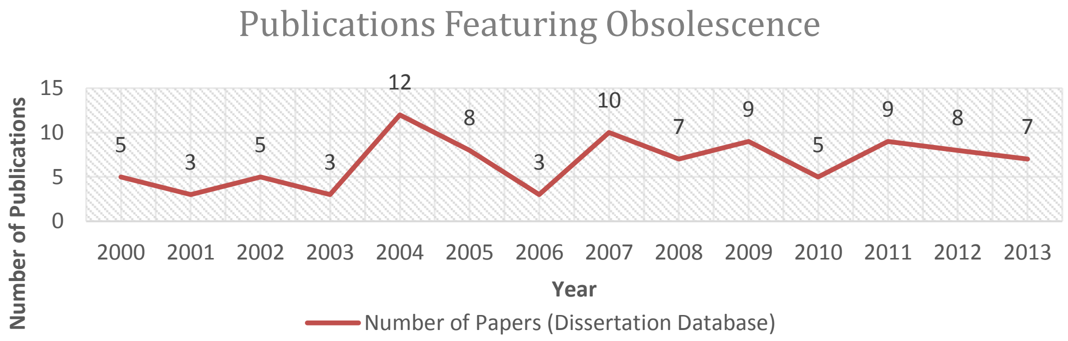

Figure 6 Bibliometric Analysis of Literature featuring keyword search: Obsolescence

In summary, there is evidence suggesting that the Built Environment as we know it, is to become digitised in the coming decade with an abundance of new data streams being created. Service delivery will experience dramatic improvements through the adoption of smart data analysis, providing tailored services to increase satisfaction of building users. Once wide spread, this is likely to become accepted as the norm and therefore a change in societal expectations upon service delivery by FM. In order to keep up with this trend and adopt further technology within our buildings, the effects of obsolescence are likely to increase, impacting both operationally and financially upon FM. It is logical, to therefore extract a need to improve obsolescence management techniques in tandem with 'dynamic' lifecycle methods to mitigate these effects both more precisely and strategically.

3. Research Design

This paper has adopted a case study design, using a UK based PFI funded London office building, which has a 100,000 m^2 foot print. This particular PFI was a refurbishment contract and the case study investigates into the effects of obsolescence into key long term asset systems. The time frame featured within this paper spans from 2010 to 2015, a decade on from practical completion of refurbishment works. A quant point to note, as the average life expectancy of software will predate this case study, whilst the 'mother' systems will require sustainment through and beyond this study.

Following discussions with the PFI contractor regarding historical procurement patterns and knowledge from the literature review, it was suggested that the following three systems be considered for this case study:

- Fire Alarm System
- Security System
- Building Management System

Historical purchase orders were analysed to investigate the pattern of investments, against the pre planned lifecycle expenditure for these systems. Specifically, any lifecycle investments associated with obsolescence were also extracted to begin formulating evidence to the scale of impact of obsolescence within this case study.

Further to the above data, meetings were held with the respective organisations involved within the supply and maintenance of the above systems to explore additional context. This qualitative element of this paper, adds to the numbers that feature within the discussion section.

In summary, it was felt a PFI funded piece of infrastructure was an appropriate case study, as it provided unparalleled access into commercial information, which if resided within the public sector would unlikely we available. PFI contracts also provide a set of constraints and drivers to optimally operate asset systems, whilst strategically planning their lifecycle replacement, creating further incentives for all stakeholders to understand the impact of obsolescence further.

3.1 Case Study Evidence

Figure 7 is a lifecycle budget for the case study site, spanning from 2005 to 2015, illustrating the annual planned expenditure to replace assets in a prescriptive manner. This projection, naturally is management by an Asset Manager and the profile can change if there are both unexpected failures of assets and unexpected expenditures. The highlighted bars show the focus of this case study, the period 2012 to 2015, where the three case study asset systems were investigated. Note, the profile of the lifecycle expenditure and how in the year 2013, around a decade on from refurbishment, considerable investment was planned. Whilst this has logical

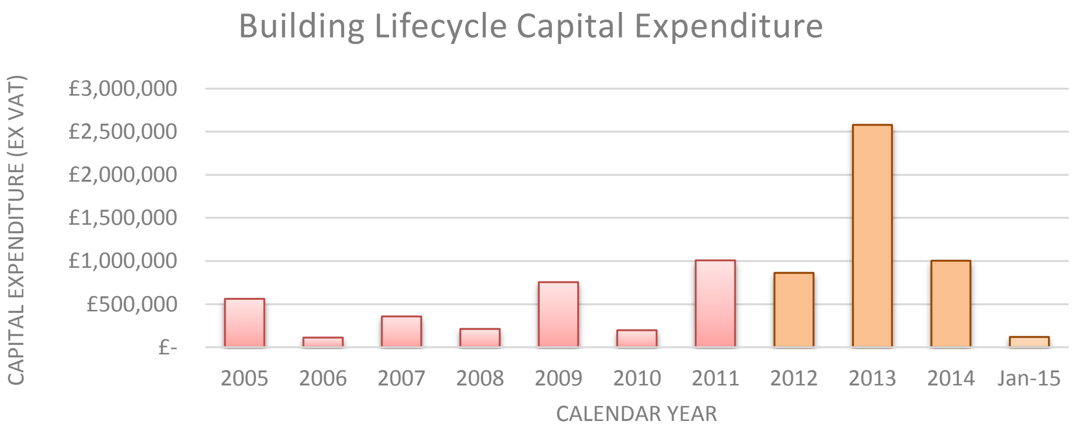

Figure 7 Building Lifecycle Capital Expenditure, across length of PFI to date

narrative, it is not data driven and it is not dynamic. The efficiency of a lifecycle fund is reliant upon the competence of the Asset Manager, and their ability to reactively reorganise programmes of replacement to offset costs.

In order to investigate the current impact of obsolescence driven investments, a snapshot of the time frame 2012 to 2015 was taken and then illustrated in Figure 8. As you can see across this short period there were considerable investments related to obsolescence (~ £1.5m). Note, it is not solely the financial size of these investments which can pose a problem for lifecycle management, but the unforeseen nature of the majority of these investments. Requirements that did not exist prior to their identification can put pressure on FM and the operational business of service delivery. Evidently, there are financial drivers to research into the management of obsolescence and lifecycling techniques, however, it is the operational impact in life critical environments i.e. major hospitals that prove to be the overriding driver.

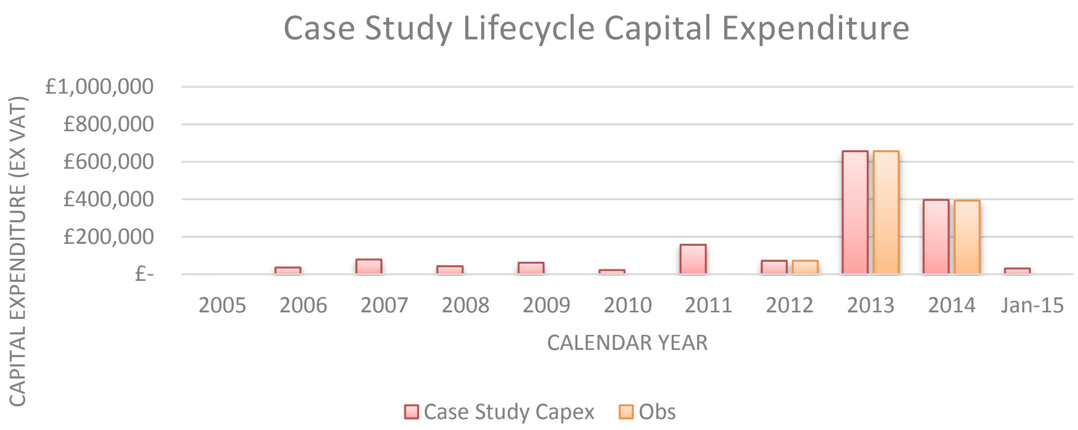

Figure 8 Case study comparison of obsolescence related investments and individual lifecycle expenditure

Mining the data further, two things were discovered; firstly, within the case study asset systems 10 years on from installation, 90%+ of the annual lifecycle expenditure was driven or associated with obsolescence, shown in Figure 8. Evidence that the effects of obsolescence may be cyclical

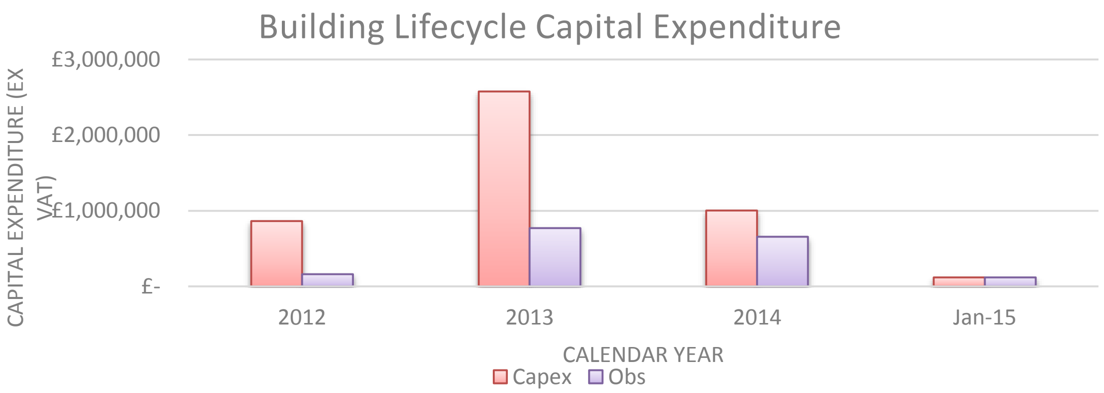

Figure 9 Case study obsolescence associated investments compared to total lifecycle expenditure for entire site

in behaviour. Figure 9 illustrates the total annual lifecycle expenditure across all systems, across the same period, 44%, 85% and 60% of the expenditure related to obsolescence was found within the three case study systems. Evidence, that the 80:20 rule is likely to apply, important when seeking to strategically manage obsolescence within the Built Environment.

In summary, the evidence provided by this case study have speculated that obsolescence may behave in a cyclical fashion, occurring in a repeated manner. Also, the Fire Alarm System, Security Systems and Building Management System are likely to concentrate your obsolescence driven investments and if only limited resource are available, to focus them on these assets. Finally, there is sufficient evidence to demonstrate that obsolescence is effecting the Built Environment currently and if managed reactively, can create significant additional lifecycle expenditure, which can cause both operational issues and lifecycle management issues.

4. Discussion

In the UK BS 8544:2013 for 'Guide for life cycle costing of maintenance during the in use phases of buildings', is widely used, it details the methodology for lifecycle costing (LCC) of maintenance for in use phase assets (BSI 2013). The methodologies encompassed by this British Standard, whilst comprehensive have two fundamental weaknesses. Firstly, due to their prescriptive nature, the effectiveness of LCC is dependent upon the competence of the individual performing the methodology and their respective experience and knowledge. In practice, it is common for this individual to change over time and for information sharing or continuity planning to fail. Secondly, the information gathered in the 'capture stage' of asset LCC must remain 'live' or dynamic in order to be applicable to the real world situation. In practice, it also not uncommon for this requirement to not be robustly implemented, therefore classifying the data being used for LCC obsolete or out of date. However, a competent and experienced Asset Manager may still posses the knowledge required to effectively manage assets through their lifecycle, maintaining their operational status.

This paper draws upon several major trends that when implemented will drastically shorten the lifecycle of many, previously long life, asset systems. This shortening will encourage obsolescence and reduce the time available to manage and plan asset maintenance. These aforementioned forces, will require a more dynamic approach to LCC, that is more flexible to sudden changes in market conditions, deeming specific component(s) obsolete, effecting useful life supportability.

The case study that features within this paper highlights how, within one example, current Asset Management practices are failing to avoid obsolescence driven investments. This has driven additional lifecycle costs and also applied short term operational risks to the organisation. Ultimately, this paper seeks evidence to suggest that the current practice for LCC should be readdressed, in order to avoid what Thomsen et al. (2015) label as 'obsolete buildings'; where building demands have changed and service delivery has failed to adapt. A recent example of the impact this can have upon the Built Environment could be, the changing buying behaviours of UK supermarket shoppers. The Financial Times reported that British Supermarkets are to write off billions of pounds from the value of their supermarkets, due to consumers shifting their preference to smaller outlets and online shopping, deeming the large style supermarket as a business model obsolete (Grover & Grover 2012).

4.1 Need for Dynamic Lifecycling

The term 'dynamic' in this paper refers to a method that is flexible and adaptive to characteristic changes. For example, a LCC method that considers obsolescence throughout the useful life, proactively monitors performance and condition deterioration, whilst amending the expected life and lifecycle replacement strategy would be considered flexible. In other pieces of literature this type of decision making model, have been described as 'data driven' as opposed to an 'expert system'.

Academic literature by Bradley & Guerrero (2008), Sandborn (2013), Feng et al. (2007), Gravier & Swartz (2009) and many others, all suggest that the impact of obsolescence is only going to increase. These thoughts were echoed by those decision makers within the aforementioned case study, who were witnessing it's effects first hand. If current methods remain stationary, whilst the trend of obsolescence risk increases, then the shift to meet growing societal expectations in the future will be a costly one.

Finally, to illustrate the possible future impact of obsolescence driven investments within the case study that features within this paper, Figure 10 was created. To create Figure 10, an assumption was made on the behaviour of obsolescence within long life asset systems, that lifecycles of components within systems across a building were so miss-aligned that obsolescence driven investments would occur on an almost annual basis in various systems. This would be represented on a lifecycle budget projection as a random/constant percentage of the annual expenditure. In order to project these percentages, the case study profile was extrapolated across the remainder of the PFI contract and visualised as a percentage of the actual planned lifecycle budget for this building.

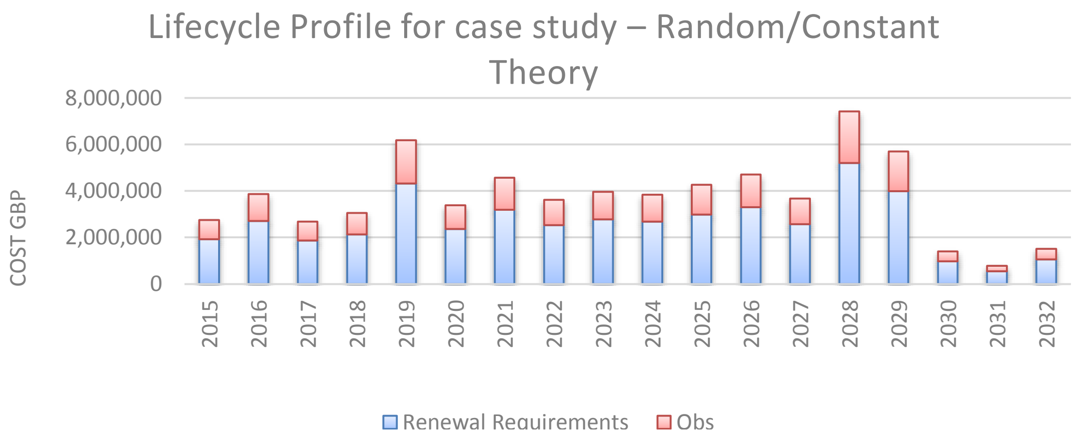

Figure 10 Extrapolated future obsolescence related investments as a percentage of planned Lifecycle expenditure for remainder of PFI

The accumulative investment associated with obsolescence for this single PFI contractor is potentially staggering. By 2032 an additional total of £20 million could be assigned to obsolescence related investments. Note, what this projection does not account for, is whether these investments are in addition to the current lifecycle planned expenditure or inclusive. This is unknown due to the timing of an obsolescence driven investment, which will massively impact an Asset Manager's ability to offset other planned lifecycle expenditures to keep the annual within budget.

5. Conclusion

To conclude, we refer back to the title of this paper 'changing societal expectations and the need for dynamic asset lifecycling and obsolescence management' and cover the key trends and points made.

In 2015 now more than half of the planet now live within cities, creating a dense urban environment. Researchers across academia and industry are both seeking to implement new technology to create new methodologies for service delivery across the Built Environment, in a way that previously was not possible, advances in this area come under the umbrella of the IoT.

History has shown us that whilst it is unclear whether society shapes technology, or vice versa, it is clear that as soon as technology is commercially accepted, it quickly becomes expected. It has been speculated within this paper that when FM actively embraces the IoT and provides new levels of service delivery, building occupants will quickly adopt and expect a consistent new service level.

The IoT has the potential to improve service delivery in almost every context, however this paper dives deeper into the 'dark side' of technological advancement and the cost of obsolescence when seeking to support asset systems within the Built Environment. Connected to obsolescence are the current LCC methods, which have proved to be sufficient in modern construction. The case study that featured within this paper has provided some evidence that the cost associated to obsolescence is significant and growing. The reactive manner in which obsolescence is currently managed and its current separation from the LCC methodology, has created a demand for a more dynamic approach, which is likely to be more data driven. This paper features some work from a current Engineering Doctorate research project, which is developing and testing data driven decision and risk tools for mitigating obsolescence.

Finally, whilst this paper illustrates a single case study which may not be homogenous across the industry, if academia is to be believed and the risk posed by obsolescence is only to increase and the industrial research on modern trends are to be believed. Then we need to adapt our methods now, in preparation for the changes we are all going to witness in both our personal and professional lives.

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The Role of Leadership and Organizational Climate in Fostering Innovation in Construction

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Abstract

Leadership has been identified by many researchers as one of the most important antecedents of innovation. Previous studies tend to conclude that transformational leadership, through motivating followers to change their status quo, has a higher positive impact on organizational innovation when comparing with transactional leadership. However, the relationships between transformation leadership and innovation are inconsistent. These contradictory findings, to certain extent, suggest that the influences of leadership on innovation can be influenced by various mediators, such as innovation climate in an organization. Leaders foster innovative behaviours of followers by creating a climate that facilitates the innovative activities through, for instance, forming organizational routines to assist in achieving innovation. This organizational climate, in turn, influence the impact of leadership on innovation. Innovation has found to be essential in enhancing work effectiveness, efficiency, and business performance in the construction sector. However, hindered by various factors, construction has long been recognized as low in innovation. Success of innovation requires intimate collaboration between multiple stakeholders in developing innovation blueprint and sustaining commitment towards innovation in technically complex areas. However, due to the different value propositions amongst organisational members, tension may arise, which affects the collaboration. Hence, this study aims to investigate the mediating effects of organizational innovation climate on the leadership-innovation relationships. A questionnaire survey is designed which adopts: i) the multifactor leadership questionnaire for assessing the perceived leadership style, ii) the innovation culture scale, and iii) the innovation scale for measuring the ability of an organization to innovate as perceived by followers. The relationships are tested by factor analyses, reliability analyses, correlation analysis, and multiple regression modelling using SPSS and Lisrel. Seven factors are identified, including charisma, intellectual stimulation, individualized consideration (transformational leadership) and contingent reward (transactional leadership) for leadership; support for innovation and resource supply for innovation culture; and innovation performance. The findings reveal that support for innovation plays a significant mediating role on the influences of both transactional and transformational leaderships on innovation. The results of this study lay solid platform for further longitudinal, qualitative studies for the dynamic intertwining relationship between leadership and innovation culture across the organizational innovation process.

Keywords: Construction, Innovation, Leadership, Organizational Climate

1. Introduction

Success of innovation requires intimate collaboration between multiple stakeholders in developing innovation blueprint and sustaining commitment towards innovation in technically complex areas. Due to the different, or even competing, value propositions amongst the stakeholders, tension may arise, affecting the collaboration (Adner, 2012). Therefore, leadership has been identified by many researchers as one of the most important antecedents of innovation (e.g., Amabile, 1998; Jung et al., 2003). While extant research tends to contribute useful insights into the associations between leadership and innovation, its ability to guide management practice is limited by the predominance of studies which focus on leaders' behaviours and on transformational leadership in particular. Although understanding how transformational leadership influence follower's creative behaviours is worthwhile, a more important concern for organizational leaders is how to lead organizational innovation across different situations and environment.

Leadership, such as leaders' psychological states and behaviours, are personal characteristics of a leader. A type of leadership effective in one situation /environment may thus not be in another (McLaurin, 2006). According to Fiedler's *contingency theory* (1972), the effectiveness of team performance is contingent upon two factors, namely the motivational pattern of a leader and the contextual factors which empowers a leader. Motivational pattern mainly refers to the leadership types of a leader, such as task-versus-relationship oriented leadership (Miller et al., 2003) and transformational leadership (Carter, et al., 2014); while contextual factors are referred as situational favourability which determines the degree to which a situation [e.g., organizational climate (Haakonsson et al., 2008)] allows the leader to have power and influences tasks (McLaurin, 2006). Hence, based on the central assertion of contingency leadership theories, this paper proposes that the relationship between leadership and innovation of followers are contingent on an organization's innovation climate.

2. Leadership and Innovation

One of the first researchers in the field of innovation was Schumpeter in 1934 who defined innovation as "the commercial or industrial application of something new – a new product, process or method of production; a new market or sources of supply; a new form of commercial business or financial organization" (see Stone et al., 2008; p.II-2). The definition evolves along the development of innovation research. Summary of extensive literature suggests that innovation can be defined as a process of "generation, development and implementation of ideas" (e.g., Dulaimi et al, 2005; p. 566) in different forms (e.g., product, process, marketing and management innovation), which are new (i.e., "novel to the institution" (Slaughter, 1998; p. 226)) and are expected to yield enhanced value (i.e., "reduction in cost and/or time associated with project delivery and improve the quality of outcomes" (Kissi et al., 2012; p. 12)). Grounded on the above broad definition, various typologies of construction innovation are identified, such as radical versus incremental innovation, bounded versus unbounded innovation, and 'hypercube' of innovation (Harty, 2008).

However, different types of innovation work in conjunction. More importantly, innovation has to evolve so as to convert the ever-changing business challenges into opportunities. In the complex socio-economic environment where an organisation needs dynamic capabilities and competencies to solve challenging tasks, innovation competence (which constitutes a type of dynamic capability) is a crucial factor (Teece and Pisano, 1994). While creativity is often referred as the source of innovation (e.g., Amabile, 1998), the ability of an organisation to create novel design, construction, management and/or service delivery approaches in the competitive industrial environment is typically dependent on individuals' domain of knowledge and capability. More importantly, competency is a key element predicting performance of construction professionals (Dainty et al., 2005) and the inability of construction parties, clients and clients' agents to adopt or absorb innovations generated by other stakeholders (e.g., contractors or consultants) hinders innovation in construction (Manley, 2006). Innovation competency governs the innovation behavior of individuals and is defined as the disposition of individuals "to act and react in an innovative manner in order to deal with different critical incidents, problems or tasks that demand innovative thinking and reactions, and which can occur in a certain context" (Cerinšek and Dolinšek, 2009, p.166). In this study, innovation competency, which can endure for a reasonably long period of time in a construction firm, is used to examine the ability of its employees to innovate in various forms to enhance performance and competitiveness at organizational levels.

Leadership has been identified as one of the most essential antecedents of innovation (e.g., Amabile et al., 2004; Mumford et al., 2002), which influences not only individual creativity but also organizational innovation (e.g., Gumusluoglu and Ilsev, 2009). Leadership, as an instrument of goal achievement (James et al., 2007), has been identified as a convergent process that acts on both organizational culture and individual behaviors (Ostroff et al., 2003). Based on the organizational goals and values perceived by a leader from the organizational culture, s/he puts intentional efforts into influencing and aligning the values, visions and behaviors of followers with that of the organization. The fundamental function of leadership for innovation is to facilitate interpretations of followers by providing meaning, to enable followers to generate, interpret and implement innovative ideas in a manner that ensures alignment with organization's mission (Berson et al., 2006). In this process, leadership and the organizational climate are entangled.

According to Bass and Bass (2008), leadership refers to "an interaction between two or more members of a group that often involves a structuring or restructuring of the situation and of the perceptions and expectation of the members...directing the attention of other members to goals and the paths to achieve them" (p.25). Transformational and transactional leaderships are the two main types of leaderships identified in the literature, in which transformational leadership refers to leaders whose focus is in fostering the higher order intrinsic needs of followers, in preference to immediate self-interests, through idealized influence (charisma), intellectual stimulation, or individualized consideration, while transactional leadership refers to leaders whose focus is in establishing an exchange-based relationships with followers through rewarding goal achievement (Bass and Avolio, 2004). Previous studies tend to conclude that transformational leadership, through motivating followers to change their status quo (Keller, 2006), has a higher positive impact on creative climate and organizational innovation when comparing with transactional leadership (e.g., Jung et al., 2003, Elenkov and Manev, 2009).

However, the relationships between transformation leadership and innovation are *heterogeneous* (i.e., correlations ranging from positive to negative) (e.g., Basu and Green, 1999; Shin and Zhou, 2003). These contradictory findings, to certain extent, suggest that the associations between leadership and innovation are *contingent* and that these associations can be influenced by various moderators, such as organizational climate [e.g., support for innovation (Jung et al., 2008) and climate for excellence (Eisenbeiss et al., 2008)]. In this study, the moderating effects of innovation climate on the leadership-innovation relationships are investigated.

3. Organizational Innovation Climate

The sociological approach to creativity takes the view that both the level and the frequency of creative behaviours are influenced by the social environment (Woodman et al, 1993). Following this theme, climate can be defined as a psychologically meaningful description of the work environment (James and Jones, 1979), and "a set of attributes specific to a particular organsiation that may be induced from the way the organsiation deals with its members and its environment" (Campbell et al, 1970, p.390). "For the individual member within an organsiation, climate takes the form of a set of attitudes and expectancies which describe the organization in terms of static characteristics … and behavior-outcome and outcome-outcome contingencies".

According to Scott and Bruce (1994), a climate for innovation can be conceptualized as support for innovation and supply of resources. Support for innovation refers to an organization which not only supports employees in pursuing new ideas, but also tolerates diversity among them (Siegel and Kaemmerer, 1978). Change is essential to the development and implementation of any innovative ideas (Poole and Van de Ven, 2004). Through managing changes in policy, procedures (i.e., first-order changes) or changes of fundamental organizational assumptions, like vision and core values (i.e., second-order changes) properly, an organization evolves (Rothwell et al., 2010; Wang and Sun, 2012). On the other hand, although diversity between employees may induce workgroup conflicts and decrease work efficiency, it is important to organizational innovation (Florida and Gates, 2003; Milliken and Martins, 1996; Scott and Bruce, 1994). It is because only employees with tolerance of diversity can be open-minded to new or improved ideas at work (Anderson and West, 1998). In addition, to nurture a group of creative employees, organizations should supply adequate resources, such as time, human resources, material, management support, so as to allow them to pursue innovation at work (Kesting and Ulhoi, 2010).

Support for innovation climate "reflects collective perception among team members that their collaborative, innovation-related activities are expected, valued and supported in the team" (Chen et al, 2013:1020). It enables members to innovate effectively by promoting a more collaborative environment whereby team members assist, support and coordinate with each other in their attempts to innovate (Chen et al, 2013). According to West (1990), higher levels of support for innovation climate motivate individuals to initiate and persist in innovative behaviours and transformational leadership fosters innovation through support for innovation by encouraging members "to collaborate and to assist each other with idea development and implementation" (Eisenbeiss et al 2008:1440). Hence, the association between leadership and innovation performance can be affected by innovation climate.

A transformational leader has the ability to arouse and change members' propensity for longer-term and more creative perspectives (Bass and Avolio, 2004), that is the leader stimulates members' efforts to be innovative by questioning their assumptions, reframing problems and approaching situations in new ways. At the same time when transformational leaders internalize the organizational climate /culture for innovation through sensemaking, their externalization of this sensemaking shapes the organsiational climate /culture of followers, resulting in followers valuing creative thought processes and innovative work approaches (Jung et al, 2003). Since organisational climate and culture represent collective social construction (Mumford et al, 2002), they serve as a sense-making device and guiding principle for more innovative work processes that could ultimately lead to innovative performance in terms of new products and services (Scott and Bruce, 1994).

4. Research Method

Based on the above, quantitative method based on questionnaire surveys is employed to test the hypothesized relationships using correlation analysis, regression modelling and structural equations modelling. Questionnaires of this study are equally distributed to 500 respondents from different organisations of client developers, construction consultants, and contractors in China. Both purposive sampling and convenience sampling are used. Data are returned from 158 respondents (31.6% response rate) via email, web-based questionnaire system, fax return, and face-to-face meeting. There is a good mix of respondents from different professional disciplines (34.8% project management, 16.5% architecture, 15.2% structural engineering, 13.9% quantity surveying, 8.2% building services engineers, and 11.4% others) and management levels (46.1% middle management, 29.8% professionals, 19.5% senior management, and 4.5% others). There are 73.4% of respondents who have amassed more than 5-year experience in the organization (36.7% more than 15 years, 25.3% 11-15 years, 20.3% 1-5 years, 11.4% 6-10 years, 6.3% less than 1 year).

The questionnaire has three main parts: i) the multifactor leadership questionnaire (MLQ) scale (Avolio and Bass, 2004), ii) the innovation climate scale (Scott and Bruce, 1994), and iii) the innovation scale (Kaiser and Holton, 1998). Respondents are asked to rate their responses in 5 point Likert measurement. To further confirm the factor structures in the current study which target the construction sector, confirmatory factor analysis is conducted to justify the validity of the factor structures of:- transformational and transactional leadership (i.e., charisma, intellectual stimulation, individualized consideration and contingent reward), innovation climate (i.e., support for innovation and resource supply), and innovation. Confirmatory factor analysis aims to test and confirm specific hypotheses concerning the structure underlying a set of items (Pallant, 2005).

The analyses are conducted by structural equation modelling using Lisrel 8.7. Although four fit indices are usually suggested to quantify the degree of fit of a structural equation model (Kline

1998), six fit indices are included in the current analysis. The resulted model fit indices are satisfactory, in which the relative chi-square values (x^2/df) are between 2 and 5 (good model fit; Diamantopoulos and Siguaw, 2000); the values of root mean square error of approximation (RMSEA) are lower than 0.08 (a reasonable model fit; Bollen and Long, 1993); the comparative fit indices (CFI); the goodness of fit indices (GFI); and the relative fit indices (RFI) are higher than 0.8 (the closer to 1, the better the model fit; Diamantopoulos and Siguaw, 2000). Meanwhile, the Cronbach's alpha value of each factor is above 0.6, indicating acceptable reliability (Hair et al., 1998; Pallant, 2001).

5. Results

The correlation results indicate that innovation is correlated positively with all leadership and innovation climate factors, including charisma, intellectual stimulation, individualized consideration, contingent reward, support for innovation, and resource supply, at $p<0.01$ significance (refer to Table 1). The results also indicate that all leadership factors are significantly and positively correlated to support for innovation and resource supply at $p<0.01$ significance, acting as support to the moderating effect of innovation climate on the leadership-innovation relationship.

Table 1: Correlation between Innovation Climate, Leadership, and Innovation

Factors	LD1	LD2	LD3	LD4	IC1	IC2	INN
Leadership							
Charisma (LD1)	1	-	-	-	-	-	-
Intellectual stimulation (LD2)	0.769**	1	-	-	-	-	-
Individualized consideration (LD3)	0.741**	0.710**	1	-	-	-	-
Contingent reward (LD4)	0.657**	0.686**	0.703**	1	-	-	-
Innovation Climate							
Support for Innovation (IC1)	0.571**	0.498**	0.498**	0.486**	1	-	-
Resource supply (IC2)	0.562**	0.556**	0.563**	0.542**	0.774**	1	-
Innovation (INN)	**0.432****	**0.428****	**0.381****	**0.406****	**0.695****	**0.664****	**1**

To investigate the moderating effect of innovation climate on leadership-innovation relationships, hierarchical regression analysis is performed using pairwise deletion (Aiken and West, 1991). Two models are developed for the moderating effects of the innovation climate variables [i.e., support for innovation (Model 1) and resource supply (Model 2)] (refer to Table 2). In the first step of each model, the four leadership variables are added. In the second step, the moderators are added. Subsequently, in the final step, the interaction terms of the moderators and the four leadership variables are added to test the hypotheses. The values of R^2, adjusted R^2 and significant F change are shown at the bottom of each model. Only support for innovation (ICI1) is found to have significant moderating effect (sig. F change < 0.05 as shown in Model 1).

Results show that before taking the interactions into account, the four leaderships are not significantly associated with innovation, indicating that the influences of leaderships on innovation are not simple straightforward effects. Support for innovation (IC1) is positively

Table 2: Hierarchical regressions

Variables	Step 1	Step 2	Step 3

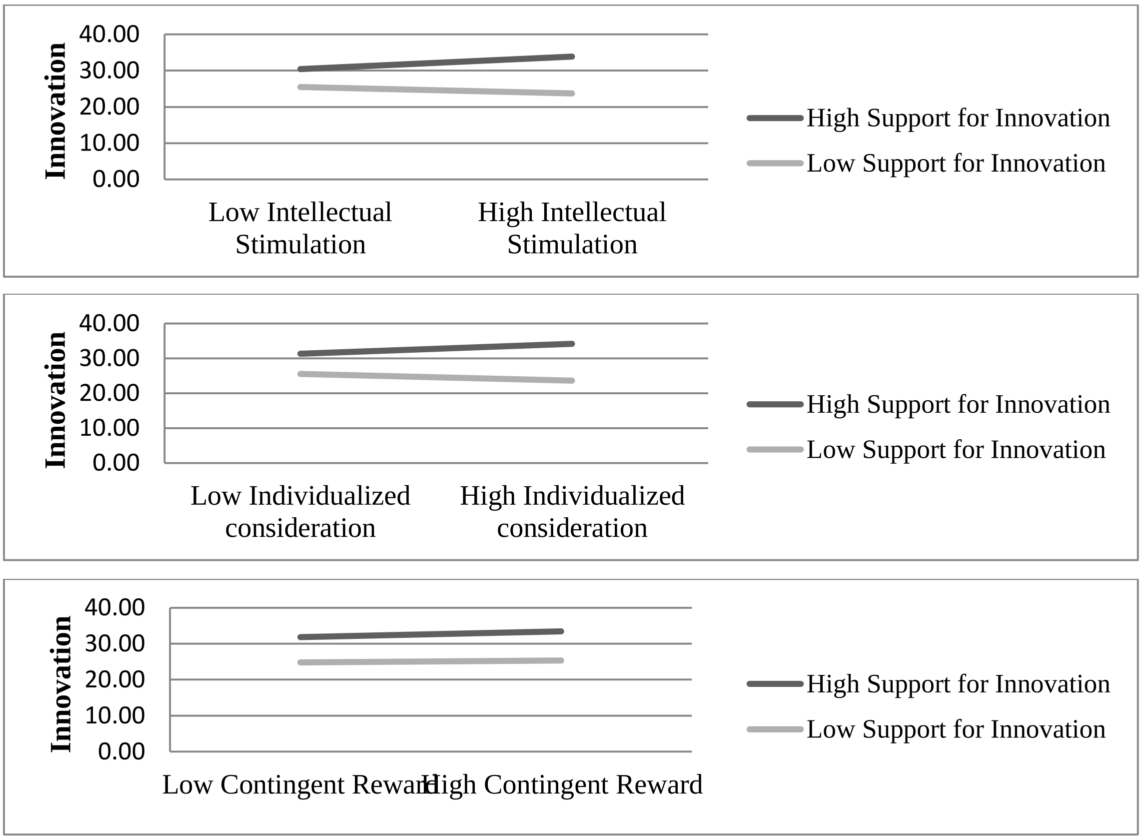
	b	ß	b	ß	b	ß
Model 1 *(Support for Innovation as Moderator)*						
Charisma (LD1)	0.172	0.196	-0.049	-0.055	0.210	0.238
Intellectual stimulation (LD2)	0.393	0.162	0.349	0.144	-10.387	-4.292**
Individualized consideration (LD3)	0.014	0.006	-0.105	-0.048	-7.539	-3.452**
Contingent reward (LD4)	0.405	0.162	0.154	0.062	13.888	5.565**
Support for Innovation (IC1)			0.557	0.650**	-0.392	-0.457
LD1 x IC1					-0.004	-0.403
LD2 x IC1					0.219	7.077**
LD3 x IC1					0.146	4.853**
LD4 x IC1					-0.282	-8.732**
R^2 *(Step 1)* / ΔR^2 *(Steps 2-3)*	0.472		0.274		***0.288***	
Sig. F Change	0.000		0.000		***0.000***	
Model 2 *(Resource Supply as Moderator)*						
Charisma (LD1)	0.172	0.196	0.075	0.085	0.295	0.336
Intellectual stimulation (LD2)	0.393	0.162	0.155	0.064	-1.043	-0.431
Individualized consideration (LD3)	0.014	0.006	-0.238	-0.109	-2.183	-1.000*
Contingent reward (LD4)	0.405	0.162	0.124	0.050	1.417	0.568
Resource supply (IC2)			0.749	0.615**	-0.021	-0.017
LD1 x IC2					-0.011	-0.566
LD2 x IC2					0.052	0.932
LD3 x IC2					0.103	1.814
LD4 x IC2					-0.064	-1.058
R^2 *(Step 1)* / ΔR^2 *(Steps 2-3)*	0.472		0.229		0.042	
Sig. F Change	0.000		0.000		0.190	

Note: * $p<0.05$; ** $p<0.01$

related to innovation (Step 2 of Model 1). However, after the interactions are taken into account (step 3 of Model 1), the influence of IC1 on innovation becomes insignificant. The interaction model containing IC1 as moderator of the four leaderships significantly adds value to the final model, in which the interactions of IC1 with intellectual stimulation (LD2 x IC1), with individualized consideration (LD3 x IC1), and with contingent reward (LD4 x IC1) on innovation are significant (Step 3 of Model 1).

Results show that before taking the interactions into account, the four leaderships are not significantly associated with innovation, indicating that the influences of leaderships on innovation are not simple straightforward effects. Support for innovation (IC1) is positively related to innovation (Step 2 of Model 1). However, after the interactions are taken into account (step 3 of Model 1), the influence of IC1 on innovation becomes insignificant. The interaction model containing IC1 as moderator of the four leaderships significantly adds value to the final model, in which the interactions of IC1 with intellectual stimulation (LD2 x IC1), with individualized consideration (LD3 x IC1), and with contingent reward (LD4 x IC1) on innovation are significant (Step 3 of Model 1).

To determine the nature of the above interactions, simple slopes are established for the significant interaction resulted in Table 6 (Aiken and West, 1991) (refer to Figures 1a-c). Under high support for innovation (one standard deviation above the mean), high intellectual stimulation and high individualized consideration foster innovation, while under low support for innovation (one standard deviation below the mean), vice versa. Under both high and low support for innovation, the higher the contingent reward, the better the innovation; while the degree of innovation is still higher under high support for innovation.



Figures 1a-c: The interactions between leadership and support for innovation on innovation

6. Discussion

Previous research on leadership and innovation tends to investigate transformational leadership as a whole (e.g., Bass et al., 2003; Pieterse et al., 2009), while inadequate focus has been put on the multi-dimensional nature of transformational leadership. Theoretically, transformational leadership composed of different factors, including charisma, intellectual stimulation and individualized consideration (Avolio and Bass, 2004). The different effects of these sub-factors on performance and innovation have been indicated. For instance, in Howell and Avolio (1993)'s study on business performance, charisma and intellectual stimulation are found to have positive impact on performance, while individualized consideration are found to have negative impact. In addition, Elenkov and Manev (2009) indicate that the interactions with sociocultural factors, such as power distance and uncertainty avoidance, change the influences of intellectual stimulation and individualized consideration on innovation from positive to negative and positive respectively. The results of this study further provide evidences that transformational leadership should not be considered as a whole. Under the interaction of support for innovation, transformational leadership of intellectual stimulation and individualized consideration have significant influences on innovation.

On the other hand, previous studies tend to conclude that transformational leadership fosters followers' creativity and innovation performance, while transactional leadership hinders them (e.g., Jansen et al., 2009; Jung et al., 2008). However, the results of this study indicate that contingent reward, a type of transactional leadership, has positive relationship with innovation under both high and low support for innovation. The higher the support for innovation, the higher the level of innovation is under the same level of contingent reward. Contingent reward leadership influence innovation through inducing compliance (Yukl, 2002). Followers carry out leaders' orders to obtain agreed awards. Thus, contingent reward leadership rely on open communication, which is important for innovation (Kickul and Gundry, 2001). Under high support for innovation climate, organizational members have higher strength on the values of innovation behaviours, which smoothen the process of communication for reward for innovation.

Transformational leadership does not necessarily foster innovation. Negative relationships are found between intellectual stimulation and innovation under low support for innovation. Intellectual stimulation leaders stimulate followers to rethink the ways they perform their works and engage in problem-solving activities in which new ideas may be resulted from the process (Bundy, 2002; Rafferty and Griffin, 2004). However, under the climates of low support for innovation, followers may not value creative ways of doing things. The intellectual stimulation of leaders can be conflicting to what the followers interpret from their environment, resulting in confusion, worries and concerns, which worsen their performance. Similarly, negative relationship is also found between individualized consideration and innovation under low support for innovation. Leaders applying individualized considerations respect and concern about follower's personal needs and development (Bass and Avolio, 1994). With leaders' understanding and support, followers are more willing to respond to change (House and Mitchell, 1974), which is essential for innovation. However, under the climates of low support for innovation, the perception that change is not valued prevails amongst followers, and that role conflict may occur between the perceived innovation climate and the individualized innovation stimulations from leaders, hindering innovation.

The results of the current research, conducted using quantitative methods, provide a foundation to examine the hypothetical relationships. However, quantitative methods attempt precise measurement of variables, while qualitative methods aim at seeking how and why things happen (Cooper and Schindler, 2006). The quantitative analysis results have not provided insights on what contribute to the differences in the associations between leadership and innovation under moderations, and why. Meanwhile, the study results are made based on sample from China only. Previous studies have indicated the influence of national culture on organizational climate and management (e.g., Hayton et al., 2002; Testa, 2009). To achieve an in-depth understanding of the leadership-innovation relationships and the moderating effects of innovation climate, it is recommended that qualitative, longitudinal research methods be adopted in further research to investigate the influence of national culture on organizational climate, leadership and innovation at organizational level worldwide.

7. Conclusions

Previous studies tend to indicate transformational leadership as an important determinant of innovation, over transactional leadership. However, evidence to this effect has been inconsistent. The results of this study unveiled one of the possibilities for the inconsistency through identifying the moderating effect of support for innovation climate on the leadership-innovation relationships:- i) Intellectual stimulation leadership is associated with increased innovation when support for innovation climate is high; ii) individualized consideration leadership is associated with increased innovation when support for innovation climate is high; and iii) the positive relationship between contingent reward and innovation can be found under both high and low support for innovation, even though the degree of innovation is higher under high support for innovation. Previous studies have investigated the influence of national culture on organizational climate and leadership. The results of this study, based on the sample from China, lay ground for further studies to investigate the relationship between innovation climate, leadership and innovation in the construction sector worldwide.

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A Study on the Optimization of Intelligent Building Operations Based on Case Study of the Industrial Innovation Center in Taiwan

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Abstract

The estimation of the next ten years, buildings will become the main reason of resource depletion. The energy consumption of global commerce and residential buildings will be responsible for nearly half of total consumption. Not only does the building process require energy consumption, the daily operations and maintenance of facilities will consume large amounts of resources. To solve issues of high energy consumption and high maintenance costs of the buildings, intelligent analysis methods are now used to increase overall efficiency. The operation models of intelligent buildings encompass many variables, so further research is required to understand the effects of the different factors and characteristics. By combining the various measurement standards and data, a more effective intelligent building operation model may be established to isolate the relativity of the physical environment and humans' biological effects, and through striking a balance between the physical and biological variables, the optimal operation model for intelligent buildings may be found and allow for the achievement of comfort and maximum environment benefits with the least amount of consumption. In the intelligent buildings, there will be many products and facilities dedicated to the comfort and health of the users, hence improvement of system efficiency and optimal operation model is based on the basic requirements of the users. The primary objective of this study is to use the building management mindset to analyze, through scientific means, the interactions and effects of "health", "comfort", and "energy efficiency" in intelligent buildings. Therefore, this study hopes to maintain the current conditions of indoor environment quality and comfort and establish "An Optimal Intelligent Building Operation Model" and conduct research and verification on case studies that have obtained the Taiwan Intelligent Building Labels.

Keywords: Intelligent building, Optimal operation model

1. Introduction

In order to promote sustainable development, energy-saving and carbon reduction of buildings, as well as to lead industries to innovate and integrate, the Executive Yuan established National Council for Sustainable Development Network in 1995. The first Green Building evaluation system in Asia, EEWH system (Ecology, Energy saving, Waste reduction & Health) was then developed based on the regulations on energy conservation in Taiwan. In 1999, the Architecture and Building Research Institute, Ministry of the Interior propelled the National Council to set up *The Evaluation Manual for Green Building*. The indicators were Greenery, On-site Water Retention, Daily Energy Efficiency, Carbon Reduction, Waste Reduction, Water Resource, Sewage and Garbage Improvements. In 2002, the Biodiversity Indicator and Interior Environment indicators were included to form the nine major indicators of the current Green Building Evaluation System.

Meanwhile, the Architecture and Building Research Institute, Ministry of the Interior was also conducting researches on Smart Living Space. After over ten years of researching since 1992, the Institute carried out the standard of quantification evaluation and instruction of standard operation based on the Intelligent Building Evaluation Index in 2003. The Institute established the Intelligent Building Evaluation Manual and started to accept the applications of Intelligent Building Evaluation Index. The Executive Yuan then continued to promote intelligent building and the industrial integration of ICT (Information and Communications Technology). In 2010, A new version of the Intelligent Building Evaluation Manual was established which included the eight major indicators of Unified wiring, Information and Communication, System Integration, Facility Management, Safety and Disaster Prevention, Health and Comfort, Convenience and Friendliness and Energy Efficiency and Management. The grading system of Intelligent Building Label and Green Building Label both identify five grade levels as follow: Diamond, Gold, Silver, Bronze and Qualified.

The industrial innovation center (IIC) in central Taiwan is the first building grading Diamond in both Intelligent building label and Green building label. The main purpose is to enter central department of Industrial Technology Research Institute and two foundations in institute of information industry information. By constructing advanced detection analysis simulation and high-level research lab, the operation between open lab and incubator were connected in order to assist central Taiwan promote technology innovation ability. The plan includes three main topics such like advanced greenhouse systems, smart devices and sense-based design.

Although we can now develop automatic and intelligent building with the advances in ICT industry, in this Era of Big Data, we can make use of the giant data base which is built up automatically or semi-automatically during the operation process to store, transform, analysis and calculate data. The data can then be applied in technology to develop a more efficient intelligent system of building. It may even help develop a technology that people can manage the building and city through the cloud with a simple device to enjoy a smart living in the future.

Taiwan is located in a subtropical zone and the latitude range of the South and the North is only around three degrees. Yet, the geographical environment and climate of Taiwan are varied. All regions are faced with different environmental issues which need different solutions. In addition to giving the priority to human health, an environmental quality which the users feel comfortable is necessary. Strategies appropriate to the local conditions and optimized operating mode of intelligent building should also be developed to achieve energy conservation of air condition, illumination system, acoustic and mechanical such facilities.

It should also be considered that if the degrees of the intelligence of building and energy saving are in a direct proportion, and if the benefits of intelligent system to the users are greater than the operating cost as well as the damage to the system's life cycle. Most of the equipment brings damage to the environment during the production process and if the intelligent building is overdesigned just to fulfil the intelligent building evaluation index, or there are too many types of equipment, or the equipment are always updated and replaced, the initial concept of intelligent building evaluation index may be broken.

Except the physical index which can be referred to the data, some of the index related to the feeling of users may not be quantified. With the big data, we may tell the trend and changes of the intelligent system. Analyzing the correlation of different data, we may develop an operating mode which works for the Central Taiwan Innovation and Research Park. Thus, the objectives of this research are as followed:

1. **Apply big data in the field of architecture**
   With the integration of data mining tools, big data analysis method and automation system, manufacturing intelligence (MI) can be built to explore and analyze enormous data and information related to the environment of building and the users. MI can be used to explore potential useful information and great forms and concepts for the basis of building management and optimizing resource distribution.

2. **Build an optimized operating mode of intelligent building**
   With the collection of records and data of past experiences, including power consumption, air condition consumption, indoor environment quality, power management system, facilities management system, electrical light current system such big data, data mining can be conducted according to the different degree of intelligence. The correlation and anticipation of the systems and elements of intelligent building will then be analyzed. The analysis will include a matching of the records of power consumption of intelligent building, correction of the related parameters of the building's optimization and test of model in order to build an optimized anticipated model of intelligent building.

2. Literature Reviews

The biggest global issue in this century is how to face the climate changes and reduce carbon emission. In order to reduce the emission, architecture department now becomes the newer approach with bigger potential then industry department. The data reported by the US Department of Energy in the US shows that buildings consume about 41% of primary energy, more than transportation sector and industry sector. (U.S. Department of energy, March 2012)

Not only the energy wastes during the building construction, the progress of facility operating and maintaining but also consume a lot of resources. Especially the consumed resource during facility operating process accounts for up to 80-90% of the entire building life cycle consumption.(Luisa F. Cabeza, 2014)

With the advances in ICT, stronger systems of the communication network of buildings, and enhanced automation of facilities, buildings are being developed from individual control to intelligent buildings with centralized and automatic control. IB integrates DT and buildings, which enhances the operating efficiency of building and the living quality of residents. The intelligence of buildings is developed by technology which includes two main categories: "environment" and "human". Regarding "environment", sensor technology and automatic facilities are utilized to enhance the efficiency of sustainable energy conservation, disaster prevention, and facilities management. Regarding "human", technology is applied to offer intelligent services which make the living safer, healthier, more convenient and comfortable.(Architecture and Building Research Institute, 2011)

The old research methods predicting energy consumption include the ways as follow. (1) vector regression analysis(Bing Dong, 2005) (2) hybrid neural network model(M.R. Amin-Naseri 2008) (3)Decision Tree(DT)(Ahmed et al., 2011) In recent years, with the rapid changes of the structure and pattern of technology, the world has gone through the Era of IT (Information Technology) and the Era of ICT (Information and Communications Technology). It is now getting to the Era of DT (Data Technology). During the Era of IT, machine automation were developed which the machines were manipulated by signals. During the Era of ICT, the transmission paths of signals were changed that people could integrate data, audio and video through different communication methods to make the manipulation more convenient. In the future Era of DT, there will be smart machines which operate in a human's logic without manual manipulation.(Liao et al., 2012)

Data Mining Technology is an artificial intelligence application, rapid gathering valuable information from several kinds of data, for instance, massively parallel processing (MPP) database, distributed database, cloud computing platform, Internet and expandable storage system. Fu Xiao et al. proposed a five-step framework for Data Mining, including data preparation, collection analysis, valuable data mining and clue finding. The data was converting to proper format during the data preparation, enabling to improve the collection quality when it comes to implementation. Moreover, it can also help us to find the hidden value in the huge amount of data by using association rules.(Xiao and Fan, 2014)

3. Methodology

Overviewing the previous researches, the demonstration and discourse on intelligent buildings are quite fragmented, some of them only focus on the environment but ignore the issues on power consumption while some of them focus on energy saving but ignore the comfortability of health of users. However, there are various factors related to the operation of intelligent building. If there is only one factor focused, the evaluation may fail to reflect the real situation. To understand the impacts of differential factors, various measurements should be applied and big data should be analyzed to develop an optimized model for Central Taiwan Industrial Innovation and Research Park. Its efficient operation should also be ensured in order to achieve the least power consumption, highest comfortability and environmental efficiency. The research methods are as followed.

1. **Literature review and comprehensive analysis.**
   Case studies on intelligent building in Taiwan will be conducted. There was a revision of the Intelligent Building Evaluation Index in 2011. The indicators were added to eight from seven and the buildings would be awarded with the labels of diamond, gold, silver, bronze and pass. Thus, this research will focus on the buildings which meet the new version of index and divide them into different categories. Later on, there will be an analysis on different buildings according to their level of intelligence.

2. **Application of Data Mining on the statistics and analyses of operation information.**
   It is very important to analyze the temperature, humidity, illuminance and power consumption of every part of the building and the micro-climate of the exterior part at the phase of data collection. Data Mining is one of the most important methods when applying big data. It is used to reveal the hidden information. Statistical analysis and models building are applied in Data Mining to look for the patterns and relationships of the data.

3. **Simulating the operating mode of Central Taiwan Industrial Innovation Research Park through data analyses.**
   After analyzing, the most applicable temperature, humidity, illuminance and controllable factors will be obtained and they should be applied to the actual operation of the system. An analysis on the power consumption and other external factors should then be carried out. We will revise the related parameters of the optimized model and set up a testing model in order to develop an anticipated model of optimized intelligent building of Central Taiwan Industrial Innovation Research Park.

4. Discussion

There are 78 rooms and 104 public spaces in the IIC located in central Taiwan. In this discussion, first we analyze electrical power utilisation. There are four types such as, Heating, Ventilation and Air Conditioning (HAVC), electricity supply for power, for lighting and for socket. From the monthly power consumption record *(Fig.1)*, July is the highest month for power consumption. Due to the high temperature, the high electricity use is also observed. Interestingly, the power consumption is less before December of 2014. The possible reason is that the part of equipment was not installed yet or the staffs were not fully entered.

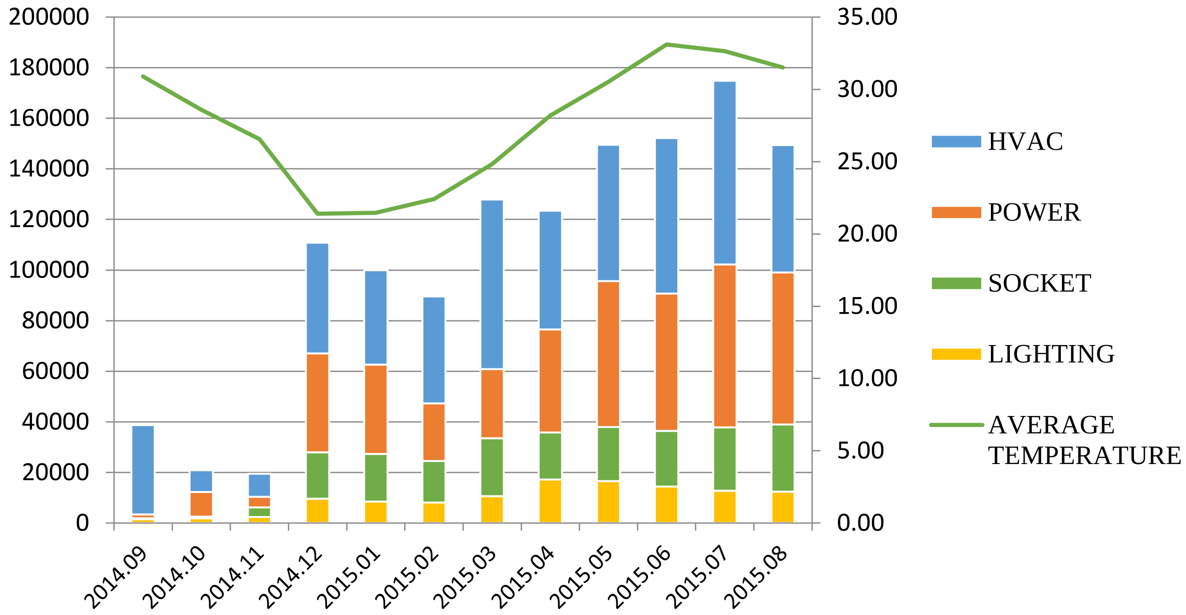

Figure 1: Types of power consumption and average temperature

The bar chart *(Fig.2)* shows the monthly power consumption proportion for 78 indoor zones. For example, the power consumption in September and October in the office of Greenhouse system Technology Center (Room A110) accounts for over half of the annual consumption. On the other hand, in most of the rooms, the main electricity consumption happened from June to August.

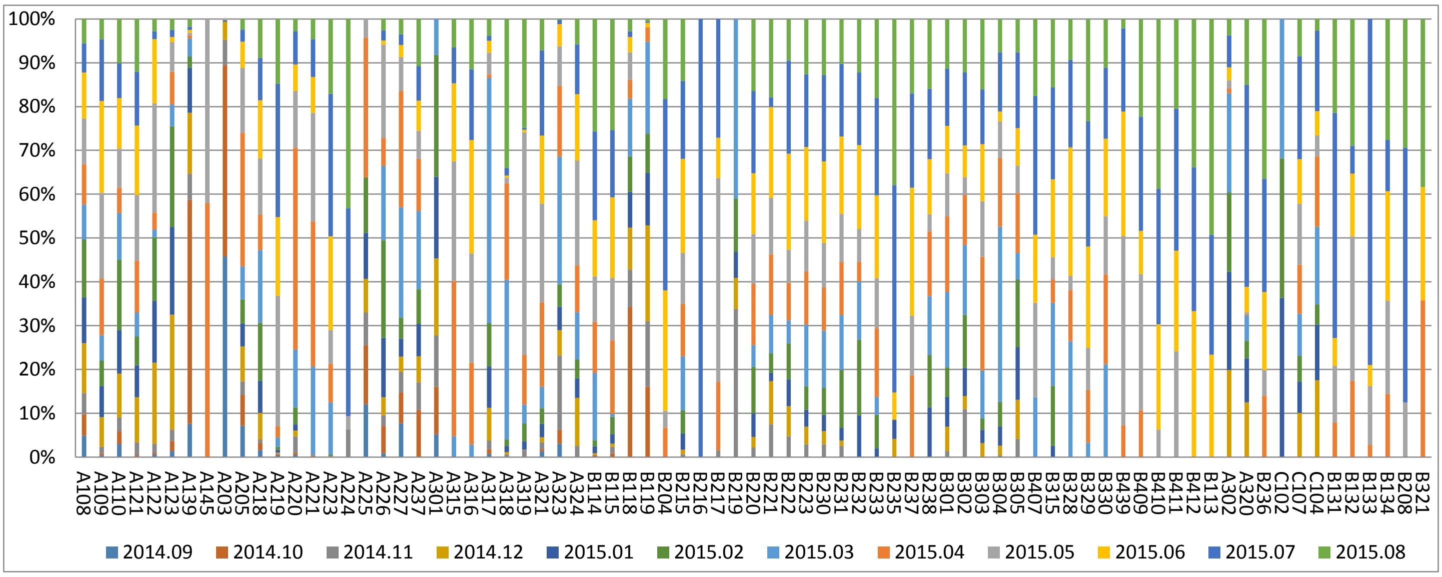

Figure 2: Monthly power consumption of different areas.

The annual electrical power consumption is shown in *Fig. 3* and the power consumption of HVAC accounts for 45% which is nearly half of the annual consumption. Taiwan is located in a subtropical zone and the climate is hot with high humidity. The IIC is located in central Taiwan where the annual average temperature is around 23℃. The average month temperatures from

June to August are higher than other months, sometimes up to 30℃, therefore, the need of the HVAC (air conditioning) is extraordinary increased.

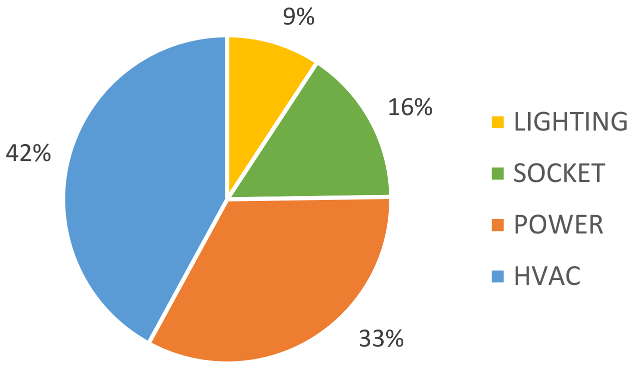

Figure 3: The proportion of annual electrical power consumption

The power consumption of Rapid Prototyping Center (Room A121) in the highest of the whole building and it accounts for almost 10% of the building's annual consumption. The accumulated power consumption of air condition of Room A121 is the highest among the rooms in the building. The power consumption of air condition of Room A219 met the highest in May and July. As the temperature of June and August was higher than the temperature of May and July but the power consumption of air condition of June and August on half of that of May and July, the factor of temperature may be excluded. The power consumption of air condition of Room A223 met the highest in July and it may be due to a more frequent use of that space.

The office of Greenhouse Technology Center on the first floor (Room A110) consumed nearly double of the average monthly air condition power in February. The office of Greenhouse Technology Center on the second floor (Room A205) consumed nearly five times of the average monthly air condition power in April and it may because the office was more frequently occupied that month.

Table 1: Room number and name

Room Number	*Name*
A110	the office of Greenhouse System Technology Center *on the first floor*
A121	Rapid Prototyping Center
A219	Computer Aided Design Greenhouse Laboratory
A223	Automatic Cultivation System Laboratory
A205	the office of Greenhouse System Technology Center *on the second floor*

The top 15 rooms are responsible for 50% of the annual electricity consumption in whole building. There are five rooms, A121, A219, A223, A110 and A205 which the main electricity consumption of these rooms are all from HVAC. The four main factors of HVAC system are Building type, Equipment distribution, Outdoor environment and User behavior. In this study, the Building type and Equipment distribution are set as fixed factor, then the relationships between outdoor temperature and power consumption will be observed. After that, by changing the behavior of the users, the electric consumption of the IIC will be adjusted.

By using Data Mining, the frequency of the staffs enter or exit the rooms from June to August and the relevance between the HVAC electrical consumption and usage by staffs can be analyzed and investigated. Fig. 4 shows the occupancy in different period in those five rooms, excluding the access of the security guards and cleaning staff. From the Fig.4, the period without staff passing can be estimated by Replace Missing Value Interpolation Line. Next, by using Data Mining and we found out the unoccupied period are mostly in afternoon.

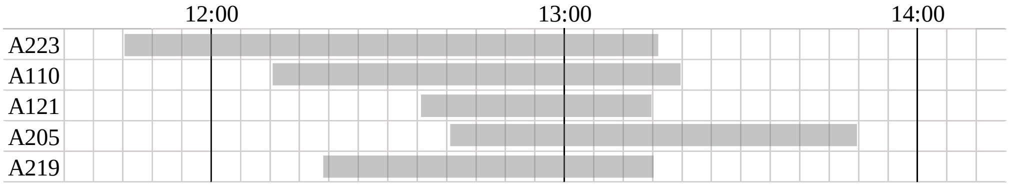

Figure 4: the period without staff passing

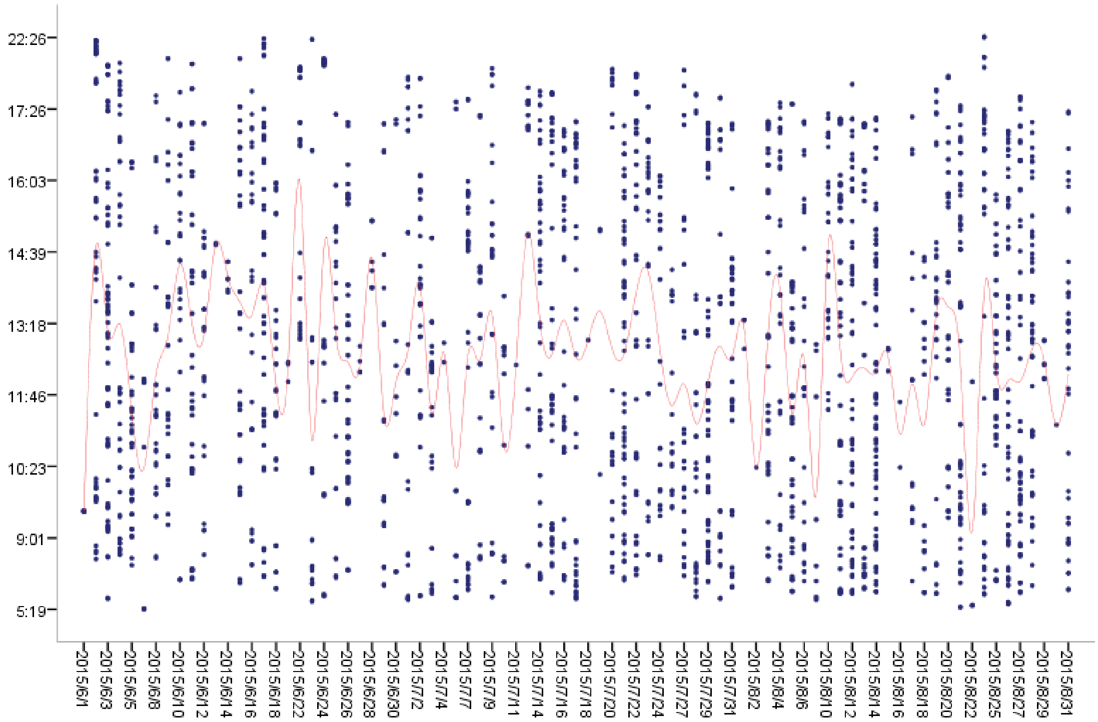

Figure 5: the frequency of the staffs enter or exit the rooms from June to August in A223

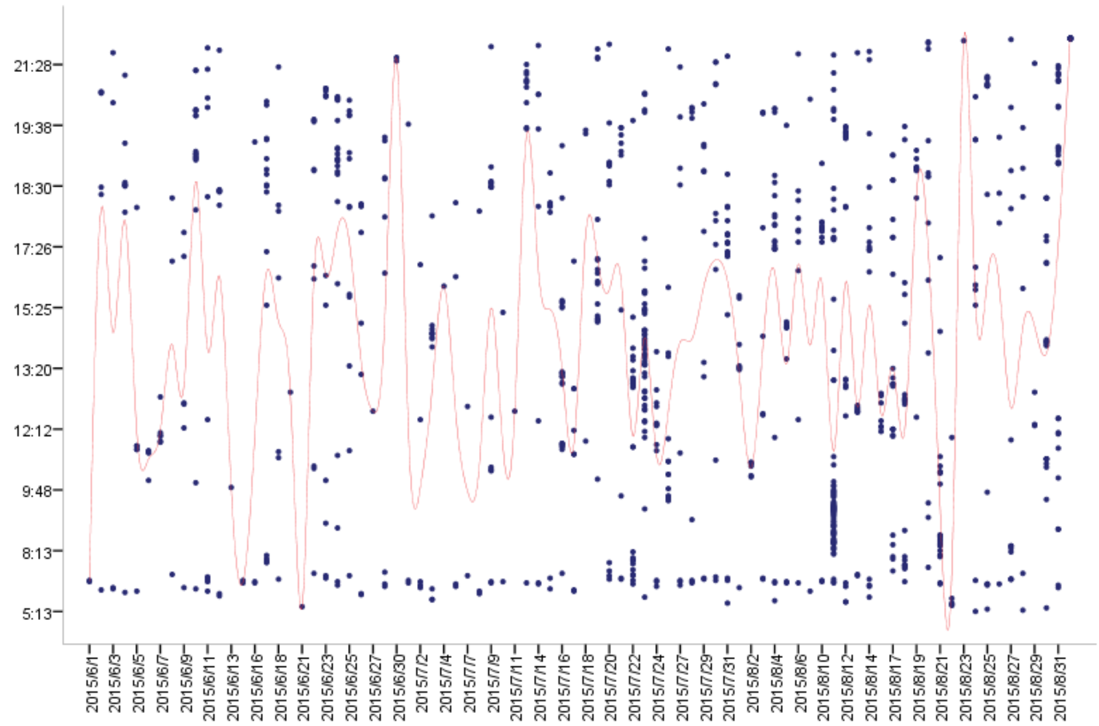

Figure 6: the frequency of the staffs enter or exit the rooms from June to August in A110

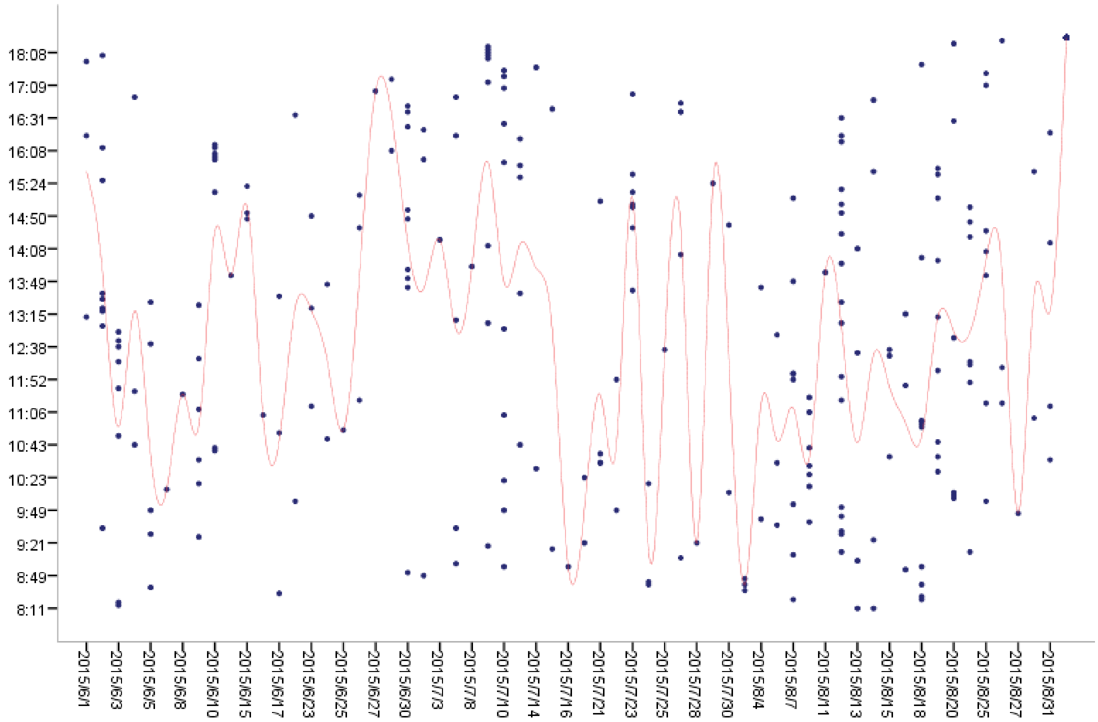

Figure 7: the frequency of the staffs enter or exit the rooms from June to August in A121

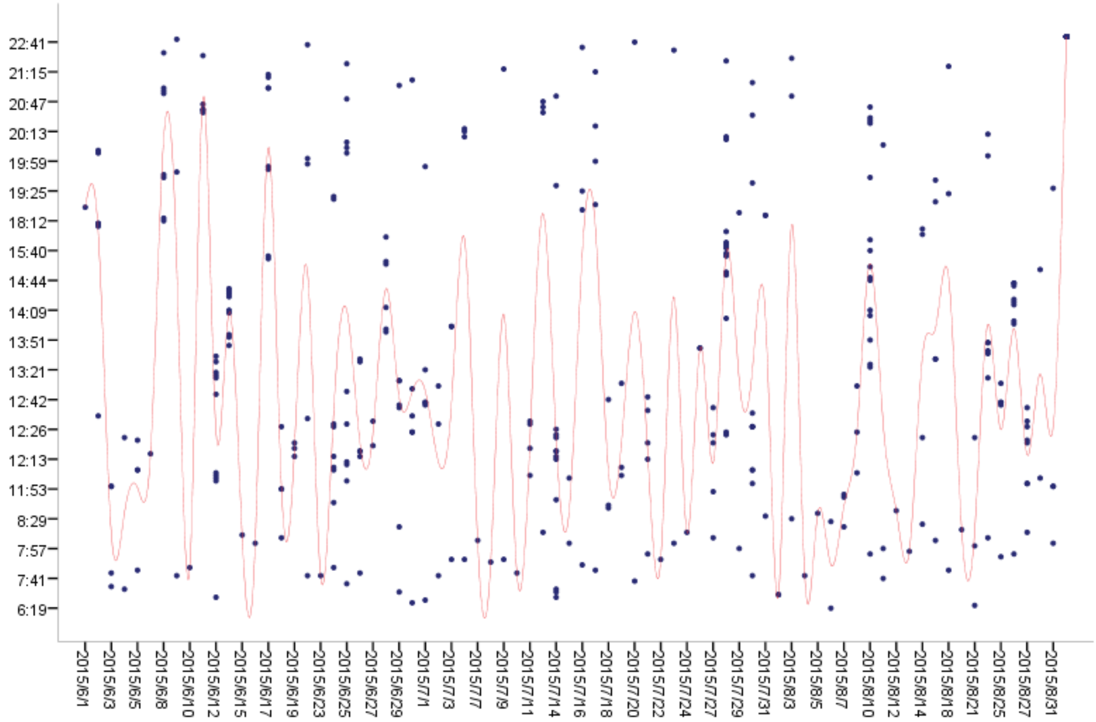

Figure 8: the frequency of the staffs enter or exit the rooms from June to August in A205

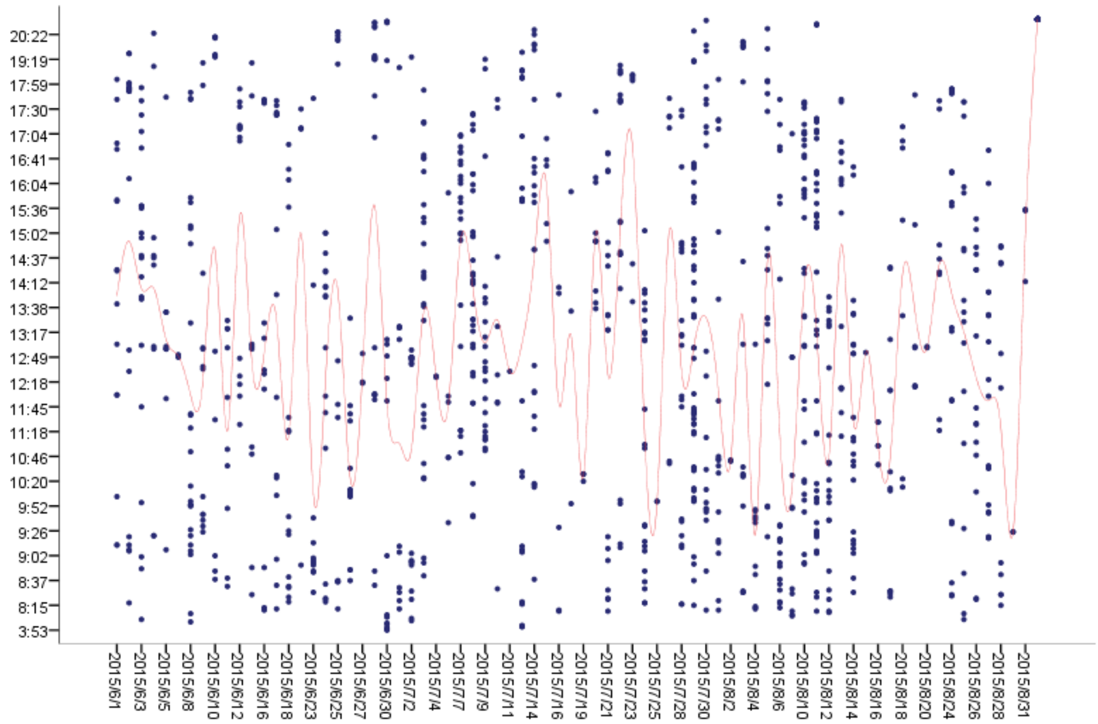

Figure 9: the frequency of the staffs enter or exit the rooms from June to August in A219

5. Conclusions

From the analysis above, the HVAC electric consumption has no absolute correlation with temperature, the number of users are also possibly involved. In this analysis of the five rooms, the time was set as variable factor. If the HVAC system was set electricity-off during 12:45-13:15, it is expected in simulation data that nearly 6% of electric consumption can be saved during the period from June to August. In other public space, since the lowest temperature that the air conditioner can adjust to is limited, if we set the temperature to 1 or 2 Celsius degrees higher, the air condition will consume less power and it will not be over-run. In addition to some of the spaces mainly use power current and the power current consumption may not be forced to reduce after an optimized operating mode is set up since the consumption is related to the period and frequency of use. However, if the power consumption can be changed due to the temperature or other controllable factors, we may adjust the standard temperature or physically change the temperature so as to reduce the power consumption of air condition.

The charts above show only the analysis of five rooms which are responsible for 50% of entire building electric consumption and only the prediction of the three months with highest temperature of all the rooms in IIC. In the following research, we expect to use the data of all areas in analysis and also take the combination of the using frequency, temperature and other quantifiable factors into consideration.The IIC has been operating one year and half only, there will be more data to be collected and analyzed afterwards. By using the data, the operation will be predicted and run for test. With the analysis of Big Data, the more accurate and smarter ways of operation can be provided, in order to optimize the operation mode.

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A Study on the Integration of Logic Systems in Intelligent Building System

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Abstract

To promote carbon-reduction of buildings, increase living qualities and guide the innovative development of the industry, Taiwan has authorized the promotion program of Intelligent Green Buildings in 2010, and the program will be co-organized and led by the government departments in collaboration. However, are these intelligent buildings operating "intelligently" according to the Taiwan Intelligent Building Evaluation System and actual implementation situations? Although Taiwan has self-developed automatic sensor and communication technologies for a long time, the "response" feature of the sensor technology in the building facilities and systems are inadequate for the automatic operation and maintenance of the intelligent systems. This is a hidden issue within the intelligence system development that needs to be answered. Hence, this study will focus on the automation of operation and maintenance of environmental factors detected in ICT and the disaster prevention, electrical supply, water supply, wastewater, air-conditioning, communications and transport systems. For example, when indoor carbon dioxide concentration exceeds 1000ppm, the air- conditioning system should open a shaft to allow fresh air to enter; when indoor air quality returns to preset conditions, the system will automatically shut down the ventilation system. This study shall use Taiwan case studies that have achieved the highest level of Intelligent Building Label as targets and explore the relations and links between the different connected systems and the controlling logics. In other words, it will mean using an integrated series of logic controllers to determine system responses, allowing the building to function with consciousness and create human-centered living spaces according to different requirements or basic environmental factors, so that the building may become a truly intelligent building entity.

Keywords: Intelligent Building, Logic System, Integration

1. Introduction

With the advance of modern technology and demand of people, the automated systems of different kinds of building have been constantly innovated and developed. There are various and complex innovations and development, for instance, air condition, electrical power and illumination system. However, the applying service subsystems from different manufacturers usually have different coding format which cause the differences of communication rate, coding format, ways of synchronize and communications specification. As a result, resource cannot be shared between the system facilities and the messages cannot be transmitted and coordinated which limit the efficiency of services management and the development of sustainable operation management. Therefore, this research focuses on the environment factors detected by the monitoring system and also the facilities such as disaster prevention system, electrical system, water supply and drainage system, air condition system and communication of the intelligent building system. It focuses on the automation of operation and maintenance management as well. In short, this research has applied a series of logical integration to give the building the features to serve as a more occupant- friendly and favourable living space according to different demand or environmental condition to become a real intelligent building.

In this research, we have reviewed the Industrial Innovation Center in Taiwan's experience on applying for the Intelligent Building Label. We have found that there are some problems of the operation of intelligent buildings needed to be discussed; especially the links and the interaction between each intelligent system which fail to achieve the original goals. Since they are still manual-controlled, they are not intelligent but automated. The significance of intelligent buildings is lost when the designed intelligence does not work well. For example, when the air quality detector senses poor indoor air quality, it draws fresh air into the indoor proactively to reduce the indoor concentration of CO_2. However, if the temperature is high outside, the drawn air will also raise the indoor temperature which increases the need of air condition. This example only presents the failed coordination between two facilities and we can imagine how complicated it is when an intelligent building connects a number of facilities at the same time. Hence, to achieve "intelligence", we must find the key points and directions of system integration, as well as focus on the strategies of software system integration and planning and the feasibility studies. The system integration and logic establishment of the coordination between the software and hardware in intelligent buildings should be analyzed. The objectives of this study are as followed:

1. System integration and logic establishment
Through case studies, we have analyzed the links between each system, as well as the main factors affecting the logic establishment and other correlation coefficients. We hope to enhance the intelligence of buildings which serve as a human-oriented and favourable living space based on different demands and environmental conditions.

2. Enhancement of efficiency of intelligent buildings
When the management efficiency and the ability in system integration of intelligent buildings are enhanced, the operation cost of buildings can also be reduced. With the automated devices and systems, the limited resources and the spaces may be utilized and developed to offer a comfortable, safe and convenient environment, as well as to save the buildings' expenses and resources consumption.

2. Literature Reviews

This research focuses on the integration of logic systems in intelligent building system; therefore, The literature review and theoretical framework include the following topics:
(1.) The definition of intelligent buildings and the importance of system integration
(2.) The application of intelligent systems
(3.) The definition of logic and the logic that this research adopts

2.1 The definition of Intelligent Buildings

In short, intelligent building refers to the integration of information and communication technology (ICT) into a building in order to enhance the efficiency of the building's management and the living quality of occupants. Regarding "human", internet technology is applied to offer intelligent services such as assistive functions of safety, health, convenience and comfort. Regarding "environment", sensor technology and automated facilities are applied to raise the sustainability and energy efficiency, safety and disaster prevention, and facilities management efficiency of buildings(Architecture and Building Research Institute, Ministry of the Interior, 2012).

Professor Clements-Croome from University of Reading defined that intelligent buildings are not completely buildings of high-technology but are able to change in accordance with the needs of occupants. They have to be highly-sustainable and provide the occupants the space to interact so as to enhance the living efficiency(Derek,2013). Thus, we believe that we should pay high attention when we analyze how to enhance the buildings from the "automated" stage to "intelligent" stage based on the progress of modern technology, as well as the architectural development in this generation.

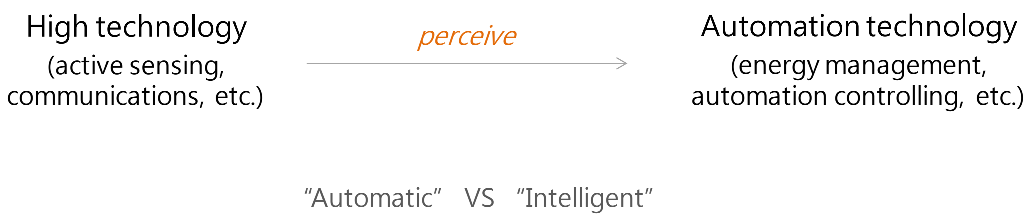


Figure 1 Relation between "automatic" and "intelligent"

The integration of a building's facilities with other related intelligent construction technology is emphasized in the functions of intelligent buildings. The integration includes automated building systems and technologies, occupied space, operating and management mechanism and how to introduce high-performance control functions to achieve the safety of air condition, illumination and disasters prevention such facilities, energy conservation and environment protection while maintaining good indoor environment(Wen,1999).

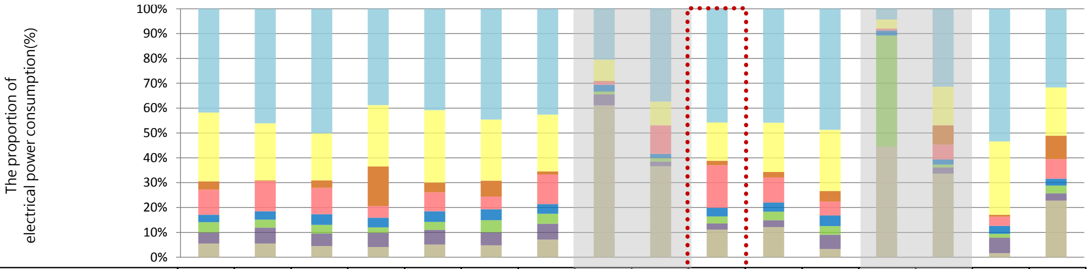
Currently, when it comes to the formation of intelligent space, the most discussed issues are (1) device heterogeneity, (2) device awareness, (3) come and use, (4) limited resource, (5) integrated multiple service management, (6) home service sharing, (7) security, (8) quality of service (QoS), (9) pay per use, (10) user authentication and (11) preference. It is to be hoped that through the integration of human, the internet and facilities, the intelligence of facilities can be enhanced and introduce the central concept of "human oriented", as well as include the related topics of health, comfort and safety(Shaikh, P. H, 2014)(Architecture and Building Research Institute, Ministry of the Interior, 2012).

Moreover, as we have come to a new generation, there have been more technological and automated services introduced in accordance with the occupants' demand. Nonetheless, the types of system are varied and always increasing. For intelligent buildings, what is saved from resource sharing, and the maintenance, change and expansion in the future of these different facility systems, or the coordination between systems and enhancement of manipulation management will affect the sustainable development of buildings. Consequently, it is necessary to consider the system integration of building which is expected to increase the efficiency of management and integrated services, reduce the dependence on labor force as well as the operating and management cost of buildings in the future.

2.2 The definition of Logic

The definition of the term "logic" includes (1) the principle of objective things, (2) a theory or a view point, (3) the rule of thinking and (4) the science of reasoning.

According to the annual report of Bureau of Energy, Ministry of Economic Affairs, in addition to special types of buildings (for example, tracks in a railway station, telecommunication equipment rooms, wastewater treatment plants and warehouses), the air condition system and illumination system account for the most electrical power consumption of different sorts of buildings. In average, the air condition system and the illumination system account for approximately 32% to 54% and 15% to 30% of the total electrical power consumption respectively. In another word, they account for 60% to 70% of the total consumption of the buildings(Taiwan Bureau of Energy, Minist of Economic Affairs,2013). (See Figure 2)



System \ Type	School	Office Building	Hospital	Hyper-market	Department Store	Hostel	Government Agencies	Railway station and tracks	Telecommunication Equipment rooms	Research Building	Exhibition Center	Composite Mall	Wastewater treatment plants	Warehouses	Airport	Othres
Air condition system	41.9%	46.1%	50.1%	39.0%	40.8%	44.6%	42.6%	20.5%	37.5%	45.8%	46.0%	48.8%	4.3%	31.3%	53.5%	31.7%
Illumination system	27.7%	23.0%	19.0%	24.7%	29.2%	24.6%	22.9%	8.6%	9.5%	15.4%	19.8%	24.7%	3.7%	15.5%	29.5%	19.4%
Refrigerate and freeze system	3.3%	0.3%	3.0%	15.9%	3.9%	6.4%	1.2%	0.2%	0.1%	1.8%	2.2%	4.2%	0.1%	7.8%	0.8%	9.4%
Sockets system	10.1%	12.1%	10.6%	4.7%	7.6%	5.1%	11.9%	1.3%	11.4%	17.1%	10.1%	5.6%	0.7%	6.0%	3.7%	7.9%
Air supply and exhaust system	3.0%	3.4%	4.3%	3.9%	4.3%	4.4%	3.9%	2.7%	1.7%	3.5%	3.7%	4.3%	2.0%	2.0%	3.2%	2.8%
Water supply and drainage system	4.2%	3.2%	3.5%	2.2%	3.2%	4.9%	4.0%	1.2%	1.4%	2.8%	3.4%	3.5%	44.7%	1.2%	1.5%	3.1%
Elevator system	4.4%	6.4%	5.0%	5.7%	5.9%	5.2%	6.4%	4.4%	1.9%	2.5%	2.8%	5.7%	0.0%	2.5%	6.3%	2.9%
Other systems	5.5%	5.5%	4.5%	4.1%	5.1%	4.8%	7.1%	61.1%	36.6%	11.1%	12.1%	3.3%	44.5%	33.6%	1.6%	22.8%

Figure 2 Distribution of electrical power consumption of different buildings(Source: Energy saving of building Manual, Bureau of Energy, Ministry of Economic Affairs)

Hence, a conclusion of the above statement is conducted when discussing logic in this research. The proportion of electrical power consumption is the basis of logic control; for instance, the proportion of electrical power consumption of air condition system, sockets and illumination are respectively 45.8%, 17.1% and 15.4% in a research building (Figure 3), According to a foreign study on energy saving potential, the system for distinguishing energy consumption is also divided into four categories (Nguyen, 2013). After categorizing the buildings, we have mainly discussed these four types of consumption. In brief, we have first controlled the equipment which consumes the most electrical power, following other equipment.

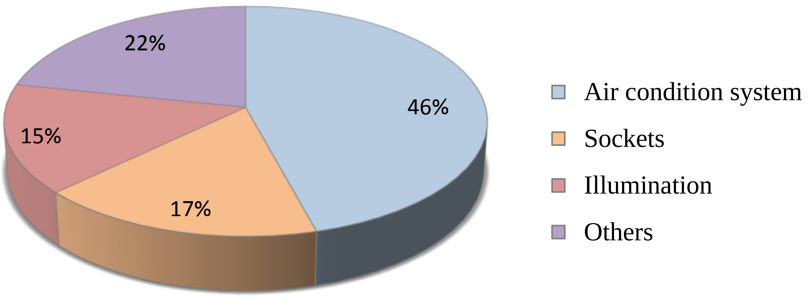


Figure 3 Proportion of electrical power consumption of research building.

However, in order to achieve improvements in building energy use at this stage, logic discussions of individual systems are necessary based on the illumination of public buildings and the air condition system(C. Aghemo et al., 2013); studies discussing the adoption of a classification method are also required to draw up an air condition system control logic (G.Graditi et al., 2015), etc. in a reasonable usage method with the living space as an example; however, the single system is generally adopted as the study case.

3. Methodology

3.1 Literature Review and Theoretical Framework

With various technologies, designs, and equipment related to intelligent buildings, in order to gather information about intelligent building applications and the current situation of development, we will collect both domestic and foreign design data related to intelligent buildings, as well as relevant literature regarding energy saving technology, equipment, design concepts, etc., in order to make a review to better understand the latest application condition of this technology and provide a reference and application for subsequent studies and discussion.

3.2 Correlation Analysis

This study adopts data collection and research as analysis research methods. Therefore, it first categorizes each system as 「Air conditioning, Illumination, Sockets, Power Current」 through the intelligent buildings, then performs a preliminary screening of the space, and finally discusses the relationship between the average total electricity consumption of air conditioning, illumination, sockets, power current and the total quantity of the electricity of the above four items together. As mentioned above, in order to observe two or more variables to determine whether other variables can be predicted from another major variable, 「Correlation Analysis」 in the statistics will be adopted as the method of this study: Pearson's Correlation will be adopted to analyze the correlation degree of the two, and the correlation coefficient (γ_{XY}) may serve as the pointer of linear correlation between two continuous variables and is defined below:

$$\gamma_{XY} = \frac{s_{XY}}{s_X s_Y}$$

γ_{XY} = Sample correlation coefficient　　s_X = Sample standard deviation of X

s_{XY} = Sample covariance　　s_Y = Sample standard deviation of Y

(1) The value of the correlation coefficient is constant between -1 and +1.

(2) +1 shows that X and Y belong to the completely positive linear correlation, while -1 shows that they belong to the completely negative linear correlation. If the value of the correlation coefficient is very close to zero, then no linear relation exists between X and Y.

(3) The correlation degree represented by the correlation coefficient is shown in Table 1.

Table 1 Correlation degree represented by the correlation coefficient

Correlation coefficient (r)	Correlation degree
Above 0.8	Extremely high
0.6 - 0.8	High
0.4 - 0.6	Average
0.2 - 0.4	Low
Below 0.2	Extremely low

After calculating the correlation coefficient, its value was found to be increasingly close to 1, indicating that the space is more correlated to the system of this class, thus improving the understanding of the correlation degree of usage amount of these four electricity consumption classes in a space, determining the order of use of each system, and discussing its operation logic.

4. Discussion

We have taken the Industrial Innovation Center in Taiwan as an example. The interior system is categorized into “air condition”, “illumination”, “sockets” and “power current” and the actual electrical power consumption have been discussed.

Table 2 Categories of intelligent system of Industrial Innovation Center in Taiwan

Category	Air Condition	Illumination	Sockets/ Light Current	Power Current	Others
System	Air quality	Illumination control	Door security system	Flood prevention	Division of fire protection
	Air condition system		Emergency system	Ground system	Energy saving and management
	Environment and wind monitoring system		CCTV system	Lightning protection system	
			Automatic pay station for car parking	Emergency generator	
			Environment monitoring system	Water supply and drainage system	
			Leak and flood detection	Environmental control power	
			Facility management system	Environment and water monitoring system	
			Other light current system	Renewable power system	

			Home automation system	Elevator	
			Spatial Assisting		
			Information Service		
			Fire alarm system		

(Data source: Summarized in this study）

Furthermore, as the place of this case lies in a circum-subtropical zone, the summer climate from June to August is the hottest part of the year. Therefore, the total electricity consumption data (as shown in Figure 4) of each space from June to August of 2015 is summarized to discuss the topics that can be researched, analyzed and improved with regard to the relatively extreme values. Of the 205 spaces, 51 had an electricity consumption that exceeded the average value, including seven spaces with an electricity consumption that exceeded the standard deviation of 1. This study classifies the use of each space as follows:

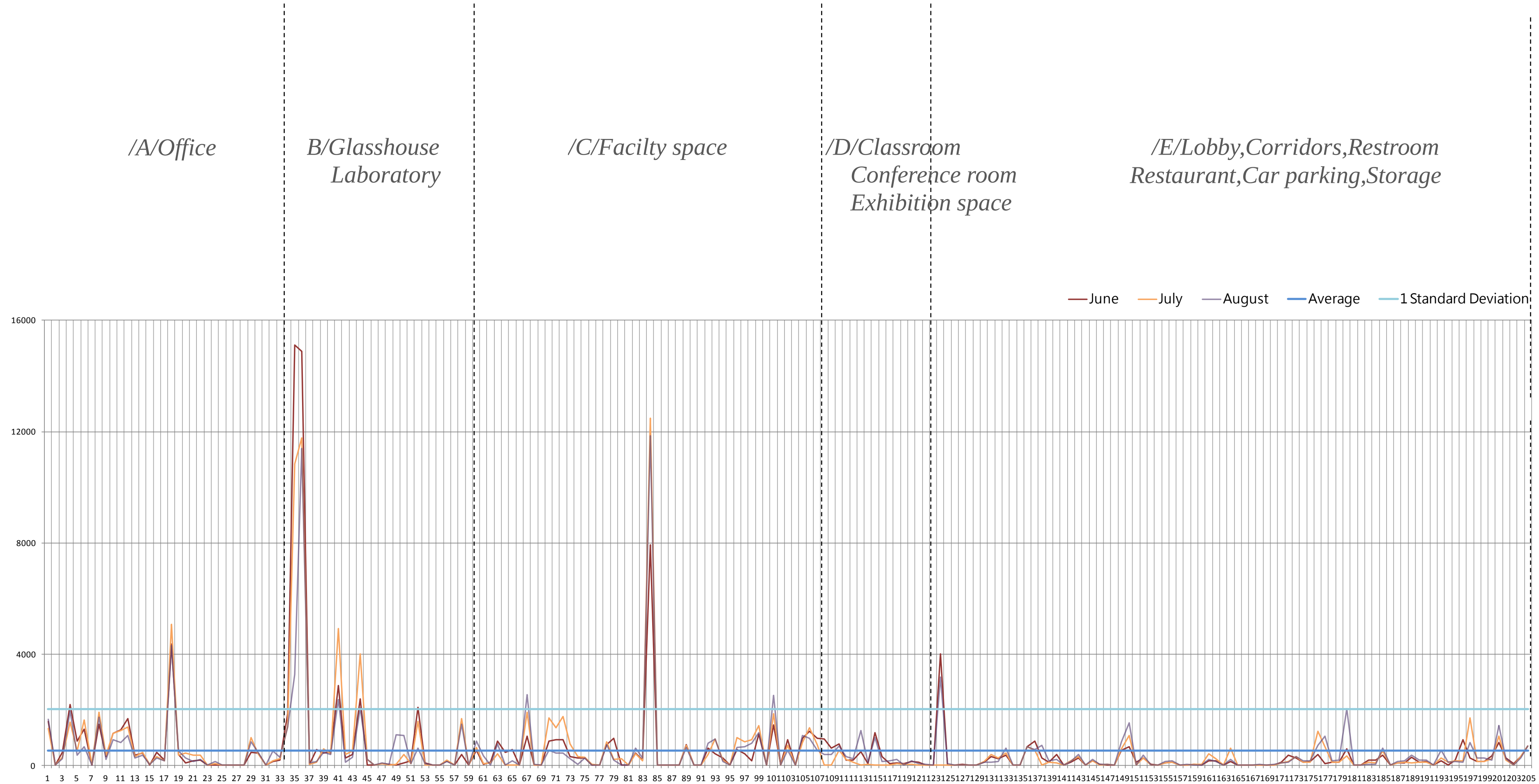


Figure 4 Electrical por consumption of different spaces

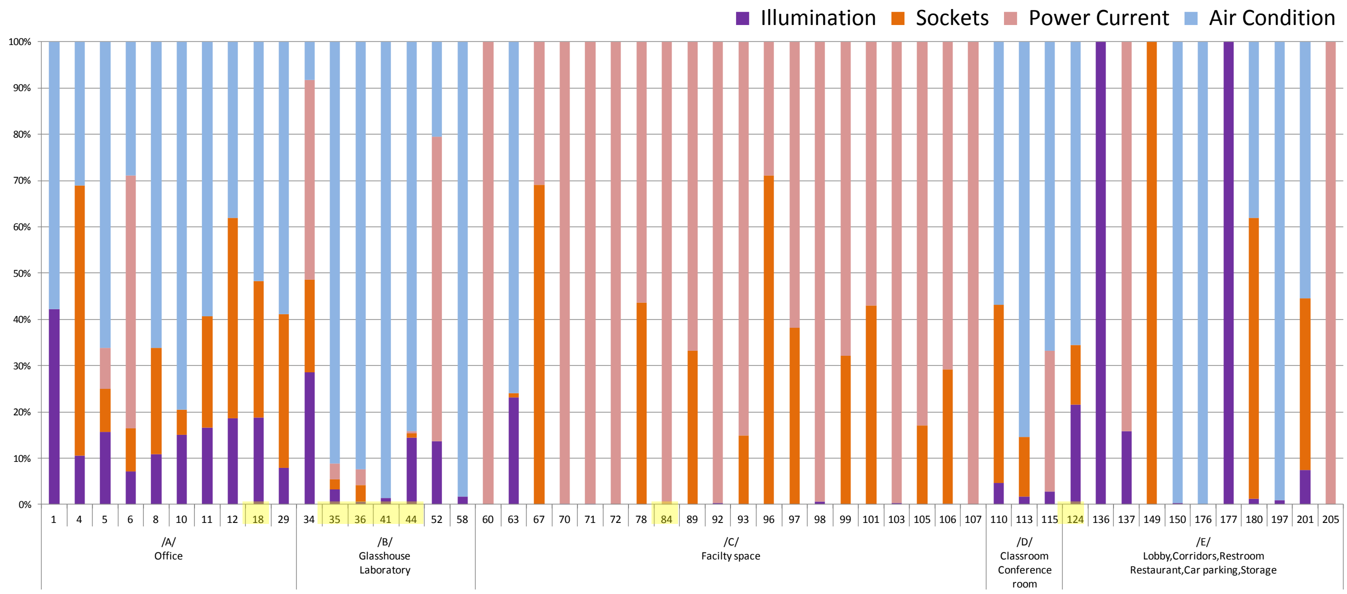


Figure 5 Proportion of electrical power consumption of different spaces in June.

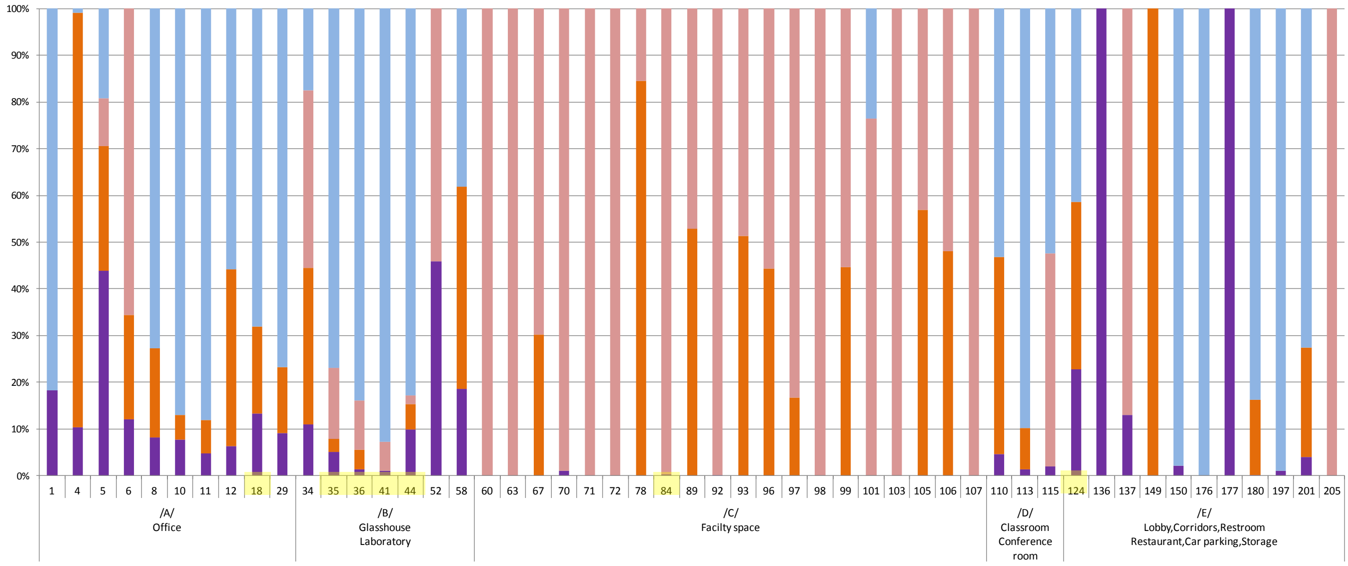


Figure 6 Proportion of electrical power consumption of different spaces in July.

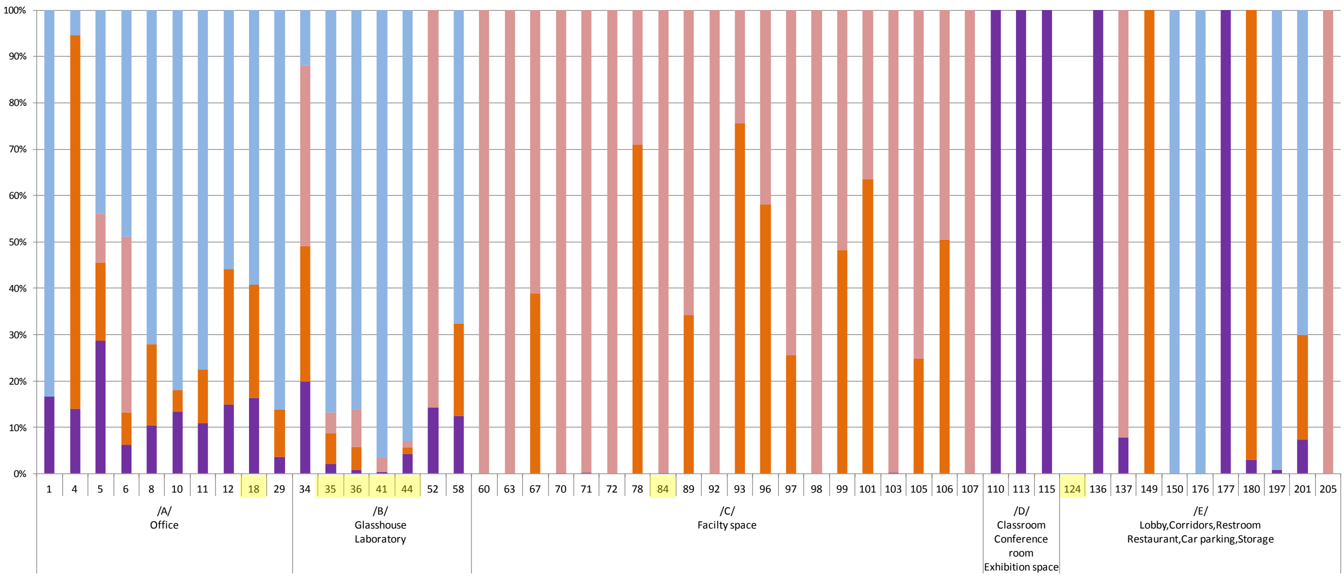


Figure 7 Proportion of electrical power consumption of different spaces in August.

4.1 Different space type analysis findings

Figure 5, Figure 6, and Figure 7 show the 51 spaces whose total electricity consumption exceeded the average value from June to August. Among them, the designation A, B, C, D, and E below indicate the class of space; the number represents the code of each space; and the areas marked with a yellow color block represent the total electricity consumption of this space that exceeds the standard deviation of 1. According to the electricity consumption proportion of each space with different uses, the main energy consumption class and total electricity consumption (as shown in Figure 8) of the space also differ.

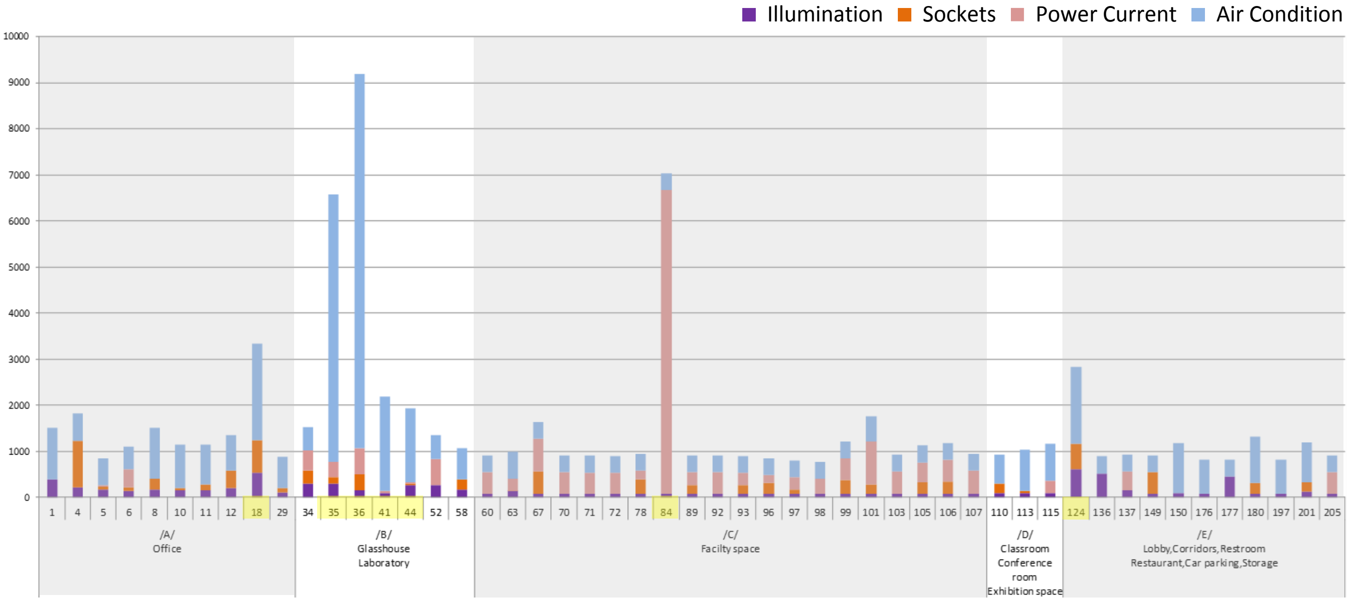


Figure 8Proportion of electrical power consumption between June and August

/A/ Office Space

The consumption of electricity for illumination, sockets, power current, and air conditioner items mostly presents a relatively uniform usage state. The systems' categories calculated using the correlation coefficient are summarized below from highest to lowest; as its value becomes closer to 1, the space is more correlated to the system of this category: **air conditioner (r=0.934), illumination (r=0.845), sockets (r=0.783), and power current (r=0.118).**

Furthermore, we drew a scatter diagram of the correlation degree, as shown in Figure 9. Using air conditioning as an example, the x-axis represents the average electricity consumption of the air conditioning category from June to August, and the y-axis represents the total electricity consumption for illumination, sockets, air conditioning, and power current from June to August. The scattered point is more densely distributed in the simple linear regression trend on-line, indicating that the air conditioning is more correlated to the office class space.

Using the system of Central Industry Innovation Research and Development Zone of Taiwan's Industrial Institute as an example, the system logic deduction used for office space is as follows: **Air conditioning system > Illumination control > Firefighting system.**

Among them, the electricity for sockets is the electricity mainly consumed by office equipment. The electricity for the power current is generally not applied in the system, so there is no arrangement.

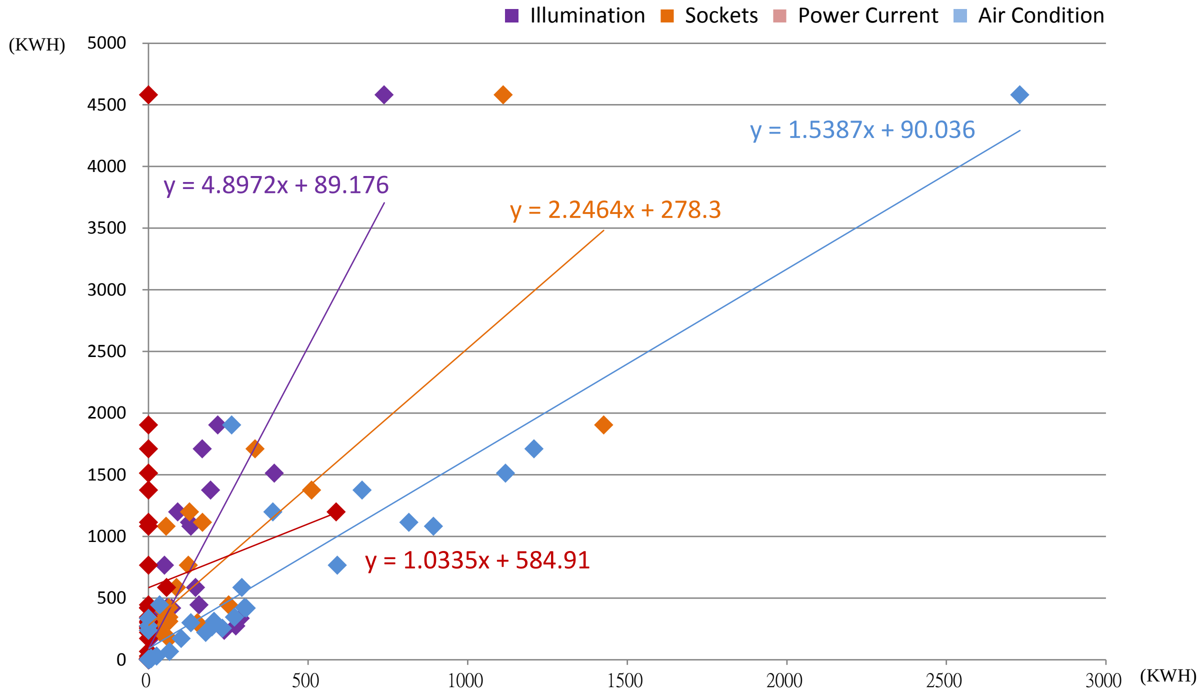


Figure 9 Correlation diagram of each system class in the office space

/B/ Glasshouse and Laboratory

Owing to the fact that the areas are majorly used as glasshouses and precision instruments are used and installed there, there is a more apparent use of air condition comparing to other space types (e.g. Figure 8, code 35, 36, 41, and 44). The correlation coefficient of each class is summarized below: **air conditioner(r=0.992), sockets (r=0.628), power current(r=0.625), illumination (r=0.428).** The system logic deduction is: **Air conditioning system** > **Air quality system** > **Firefighting system** > **Illumination control**

Among them, the electricity used for sockets is mainly the electricity consumed by greenhouse or research equipment, except for the part of electricity consumed for detection of the firefighting system. The electricity used for the power current is also the same; thus, there is no arrangement.

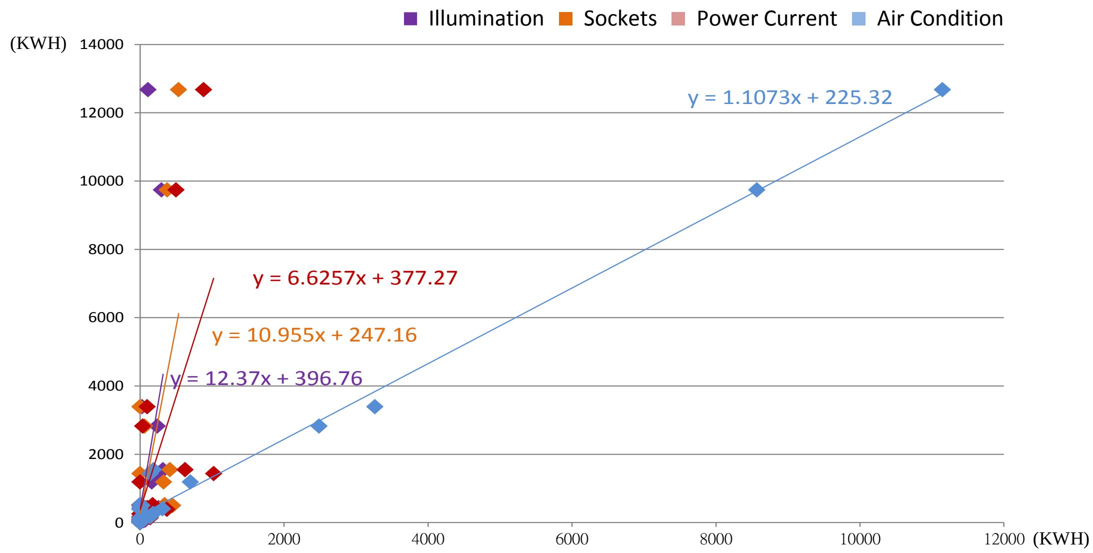


Figure 10 Correlation diagram of each system class in the glasshouse and laboratory space

/C/ Faculty Space

There are many huge machines in this space type which generate heat during operation. Therefore, air condition is necessary to adjust the temperature so as to maintain the operation of machines.The correlation coefficient of each class is summarized below: **power current(r=0.990), sockets(r=0.134), air conditioner(r=0.058), illumination(r=0.029).**The system logic deduction is: **Emergency generator system > Environmental control power system > Firefighting system > Air conditioning system > Illumination control.**

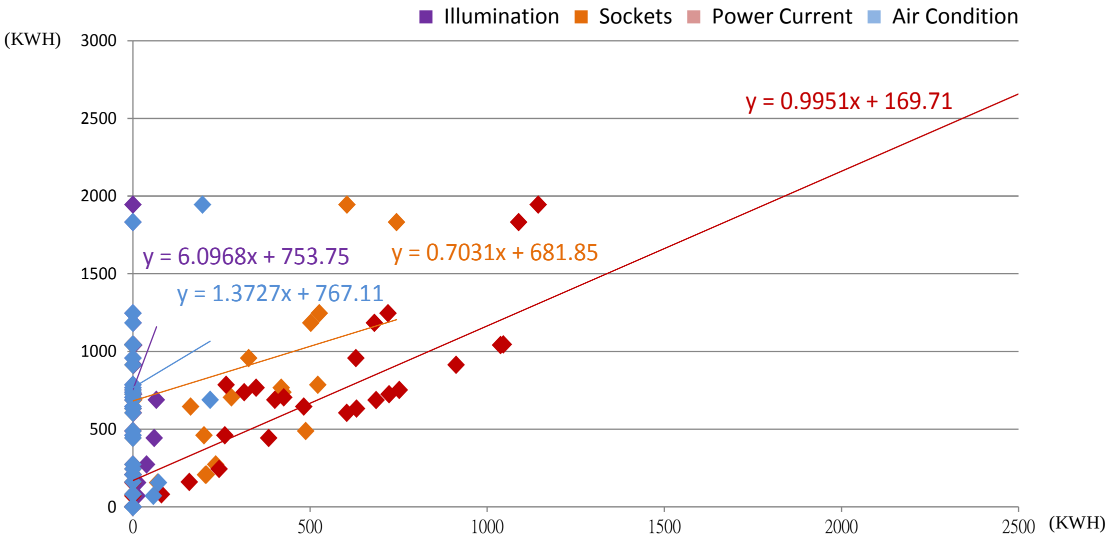


Figure 11 Correlation diagram of each system class in the faculty space

/D/ Classroom, Conference room and Exhibition space

In addition,some of spaces are only occupied sometimes so they only consume power for illumination during normal occasions, such as experience room, meeting room and show area. (Figure5.6.7 /D/ class of space) .The correlation coefficient of each class is summarized below:**air conditioner(r=0.889), illumination(r=0.525), sockets(r=0.505), power current(r=0.067)**. The system logic deduction is: **Air quality system > Air conditioning system > Illumination control > Firefighting system.** The electricity used for sockets is mainly the electricity consumed by the equipment, while part of the space may have electricity consumption with regard to power current under particular usage conditions. Therefore, this correlation is extremely low.

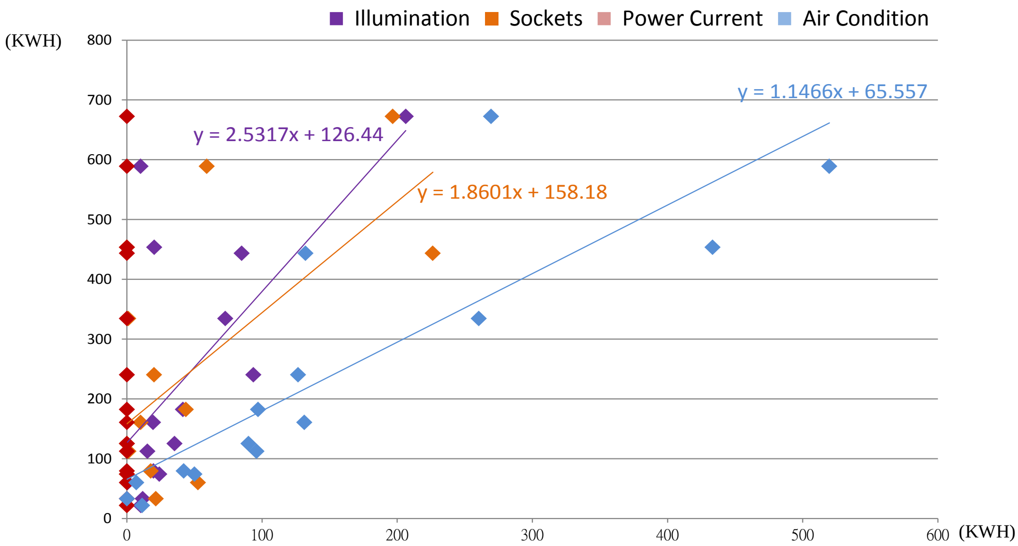


Figure 12 Correlation diagram of each system class in the classroom, conference room and exhibition space

/E/ Lobby, Corridors, Restroom, Restaurant, Car parking and Storage

The major electrical power consumption of this space type is quite different. For example, illumination is the major consumption for the car parking, air condition is the major consumption for the lobby, pantry and elevator lobby, and power current is the major consumption for the kitchen.The correlation coefficient of each class is summarized below: **air conditioner(r=0.851), sockets(r=0.636), illumination (r=0.490), power current(r=0.081)**. The system logic deduction is: **Air conditioning system** > **Air quality system** > **Firefighting system** > **Illumination control**.

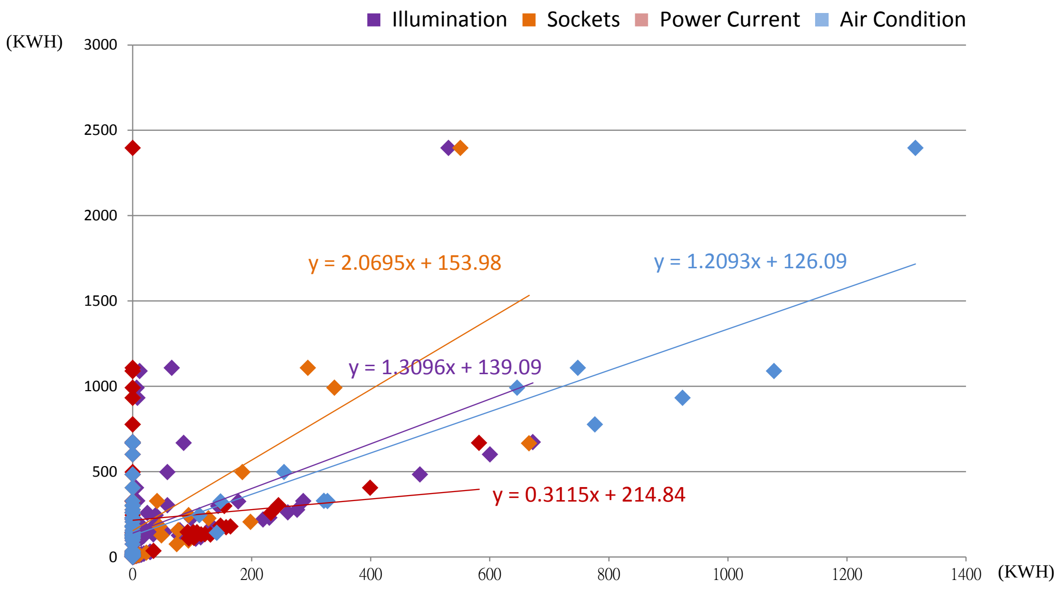


Figure 13 Correlation diagram of each system class in the other space

As we have mentioned, the air condition system and illumination account for the most electrical power consumption of most of the buildings which is approximately 60% to 70% of the total consumption. Nevertheless, our case studies findings show that the air condition system and power current actually account for approximately 70% of the total consumption (see figure 14). From the data shown above, we have inferred that it is because the analyzed building is a research institute which mainly relies on the air condition and power current. Apart from that, it may also be resulted from the good design of adopting the natural lighting of the Industrial Innovation Center which can satisfy the demand of illumination. The illumination only accounts for 11.25% of the total electrical power consumption.

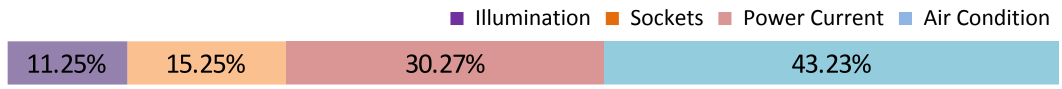


Figure 14 Proportion of electrical power consumption of Industrial Innovation Center between June and August

5. Conclusions

According to the statistics of the annual review report of the Bureau of Energy, Ministry of Economic Affairs in its study of the proportion of electricity consumption in different classes of buildings, it arranged as the following four categories according to the proportion of total electricity occupied: air conditioning, power current, sockets, and illumination electricity. Furthermore, as the above arrangement is only the order of "Total Electricity Consumption" obtained in the case, if the order and control logic of the four system classes are thus deduced, the final conclusions obtained will be unable to completely apply to the space of the ABCDE classes according to their spatial characteristics. Therefore, discussions shall be respectively made according to different "Space Properties".

Furthermore, through the *4.1 Discussion of each space class* section above, the deduced system order of A to E classes is obtained. From the perspective where the logic model of the system applied in this space is deduced, in order to comply with this study's purpose of making energy saving and efficient improvements, different spaces and usage methods can be followed to establish intellectualized regulations and controls according to the logic precedence order, as well as to practically summarize the energy saving countermeasures required for this space in a more friendly way. This research case is illustrated as follows:

(1) /A/ Office space; /B/ Glasshouse and Laboratory; /D/ Classroom, Conference room and Exhibition space; /E/ Lobby, Corridors, Restroom, Restaurant, Car parking and Storage

The system class mainly used for the above spaces mostly takes "Air Conditioning" as the bulk; therefore, this study considers air conditioning energy saving practices and can also further the understanding of the usage situation of spaces (for example, according to the investigation on people's use of some spaces, in the state of non-use for a long time, the system will automatically judge to turn the air conditioning off, regulate the temperature, etc.).

(2) /C/ Faculty Space

The main electricity consumption for the system classes of power current, sockets, air conditioning, and illumination is a small amount. With limited re-improvement efforts with regard to energy saving, in order to maintain the equipment operation in the faculty space, a certain amount of electricity consumption shall be required for the power current. Therefore, this part may determine the mechanical and electronic design during the construction or choose the equipment with better energy saving performance in subsequent updates.

In a future study, the data of other months of each space of the Central Industry Innovation Research and Development Zone will be analyzed, more space information will be adopted to discuss the actual situation in closer relation to this case, and the related data of other construction environments will be collected. Then a detailed discussion will be made on each system of intelligent buildings in order to summarize the establishment and operation of each system of intelligent buildings and inter-system logic models.

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Investigating the Maintenance Management Practices for Urban Roads in India

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Abstract

The demand for quality urban infrastructure has been increasing rapidly in developing countries. In India, there is a huge demand and supply mismatch in the urban infrastructure sector and this situation has been further worsened by the poor maintenance of existing infrastructure. Urban roads in India are reeling under similar scenario and the poor quality of urban roads has been affecting convenience and safety of road users. In this context, the analysis of maintenance management practices followed by the urban local bodies (ULBs) for urban roads was carried out. A case study based approach has been adopted to analyse the maintenance management practices in three urban local bodies. The case study analysis indicates the absence of structured process for prioritizing maintenance of urban roads. A model has been developed for prioritizing the maintenance of urban roads using fuzzy logic approach. The findings of this research study would help the officials of ULBs to allocate constrained resources in more effective manner and ensure better quality urban roads.

Keywords: Maintenance Management, Urban Roads, Urban Local Bodies, Fuzzy Logic

1. Introduction

Road network is one of the important factors that contribute to the economic growth of any country. It is imperative for economic progress that roads are well laid out and maintained. Although the Indian road network is large, next only to the road network in the United States of America, an underlying problem is the quality of roads. Roads are often poorly maintained, leading to delays and disruption in traffic, environmental pollution, and inefficiencies in economic transactions.

According to a report published by High Powered Expert Committee (HPEC), constituted by the Government of India for estimating the investment requirements for urban infrastructure services, an investment of USD 82.67 billion(2009-10) and 44% of investment in urban infrastructure are required over the next twenty years for improving urban roads (Ministry of Urban Development, 2011). The achievement of objectives of any infrastructure depends not only on construction of the asset but also on quality maintenance of the created asset. The HPEC's report mentions that only 1.7 % of per capita investment on urban roads is spent on maintenance in India. This compromises on the life of the asset and fails to earn the value of investment on asset creation.

In India, the responsibility of urban road maintenance lies with the urban local bodies (ULBs). The poor maintenance management practices among ULBs have been often mentioned as the reason for the current poor state of Indian urban roads. In this context, a research study was carried out to understand the road maintenance management practices followed by ULBs and develop a model for the prioritized maintenance of urban roads in India. This paper describes outcomes of this research study.

2. Research Methodology

The research methodology for this study comprised literature survey, case study, questionnaire survey and modelling with fuzzy logic approach. A review of literature was first performed to understand the current practices among ULBs for maintenance of urban roads and best practices, decision frameworks and models for urban roads. This was followed by case studies of maintenance management practices in three ULBs in the state of Gujarat. The primary objective for these case studies was to understand how the urban local bodies undertake the maintenance management of urban roads and analyse these processes from a theoretical angle provided by the framework discussed in section 3. The challenges faced in adoption of systematic process for maintenance management of urban roads were also identified.

Three ULBs in the state of Gujarat, India were selected. These three urban local bodies are among three prominent cities in the state. These ULBs were selected on the basis of parameters like urban population, geographical area, length of urban roads, capital expenditure of ULBs and financial allocation towards construction and maintenance of urban roads. The profile of these three ULBs is shown in Table 1.

Table 1 Profile of ULBs

Sr No	*Aspects*	*ULB – A*	*ULB – B*	*ULB – C*
1	*Population [No]*[1]	*55,70,585*	*44,62,002*	*16,66,703*
2	*Area [sqkm]*[2]	*464.16*	*326.515*	*159.95*
3	*Length of Urban Roads [km]*[3]	*2399*	*2874*	*1000*
4	*Administrative and Political units of ULB responsible for road construction and maintenance*	*Road & Building Committee [E], Road Project Department [A], Road Department [Z]*	*Standing Committee [E], Road Development Department [A], Road Department [Z]*	*Standing Committee [E], Road Project Department [A], Road Department[Z]*
5	*Capital expenditure of ULBs [Million INR] (2013-14)*	*20750*	*16251*	*2612*

[E]: Elected Wing, [A]: Administrative Wing, [Z]: Zone Level,1 USD = 66 INR, 1: Year 2011 (Census of India, 2011), 2: Area under the jurisdiction of ULB, 3: In the year 2011

All these ULBs are from the state of Gujarat and therefore suited a natural comparative multiple case study research design. These ULBs shared similar policy environment and procedures at the state level, but differed in parameters such as organizational structure, aspirations of political members and ULB officials, organizational procedures and practices, and road infrastructure assets. Therefore, our case study design provided natural controls of the study as well as environment for analytical generalization and theory building.

The data pertaining to case studies was primarily gathered by semi structured interviews with the officials of ULBs, and this data was supplemented and supported with the information gathered from municipal manuals, archival records, websites of ULBs, contract agreements, organizational policies and guidelines pertaining to maintenance practices in selected ULBs. The interviews were recorded and further transcribed. The transcripts were analysed with the NVIVO software, and the analysis involved "axial coding" – line by line coding of transcripts, gathering of similar information under different themes and preparation of final themes by merging and consolidation of related themes. Table 2 provides background of interviewees. In total, 18 interviews were carried out in three urban local bodies. The themes that has emerged from the analysis of these interviews are discussed in Section 4.

Table 2 Information about Interviewee

Sr No	*ULB*	*Level of Authority*	*Designation*	*Number*
1	*ULB-A*	*Top Level*	*Additional City Engineer*	*1*
		Middle Level	*Assistant Engineer*	*4*
		Bottom Level	*Technical Supervisor(2), Budget Department Employee (1)*	*3*
2	*ULB-B*	*Top Level*	*Chief Accountant*	*1*
		Middle Level	*Assistant Engineer*	*2*
		Bottom Level	*Technical Supervisor*	*1*
3	*ULB-C*	*Top Level*	*Budget Head, Additional City Engineer*	*2*
		Middle Level	*Assistant Engineer*	*3*
		Bottom Level	*Technical Supervisor*	*1*

The last step involved development of a model for the prioritisation of urban roads for maintenance. Fuzzy logic along with MATLAB software was used for modelling. Three road networks from these ULBs were selected for the application of this model. The process for the development of model is as follows:

1) The earlier two steps – literature review and case study analysis assisted in the identification of factors for prioritization of urban roads and modelling these factors,

2) For defining inputs, data collection was done based on two questionnaires for 'Importance of the factors' and 'Importance of the factors with respect to roads', and

3) Fuzzy logic was applied in two stages for the responses of the officials to achieve the prioritisation of the urban roads for maintenance.

- Stage 1 – Application of fuzzy logic for officials' responses for 'Importance of the factors' as well as for 'Importance of the factors with respect to roads'.
- Stage 2 – Application of fuzzy logic for Stage 1's outputs with reference to particular urban road network for carrying out prioritization of roads for maintenance operations.

3. Maintenance Management for Urban Roads

As part of the first step of this research study, literature was surveyed in order to analyze the various processes involved in the maintenance management of urban roads. The maintenance management has been conceptualized from process perspective with steps like deciding objectives of road maintenance, assessment of road performance, planning and decision making, and interventions to be adopted for road maintenance. These steps are not necessarily sequential in nature; rather there is cooperation and coordination required among them for effective maintenance management. The identified processes are presented in Figure 1 and briefly as follows.

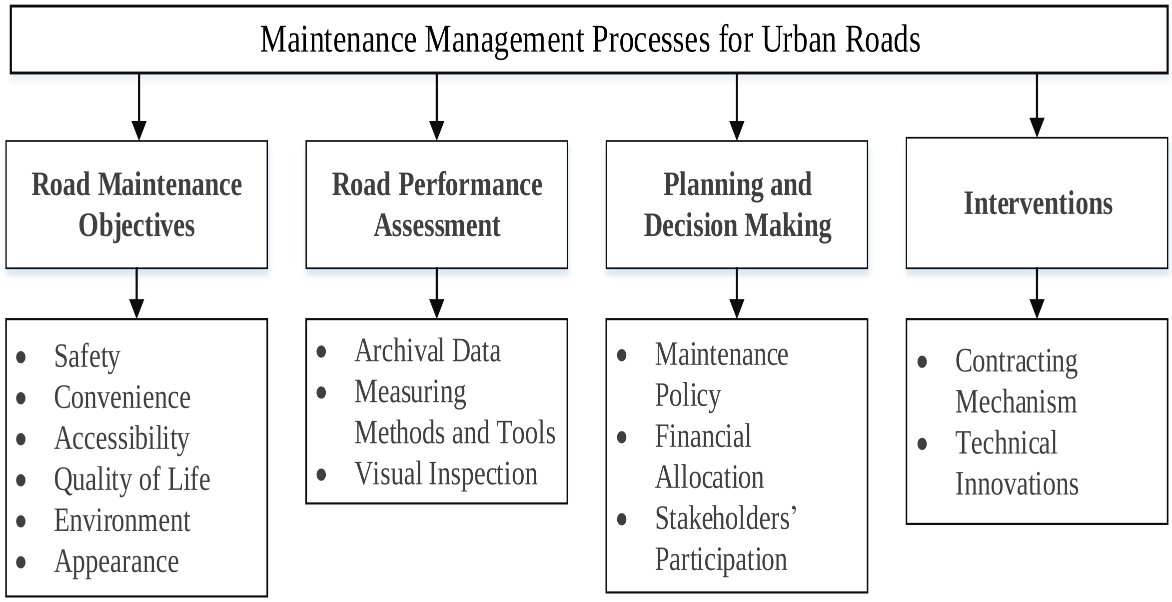

Figure 1Maintenance Management of Urban Roads

The road maintenance objectives elaborate the reasons behind undertaking road maintenance (Schraven et al 2011; Adey et al 2014). The ULB deciding the maintenance strategy for urban roads may pursue single or multiple objectives. The challenge faced by ULB is to strike a balance between these varying objectives. Safety and accessibility can be primary objectives which are required to be fulfilled by any ULB because they emphasize on the basic requirements for human accidents and road connectivity. Convenience and appearance focus on the quality of the road and the operational efficiency (impacts of the road quality on vehicles' performance). The management of traffic as well as road conditions result in good quality of life. Environmental considerations focus aspects like noise and air pollution.

Road performance assessment is typically undertaken to understand the conditions of existing road infrastructure asset and the outcome of this assessment provides valuable suggestions for deciding future courses of action (Schraven et al 2011; IRC 1989). The archival data that includes age of the roads and the past operations that were carried out on the roads as a part of maintenance must be analyzed. The performance measurement can be carried out with visual inspection and / or measurement methods or tools. Visual inspection includes recording the details of maintenance requirement based on the visual observation while measure methods and tools uses advanced road pavement monitoring equipment for assessing damage and its intensity.

Planning and decision making is important as it formulates the philosophy for the maintenance works (Sharma and Vohra 2009; Too 2012; Osman and Nikbakht , 2014). The rules and standards for maintenance work are decided based on the maintenance policy formulated and adopted by the ULB. There are diverse sets of stakeholders involved in both policy formulation and implementation. Therefore, the technical system of maintenance management, which is the focus of processes like deciding maintenance objectives and road performance assessment, is intertwined with the social system involving asset managers, users and political decision makers. Based on the maintenance policy and stakeholders viewpoints, financial resources are allocated for the maintenance of urban roads. The interaction between the above three processes, results in the design and implementation of appropriate intervention strategies. These interventions aim to maintain quality of asset and provide targeted user benefits (Sharma and Vohra 2009; Too 2012). It involves the use of contracting mechanisms like percentage rate contract, performance base contract etc. and new innovations like polymeric roads, micro surfacing etc.

4. Case Study Analysis

4.1 Collaboration between actors involved in the socio technical system

The evidence from the case studies indicates that the process of maintenance management is complicated by the involvement and interaction of multiple stakeholders. The effectiveness of this process hinges on identifying the urban road as a "socio technical system" and striking a balance between expectations of different stakeholders. Osman and Nikbahat(2014) discussed the complex interactions that occur between the agents like roadway users, asset managers and politiciansfor roadway performance and asset management. They have modelled these interactions with game theoretic approach, indicating how behaviour of various agents involved in the asset management impacts their collective decision making behaviour. Similar scenarios have also been observed with "cooperative as well as non-cooperative game" between different set of stakeholders. The influence of politicians in the sphere of selection of roads for maintenance and fund allocation prominently emerged in the case analysis. Often, this influence is contested by the administrative officials of the ULBs. The dislike towards undue influence of politicians in the decision making process was aptly narrated by an official of ULB – A:

"Political involvement also plays significant role in prioritisation but that doesn't mean that the road is not required to be prioritised. We don't adopt the suggestions of political parties if road is really not required to be maintained."

The absence of meeting of minds of politicians and technical persons was summed up by the ULB – A official:

"I want to tell you that ideally requirement should be generated by technical department and not by any political corporators at zonal level but still the situation is the same only. There are many roads which we have made according to our technical knowledge avoiding the suggestion by the political councillors."

Although, there was a common agreement between these important decision makers – politicians and administrators–over collecting feedback from the road users for understanding maintenance needs, there was disagreement over the question of whose opinion would have a final say in the maintenance management process. This non-cooperation observed between asset managers and politicians over the prioritization of urban roads for maintenance stems from the lack of appreciation of urban roads as a "socio technical system". This often results in undue delays and short sightedness in the decision making process.

4.2 Policies and guidelines required for effective maintenance management

The policies for maintenance management of urban roads help in articulation of strategic goals and charting out procedures to achieve these goals. The case study organizations have been following set procedures for the maintenance of urban roads; however, these procedures lack strategic orientation and direction. The interviews with the ULB – A, B and C officials revealed that there is lack in clarity over the objectives to be pursued for the maintenance of urban roads and they were considered implicit part of any maintenance approach. As a result, the benchmarks for assessing effectiveness of maintenance strategy were often either not set or vague. All ULBs expressed that they sought guidance from the manuals prepared for maintenance by National Highway Authority of India (NHAI) and Ministry of Road Transport and Highway (MORT&H). However, lack of particular policy and / or manual for the maintenance of urban roads was mentioned as a key impeding factor by many interviewees from these ULBs. Diverse views over maintenance objectives among the officials of a single case study ULB and financial constraints faced by these ULBs necessitate the clarity over maintenance objectives. An official of ULB – A mentioned the objective for maintenance and its effectiveness as follows:

"See, when we talk about the urban roads they already have thickness of 1m. So, there base is very strong. They just require there riding surface to be appropriate. Yes but one thing is very important and that is quality of maintenance. If quality of maintenance is improved then many issues can be resolved."

Most of our interviewees mentioned improvement of "quality of riding surface" as a maintenance objective, with a little or no mention about the other objectives like accessibility, convenience, quality of life and safety. Scharaven et al (2011) stressed the importance of formulating "infrastructure objectives" before undertaking maintenance by public agencies. They postulated that clarity on infrastructure policies and objectives would result in 1) devising of appropriate maintenance strategies, 2) formulation of indicators and maintenance norms for assessing effectiveness / performance of maintenance strategy, and 3) cost efficiency in maintenance management.

The absence of maintenance policy also affects allocation of financial resources. The construction of new roads gets priority over maintenance of existing roads during allocation of financial resources. This clearly shows that budget for maintenance is not satisfied considering the requirement of the new construction. This results in poor life cycle of the created asset. A comparison of financial resource allocation towards construction and maintenance of roads in three ULBs (Refer Table 3)shows that despite increase in construction of new roads, maintenance is not prioritised and/or focused as required. The backlog in allocation of financial resources is higher in the case of ULB-A and ULB-C. In case of ULB-B, construction of roads as well as maintenance has increased over time. Therefore, design of maintenance policies and objectives in the case study ULBs is essential.

Table 3. Financial budget for construction and maintenance of urban roads

Year	*2010-11*	*2011-12*	*2012-13*	*2013-14*
ULB –A				
Maintenance	*971.10*	*876.51*	*1099.52*	*757.45*
Construction	*518.87*	*675.61*	*2147.82*	*2088.36*
ULB –B				
Maintenance	*431.26*	*482.56*	*614.53*	*702.01*
Construction	*861.50*	*1176.98*	*1972.63*	*2279.57*
ULB –C				
Maintenance	*93*	*103.9*	*135*	*125*
Construction	*544.3*	*590.5*	*711.3*	*538.6*

Figures in million INR. 1 USD = 66INR

4.3 Role of private sector in maintenance management needs to be managed effectively

The construction and operation of highways in India has seen a gradual shift towards increased private sector participation with contracting mechanisms like build operate transfer (BOT), annuity contracts and engineer procure and construct (EPC) contract. Similar trends were observed in the case study organizations with increased participation of private contractors. Traditionally these ULBs have been undertaking maintenance of urban roads with in-house equipments, labour and technical personnel. However, over the years, these ULBs have changed the approach and now different contracting mechanisms are adopted for private sector involvement. This transition in the contracting mechanism was shared by an official at ULB-C as follows:

"Another important thing I want to add is that before 10years works have been done in house. Outsourcing is invited from 10 years only. Now as a packaged and performance based contracts are given to the contractors."

Small maintenance jobs are executed with in-house resources while large maintenance activities are undertaken with private sector participation. Two contracting models in these ULBs were primarily used: percentage rate contract and performance-based contract. Performance-based contract encourages technical innovation of private sector with the use of techniques like micro surfacing, milling process, polymeric roads, etc. The adoption of technical innovations for the maintenance of urban roads was summed up by an official as ULB-B as under:

"In recent past we have done experiments on it. With the help of plastic waste we have constructed the roads. Now we are checking the performance. Another thing which we are doing is micro surfacing. Sometimes the only upper layer of the road has get deteriorated that doesn't mean that we will construct the whole road again."

The case study evidence indicates that the primary reason behind increasing involvement of private sector in maintenance of urban road was improved quality and cost effectiveness. However, it is important to note that the capacity of ULBs to manage these innovative contracting and technical mechanisms is a central factor for achievement of benefits with private sector participation. Too (2012) mentions this capacity as "technology absorptive capacity, i.e. the ability to embrace and capitalise on new technologies to enhance their maintenance management process. Our analysis shows differences in the "technology absorptive capacity" among the ULBs. ULB-A and ULB-C lag in the adoption of innovations due to constraints such as lack of skills to investigate feasibility of carrying out these works, absence of financial resources and so on. Although ULB-B has adopted performance-based contracts to a larger extent, the capacity to monitor and assess benefits from these contracts is lacking. Therefore, these ULBs must initiate steps towards creation of technology absorptive capacity, as mentioned by Too (2012), in the immediate future.

5. Development of Road Maintenance Management Model

The case study analysis of the three urban local bodies indicated the need for structured approach towards maintenance management of urban roads. The third stage of this research study focused on development of road maintenance management models. This stage can assist decision makers in urban local bodies in the selection of appropriate urban roads for maintenance.

A literature survey has been carried out focusing on different modelling methods for road prioritization. This led to the selection of the fuzzy logic approach for the maintenance model. Although fuzzy logic was developed in 1965 as a part of soft computing research, the method gained attention only after a decade. In spite of having roots of soft computing, fuzzy logic has been widely used as a prioritisation model. Tah and Carr (2000) have studied construction project risk assessment using fuzzy logic. In this model, severity of the risk is first derived and then the probability of their occurrence is analyzed. Fuzzy logic is used to map the input with the help of realistic output. When the ratings given to the various factors do not include the probability of the consideration of these factors, they do not provide a realistic approach. Fuzzification of these ratings considers the importance of these factors as well as the probability of them falling in the criteria for that rating. Probability of occurrence is measured by different membership function in fuzzy logic. The same approach can be applied in this research, where in fuzzy logic is used to know the importance of the factors for the prioritization of urban roads for maintenance. Then, for particular road networks, significance of these factors can be derived for establishing prioritization of urban roads. A literature survey has been carried out for the identification of factors for the prioritization of urban roads for maintenance. The case study analysis carried out in the previous step helped in refining and grouping factors that emerged from the literature survey. There are 12 factors in total which are grouped into five categories: social, decision makers, environment, maintenance operations and their impact, and road performance assessment (Table 4). Three road networks from the ULBs, that formed the part of analysing maintenance management practices, were selected for the application of model for prioritising the roads for maintenance operations.

5.1 Fuzzy Modelling

5.1.1 Data collection

The responses of officials associated with the maintenance of urban roads in these three ULBs were collected in the form of questionnaires.

Questionnaire 1 - Importance of the factors: The objective of this questionnaire was to know the importance of these factors from the viewpoint of officials who are only responsible for road prioritization.

Questionnaire 2 - Importance of factors with respect to roads: The reason behind conducting this questionnaire survey was to consider the importance of the factors for a particular road network for prioritising maintenance of different roads.

Table 4. Factors for prioritization of urban roads

Sr No	*Factors*	*Shohet And Perelstein (2004)*	*Osman And Nikbakht (2014)*	*Schraven Et Al. (2011)*	*Ugwu (2005)*	*Dalal Et Al. (2010*
1	*Social*					
1.1	*Commercial Developments*	*N*	*N*	*Y*	*Y*	*Y*
1.2	*Infrastructure Expansion*	*N*	*N*	*N*	*Y*	*Y*
2	*Decision Makers*					
2.1	*Responses of Elected Wing*	*N*	*Y*	*N*	*N*	*N*
2.2	*Users' Satisfaction*	*Y*	*Y*	*Y*	*Y*	*Y*

3	*Environment*					
3.1	*Disaster*	*N*	*N*	*N*	*N*	*Y*
3.2	*Climatic Effects*	*N*	*N*	*N*	*Y*	*Y*
4	*Maintenance Operations and Their Impacts*					
4.1	*Estimated Cost for Maintenance Operation*	*Y*	*Y*	*Y*	*Y*	*N*
4.2	*Time Taken for Maintenance*	*Y*	*Y*	*Y*	*Y*	*N*
4.3	*Life Cycle*	*Y*	*Y*	*Y*	*Y*	*Y*
5	*Road Performance Assessment*					
5.1	*Traffic*	*Y*	*Y*	*Y*	*Y*	*Y*
5.2	*Road Safety*	*Y*	*Y*	*Y*	*Y*	*Y*
5.3	*Road Condition*	*Y*	*Y*	*Y*	*Y*	*Y*

Y: Yes; N: No

5.1.2 Fuzzification

The ratings collected by officials were first fuzzified in order to achieve sharp output. Ratings by the officials have certain probability of occurrence which was achieved by their fuzzification. These inputs were fuzzified with the help of Gaussian curve membership function, which can generate a smooth input. For applying rules for fuzzification, "and" function was used. The function takes the minimum value of the all inputs at is the optimum rating given to it. This function defuzzifies it with Gaussian Curve Membership Function.

Gaussian Curve Membership Function (Gaussian Curve Membership Function, MATLAB- gaussmf)

y = gaussmf(x,[sig c])

The symmetric Gaussian function depends on two parameters σ and c as given by

$[\![-(x-c)]\!]^2/(2\sigma^2)$,$f(x;\sigma,c)=e$

The parameters for gaussmf represent the parameters σ and c listed in order in the vector [sig c].

5.1.3 Defuzzification

In order to achieve a sharp output, the rankings given by the officials had to be defuzzify. The triangular-shaped membership function was used for this. The centroid of this triangular membership functions were considered and output was generated. Based on the ratings given by this triangular membership function, ratings were considered for prioritization of urban roads.

Triangular-Shaped Membership Function (Triangular-Shaped Membership Function, MATLAB- trimf)

y = trimf(x,params)

y = trimf(x,[a b c])

The triangular curve is a function of a vector, x, and depends on three scalar parameters a, b and c as given by,

$$f(x;a,b,c)=\begin{Bmatrix} 0, & x\le a \\ \frac{x-a}{b-a}, & a\le x\le b \\ \frac{c-x}{c-b}, & b\le x\le c \\ 0, & c\le x \end{Bmatrix}$$

Or more compactly by,

$$f(x;a,b,c)=\max\left(\min\left(\frac{x-a}{b-a},\frac{c-x}{c-b}\right),o\right)$$

The parameters a and c locate the “feet” of the triangle and the parameter b locates the peak.

5.1.4 Application of Fuzzy Logic in MATLAB

Fuzzy logic was applied in two stages to analyse the importance and impact of the factors for road prioritisation for maintenance. *Stage 1 (Part 1):* Ratings collected from questionnaire 1 were fuzzified. The fuzzification of these inputs provides the importance of the factors irrespective of roads on which the model would be applied.

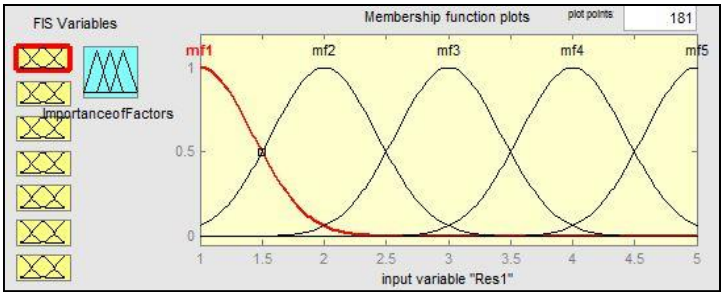

Figure 2. First Stage (Part 1) Fuzzy Structure

Stage 1 (Part 2): Ratings from questionnaire 2werefuzzifiedto know the impacts of the factors with respect to roads of that particular road network.

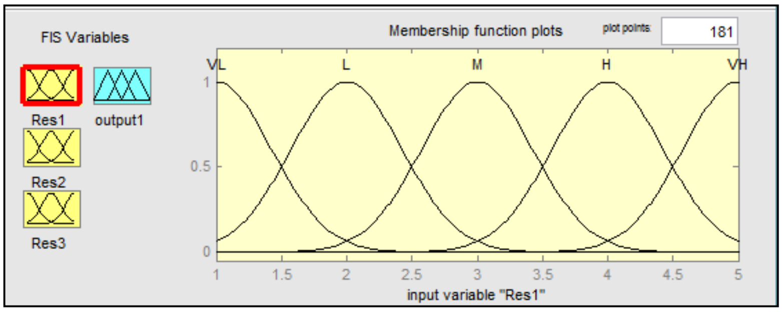

Figure 3. First Stage (Part 2) Fuzzy Structure

Stage 2: Outputs from Stage 1 (Part 1 and Part 2) were considered as inputs here, and fuzzy logic was applied to give the fuzzified ratings for the factors with respect to their importance and the impacts with respect to the roads. The fuzzy output gave the impact of every factor generated on the roads of this road network. Roads with highest number of the factors having highest were prioritised as they have the highest requirement of maintenance.

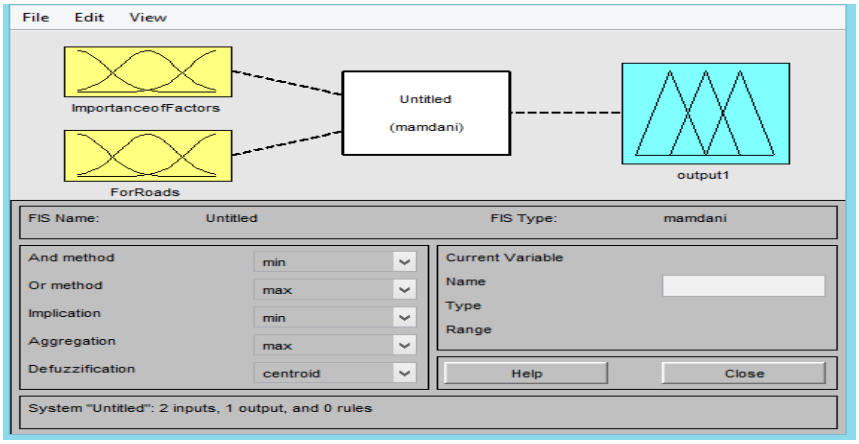

Figure 4. Second Stage Fuzzy Structure

6. Conclusions

Case study analysis indicated that ULBs face challenges on various fronts while carrying out the maintenance management of urban roads. These challenges can be broadly categorized under different themes like collaboration between stakeholders, need for maintenance management policies and guidelines and capacity for managing involvement of private sector. The ULBs and development actors must initiate strategic steps for addressing these challenges. The prioritization of urban roads for maintenance is the central theme for maintenance management processes, which becomes very complex owing to expectations of different stakeholders. The factors identified for the prioritization of urban roads in this research study along with the maintenance management model would help decision makers in systematically arriving at a decision to select appropriate roads for maintenance. This model would not only assist in meeting immediate needs of roads prioritization but also systematize the entire process of maintenance management.

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Construction Entities Tracking Based on Functional Integration and Online Learning with Site-customized Datasets

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Abstract

In construction domain, visual tracking of construction entities has received high attention and many researchers have investigated tracking methods. Although previous methods showed promising results, it has still limitations to reflect various characteristics of construction sites and entities: dynamic movements and various conditions (shapes, colour, type). One of the most common methods is tracking with probability, but it is sensitive to abrupt shape/scale changes and dis/re-appearances of objects. For the other methods based on pre-trained detectors, it is impractical to collect training datasets for all possible conditions such as entity types, colours and shapes. To deal with such shortcomings, a novel tracking method based on functional integration and online learning was proposed in this paper. Functional integration enables to track a target object under its dynamic movements by running a detector and a tracker at the same time. Online learning is able to reflect various characteristics of a target object developing site-customized datasets in real-time and automatically. The proposed method was validated with the video data recorded from the real construction sites. The results showed it has a high potential for tracking construction entities with 87% of a precision and 86% of a recall rate. It was possible to track a target object under its dynamic movements for various object types and their different colours and shapes. With the acceptable tracking performance, visual analyses on construction sites can be improved.

Keywords: Vision-based, Tracking, Detection, Functional integration, Online learning, Site-customized datasets

1. Introduction

On construction sites, a number of construction entities (e.g. workers, equipment) are scattered within the limited area; thus, unexpected events such as safety accidents occur frequently. The needs for on-site information have increased to manage the crowded and busy working environments effectively and efficiently. In detail, site information such as input entities, work in progress, and working/idle time can be used for the productivity and safety analyses (Gong and Caldas, 2010; Memarzadeh et al., 2013).

To collect site information, direct observation or survey/interview-based methods have been commonly performed. However, such methods revealed the following limitations; error-prone, time-consuming, and expensive processes (Navon and Sacks, 2007; Gong and Caldas, 2010; Chi and Caldas, 2011). To overcome such shortcomings, real-time vision-based site monitoring systems have been proposed due to its potential to extract various site information automatically and support decision making in project management (Chi et al., 2009; Chi and Caldas, 2011; Gong and Caldas, 2013; Memarzadeh et al., 2013; Golparvar-Fard et al., 2013).

To produce meaningful information from video streams, a high performance tracking should be acquired: the essential information including locations and types of the target entities can be generated from tracking processes. Moreover, the tracking can provide additional information for enhancing project management performance such as working type, idle/working time, and other productivity or safety related movements (Memarzadeh et al., 2013; Golparvar-Fard et al., 2013).

In response to the needs of tracking methods, many researchers have investigated tracking methods for construction entities. However, they have a low applicability due to a difficulty of reflecting various characteristics of construction sites and entities. It easily fails to track a target construction entity when it moves dynamically, and it is impractical to develop datasets that includes all possible conditions on construction sites. To overcome the limitations, this paper proposes a novel tracking method based on functional integration and online learning. It is expected that functional integration is able to track a target object under dynamic movements and online learning enables developing site-customized datasets.

2. Literature Review for Problem Setting

Many tracking methods have been investigated to understand site conditions more accurately. Tracking algorithms using Kalman filters or particle filters were simple and popular methods for object tracking (Hue et al., 2002; Yilmaz et al., 2006). Chi et al. (2009) presented the tracking method based on the background subtraction and pre-trained classifiers. A point matching method was suggested to track construction workers and equipment (Brilakis et al., 2011). Colour and spatial modelling algorithms were also proposed by Park and Brilakis (2012). Such tracking methods can be categorized into two main approaches: tracking with probability and tracking by detection (Yilmaz et al., 2006). Tracking with probability methods infer the posterior movements (e.g. location, velocity, and acceleration) of target objects with the comparison to their priori movements. It is performed with user initialization in the first image and it does not need any pre-training process. However, the algorithms are sensitive to tracking failures such as shape/scale changes of objects and dis/re-appearances after in and out from the camera's field of view and occlusion of target objects (Yilmaz et al., 2006). In contrast, tracking by detection methods are relatively robust in handling those failing cases since they use pre-trained detectors. However, to train a robust and powerful detector, various datasets and time-consuming tasks are required. In addition, the quality of dataset significantly determines the detector performance (Dollar et al., 2009; Benenson, 2014). Furthermore, tracking by detection methods are not able to realize objects that are not presented in the training dataset.

Although the previous tracking methods showed the acceptable results, it has a difficulty to reflecting the characteristics of construction sites and entities. The characteristics are represented by two main factors: site conditions and entities. First, surrounding conditions—which should be considered as the background in the detection and tracking process—vary on sites. Different types of equipment appear on different sites (Figure 1), which means that target objects to be tracked are difficult to be decided in advance. Second, each entity has high intra-class variations. Concretely, not only the same type of equipment has diverse colours and appearances but also appearances and shapes of the same object can change due to different working postures and camera's viewpoints (Figure 2). Moreover, the entities are easily disappearing or re-appearing because of occlusions and moving in and out of a single camera's view.

Those characteristics of construction sites and entities reveal practical limitations of the previous tracking methods. When developing training datasets for tracking by detection, it is very impractical to include all possible conditions of different surrounding conditions, various types of equipment, and high intra-class variations. In other words, it is labour-intensive to pre-collect training datasets to satisfy all possible working conditions. In case of tracking with probability, it is difficult to handle shape changes and re-/dis-appearances effectively. In summary, the most of previous tracking methods in construction have limitations to reflect the complex characteristics of real construction sites. This paper presents a novel tracking method based on functional integration and online learning with site-customized datasets. The proposed method is expected to have high potential for the long-term tracking under the dynamic working environments as well

Figure 1: (a-1) Trucks from site A. (a-2) Excavators from site A. (b-1) Truck from site B. (b-2) Excavators from site B. (c) Truck from site C.

Figure 2: High intra-class variations. (a) The same truck in different viewpoints. (b) The same excavator in different viewpoints.

as re-tracking in case of dis/re-appearances. It is also applicable to unknown objects developing training datasets in real-time and automatically.

3. Technical Development

The proposed method is composed of two main concepts: 1) functional integration of a detector and a tracker and 2) online learning with site-customized datasets. The details for each concept are described in the following sections.

3.1 Functional Integration of a Detector and a Tracker

Functional integration is a process of running a detector and a tracker at the same time and determining final results as comparing and analysing their results. The detector functions independently in each frame, finds a target object, and it offsets effects by shape/appearance/scale changes; however, it requires a time consuming pre-training step. The tracker estimates locations of a target object considering the object state in a moving condition such as velocity, location and shape among the consecutive image frames (Kalal et al., 2012). Thus, it easily fails and is not able to recover when the shape/appearance suddenly changes and an object moves out of camera's field-of-view or re-appears after occlusions. To share their advantages and reduce shortcomings, a combined detector and tracker was designed to act at the same time as shown in Figure 3. The errors can be corrected by each other. The sensitiveness of the tracker to occlusions, re-appearances, and abrupt shape changes can be reduced by the application of the detector. The detector can be trained with the automatically labelled datasets from the tracking results. Such functional integration also helps to generate the effective positive (i.e., objects that should be tracked) and negative (i.e., background) samples during the detector training.

3.2 Online Learning with Site-customized Datasets

Online learning is a training or real-time learning process using the data that is updated while mapping tracked objects from corresponding labels in the dataset in sequential images (Shalev-Shwartz, 2011). There are two main differences from the offline learning. First, training dataset is produced from working environments where the object detector is applied. Second, it can be

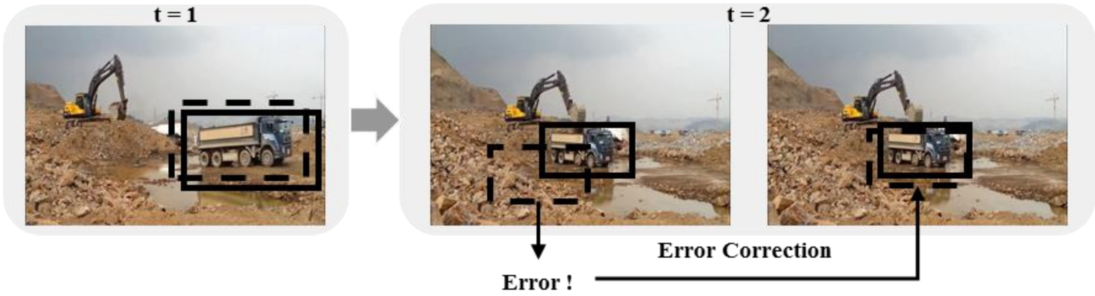

Figure 3: Error Correction Based on the Functional Integration a Detector and a Tracker.

Figure 4: Production Process of Initial Training Dataset.

applied for unknown objects. Based on the online learning, it is available to train a detector for any types and non-rigid objects by capturing datasets from the construction sites where the detector is applied; thus, the training datasets can be developed and customized by different site characteristics without a pre-collection process.

3.3 Framework of the Proposed Method

The framework of the proposed method is described in Figure 5. There are total three steps: 1) initialization, 2) functional integration and 3) online learning. Details of each step are described as follows.

Initialization. In the first image frame, initialization should be carried out. In Figure 4, a target object can be initialized with the bounding box by users, and the positive and negative samples for training datasets are produced online by considering the boxed area. The positive samples are extracted from shifting up/down/left/right the initialized box by 5% as shown in Figure 4. Contrary to the positive samples, the negative samples are generated in other regions in the image frame. Parts of the target object are not included in the negative samples, but it can be possible to have information related to non-target objects. After producing training datasets, the first step of online learning is performed to train and activate the detector. In case of tracking, tracking starts immediately after the initialization step is finalized.

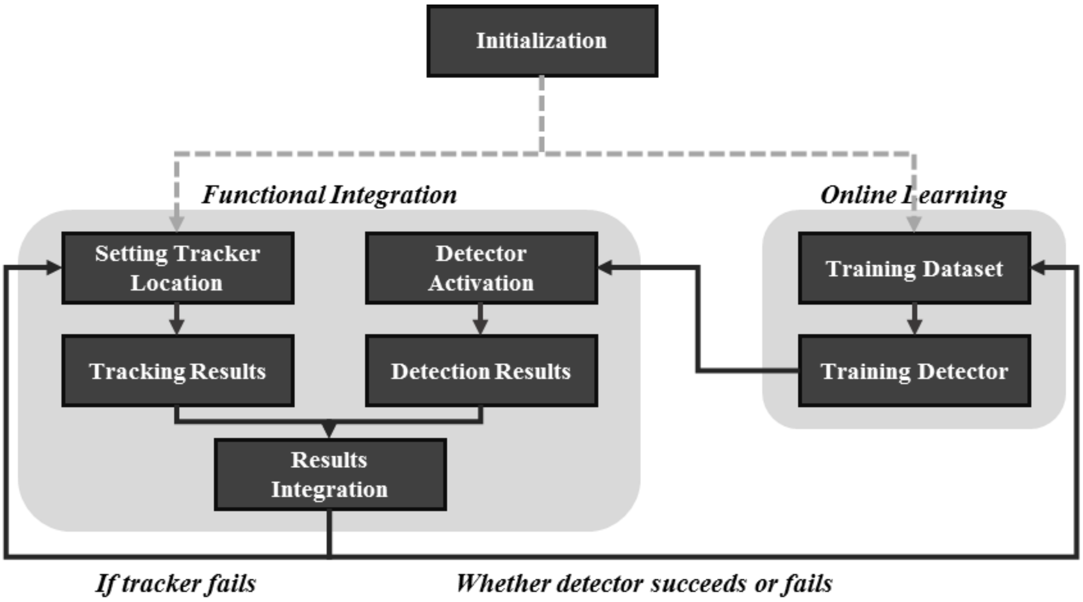

Figure 5: Framework of the Proposed Method.

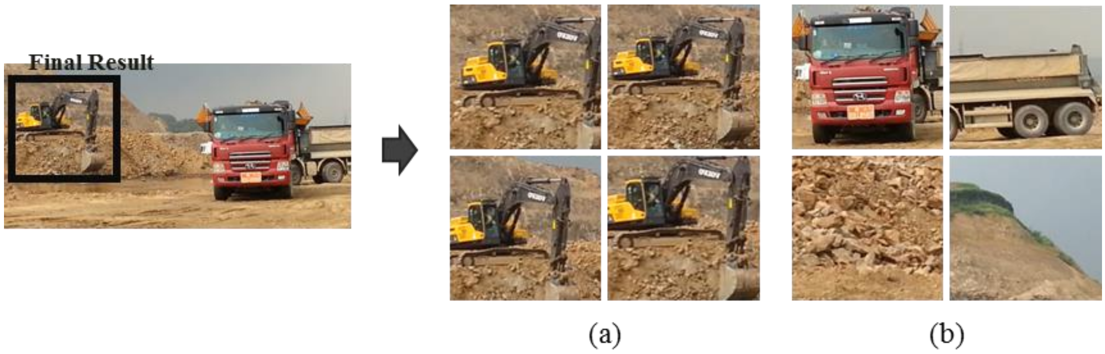

Figure 6: Dataset Example of Online Learning. (a) Positive samples. (b) Negative samples.

Functional integration of a detector and a tracker. Detection or tracking errors can be identified by comparing the results and their confidence. There are four cases: 1) both of them succeed, 2) both of them fail, 3) tracking fails and detection succeeds, and 4) tracking succeeds and detection fails. When both of tracking and detection succeed (the first case), the location and the size of the object are determined with the confidence and generates the black bounding box as shown in Figure 6. In contrast, when tracking and detection failed (the second case), the tracker stops to find an object and waits until the detector succeeds to find an object, and the searching area of the tracker is then reset by the detected information. It is possible because the detector scans all image pixels to localize a target object and performs independently in a single frame. This function enables to deal with dis/re-appearances caused by full occlusions or out-of-view movement. For the third case, the result of detection is accepted and searching area of the tracker is relocated at the detection area as explained previously. It allows the tracker to recover the target object. Finally, in the fourth case, tracking results are selected but the failure of detection is considered as the negative sample of the training datasets. However, the positive samples are extracted from the tracking results. Such technical approach that produces positive and negative samples makes the detector more robust.

Online learning with site-customized datasets. Based on functional integration of the detector and the tracker, the training datasets can be created. The detection can either succeed or fail. If the detection fails, the detected area is extracted for the negative samples to avoid similar errors. For the positive samples, the relocated area by tracking results can be assigned as the target object. Reversely, when detector localizes an object correctly, the detected area is selected for the positive samples and the negative samples are produced from the area except the detected area. The online learning based on the functional integration the detector and the tracker can customize the detector to the target object and background as shown in Figure 6.

4. Experimental Results

4.1 Data Collection and Description

To validate the performance of functional integration and online learning with site-customized datasets, the experiments were conducted with the video stream obtained from different construction sites where various types of equipment operated. Normal vision cameras were used for the data collection.

As shown in Figure 7, the collected datasets included various types of construction entities and working postures in different point views from four different sites. Occlusions and moving in and out of camera's field of view also existed and led tracking to become challenging. Total streaming time was about 45 minutes; the number of total frames was 64,968; and the resolution was 720 x 480. The proposed method was applied to unknown objects, which means that it does not need any pre-trained detector.

4.2 Quantitative and Qualitative Results

For the quantitative evaluations, the precision, recall rate and F-measure metrics were analysed. The precision is the number of true positives divided by the number of all responses, and it explains the reliability of the proposed method. The recall rate is the number of true positives divided by the number of target objects in all sequences. The high value of recall rate specifies whether the detector or the tracker works stable. The F-measure is calculated by the precision (P) and recall rate (R), 2PR / (P + R).

Table 1 summarizes the performance results. The processing time was 6 – 15 fps that satisfied eal-time processing. The average precision and recall rate were 87% and 86% respectively. It

(a) (b) (c) (d)

Figure 7: Examples of the Collected Dataset. (a) Dataset from site A. (b) Dataset from site B. (c) Dataset from site C. (d) Dataset from site D.

means that the proposed method has high potential for tracking construction entities, and the characteristics of sites and entities can be promisingly handled by the proposed method. Figure 8 and 9 shows the examples of the results. The bounding boxes were the predicted locations of the target objects. The Figure 8 explains the functional integration of the detector and the tracker that allows tracking the object in the long-term time frame. In Figure 8(a) describes the effects of error corrections. When the tracker/detector was about to miss the object, the detector/tracker relocated the tracking/detection position and it significantly reduced the sensitiveness to tracking/detection failures. Figure 8(b) is the dis/re-appearances. Although the truck re-appeared after out of camera's view, the proposed method was able to steadily re-track the target. It showed the robustness to dis/re-appearances and occlusions.

The results of online learning with site-customized datasets are illustrated in Figure 9. The datasets produced in real-time and online are illustrated in the left/right hand-side as the small image patches in Figure 9. With the site-customized datasets, the partial occlusion was able to be handled effectively as shown in Figure 10(a). Moreover, the difficulties of shape changes in different viewpoints were offset. As the backhoe rotated (the viewpoints change) as in Figure 10(b), the tracker kept localizing the backhoe correctly. In Figure 10(c), it showed the objects are kept tracking under the dynamic environment. Although the excavator had pose variations such as digging, hauling, dumping, and swinging, the method was able to maintain tracking with the application of the correction process.

Table 1: The Results of Performance Metrics

Metric / *Equipment Type*	*Precision*	*Recall Rate*	*F-measure*	*Processing Time*
Excavator	*0.8679*	*0.8654*	*0.8667*	-
Truck	*0.8913*	*0.8792*	*0.8852*	
Loader	*0.8455*	*0.8455*	*0.8455*	
Backhoe	*0.8511*	*0.8511*	*0.8511*	
Average	***0.8653***	***0.8621***	***0.8637***	***6 – 15 fps***

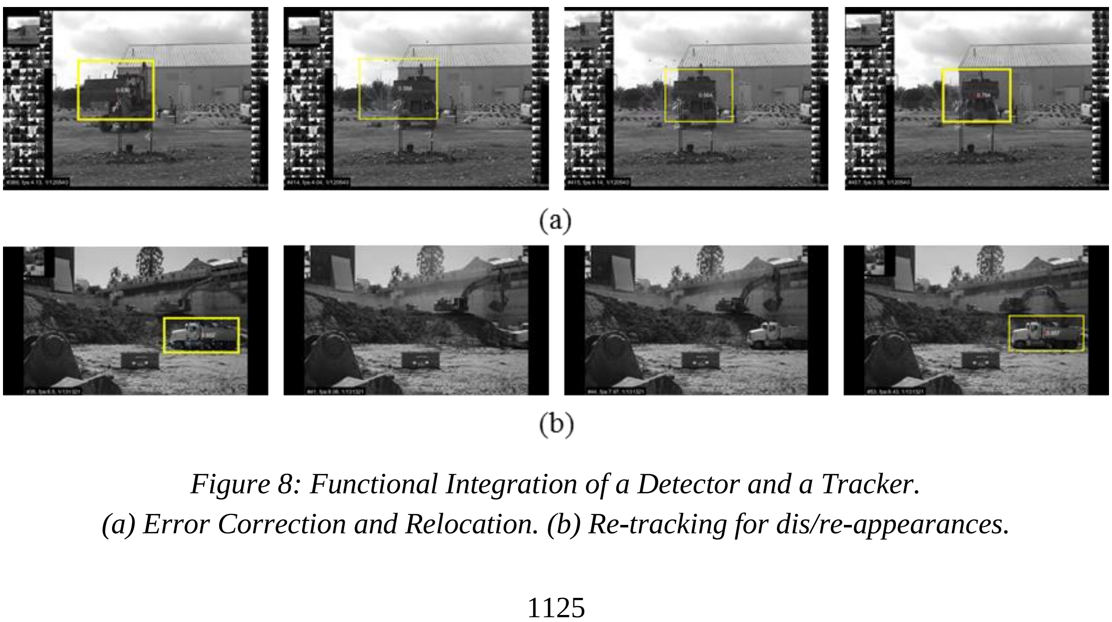

Figure 8: Functional Integration of a Detector and a Tracker.
(a) Error Correction and Relocation. (b) Re-tracking for dis/re-appearances.

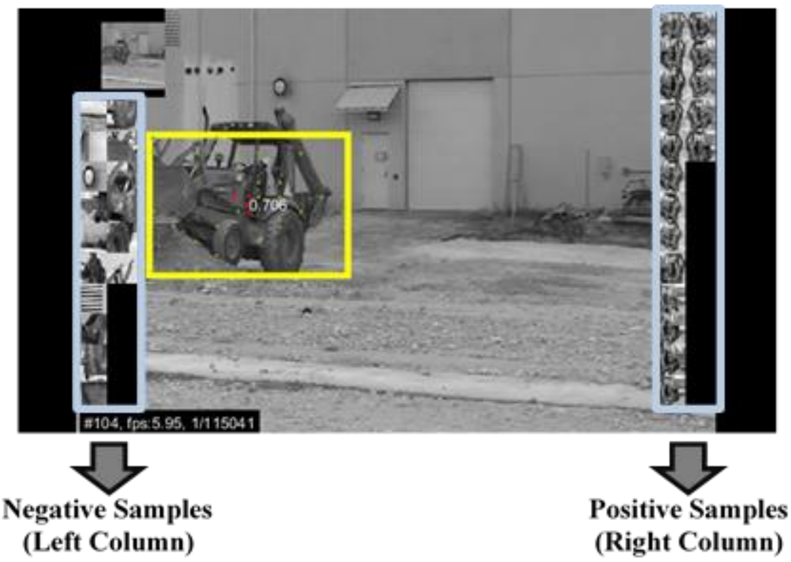

Figure 9: Online Production of Training Datasets.

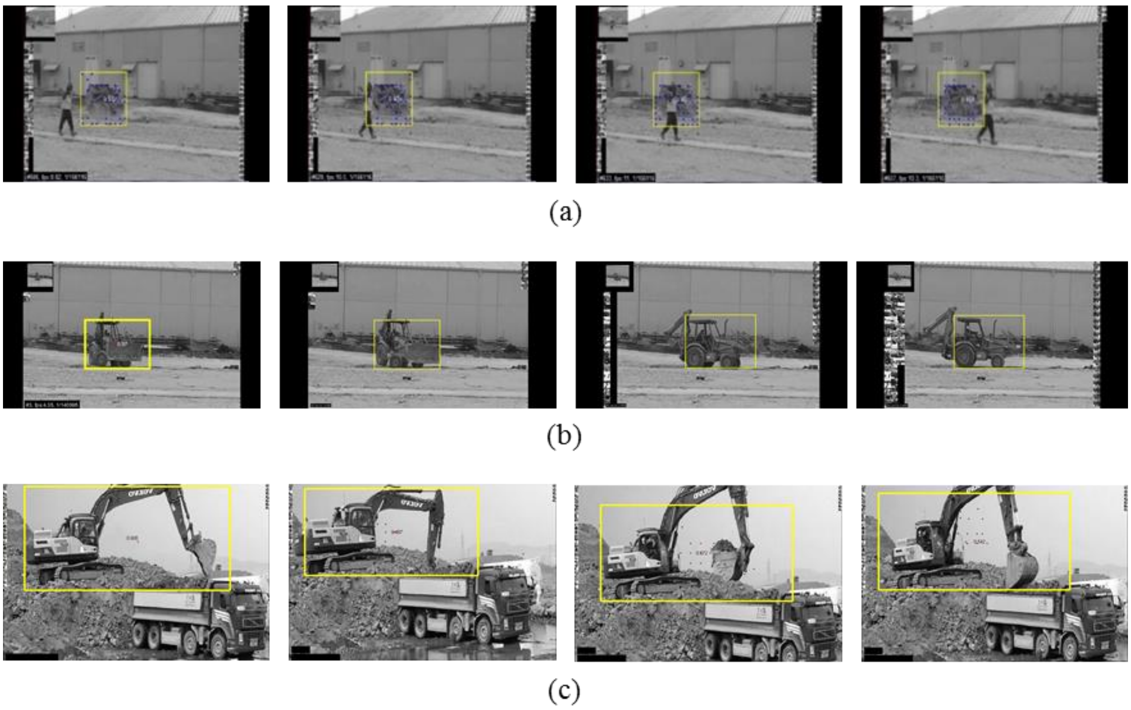

Figure 10: Online Learning with Site-customized Datasets.
(a) Partial Occlusion. (b) Shape Changes in Different Viewpoints. (c) Pose Variations

5. Conclusions

This paper proposed a novel method that can track construction equipment in the long-term considering the unique and complex characteristics of construction sites and entities. The main components are 1) functional integration of a detector and a tracker and 2) online learning with site-customized datasets. The results showed the high potential for tracking various types of equipment under dynamic construction environment. With the acceptable tracking performance, it is available to achieve visual analyses on construction sites. However, the study can be still further improved with the following issues. The first issue is an expansion to multi-target tracking. For application on real construction sites, multi-target tracking should be implemented. Second, the proposed method should be applied to more various types of construction entity.

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Relevance of Five Generic Business Ideation Approaches vis-à-vis Contexts Embedded within Construction Markets

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Abstract

In general, ideation encompasses the formation of ideas or mental images of things not present to the senses or simply the creation of new ideas**.** Business ideation is herein perceived to be the core area within future-oriented business management (BM). The main aim of the paper is to assess and advance the relevance of the five generic approaches to business ideation vis-à-vis firms targeting contexts embedded within construction markets. A typology differentiates between the fitting, value-creating, profit generating, systemizing, and commercializing approaches. It is argued that each approach is, at minimum, highly relevant in the case of business unit (BU) management targeting preferred client investment and procurement behavior within construction markets. Approach 1 involves BUs aiming at fit between clients and their needs as well as units' offerings and operations, respectively. Professional clients couple needs with preferred procurement methods whereas competing BUs are trying to achieve best fit between solutions and client behaviors. This approach calls for research on how to sustain such fit between a BU and clients when changes occur. Approach 2 enables BUs to create value by specifying high-value propositions, producing value to clients, and capturing their fair shares of produced values. Farsighted clients look for more or novel values for construction investments and, thus, units are collaborating and co-producing values to clients. This approach calls for research on a BU's value co-production with such clients, value capture, and offerings integration. Approach 3 accommodates BUs that are focusing on generating profits, achieving high-profit levels, and sustaining them. Pioneering clients pursue complex investment aims that can be met only by radical solutions. This approach calls for research on a BU's profit-generating mechanisms related to clients with complex investment needs and radical solutions. Approach 4 facilitates BUs to systemize businesses around core ideas. Sectoral clients have large or complex needs and, in turn, units are satisfying them by engineering systems as wholes and delivering them as parts. This approach calls for research on BUs with systems and clients, multi-dimensional investments, and system engineering as wholes and parts. Approach 5 facilitates BUs to couple ideas with commercializing dimensions such as entrepreneurship, innovation, business development, venturing, or spin-offing. Risk-taking clients prefer to enter high-innovation contracts and, thus, units are offering novel solutions and emerging business cases. This approach calls for research on a BU's entrepreneurial competencies and risk-taking clients, wicked investment needs, and high-innovation contracts. In the same vein, the suggestions are put forth to CIB-related scholars for directing research on along the BM and ideation dimensions and adopting most relevant approaches. Likewise, management in firms and BUs competing in construction markets are encouraged to assess the business case-sensitive relevance of each of Approaches 1-5 and try out those with initial high relevance.

Keywords: Business ideation, business management, construction markets, literature review, management concepts

1. Introduction

Managing a single business (un)successfully is herein seen the most fundamental area of strategic management. In the same vein, *business management (BM) research* is perceived as the most important and evolving sub-field within strategic management research. Within the BM scope, the focus is on managing business issues. In general, ideation encompasses the formation of ideas or mental images of things not present to the senses or simply the creation of new ideas (OED 2012)**.** Business ideation is herein perceived to be the core area within future-oriented BM. The *focal contexts* are embedded within *construction markets*, i.e., the contracting, design, construction, servicing, project-based, and life-cycle aspects of capital and construction investments in natural resources usage, energy supply, telecommunications, transportation, infrastructure, manufacturing, general building, and other real estate concerns.

This paper is part of the pioneering reviewing of construction-related BM research (e.g., Huovinen 2003a, 2006a-b, 2015a-c). The *nature* of this paper is that of reporting on the conduct and findings of a *focused review* of relevant published, conceptual knowledge about business ideation as part of BM. The rationale is that advancements can be designed based on the revelation of the current states of business ideation affairs via a review of the 71 construction-related BM concepts that have been published via the formal channels between 1990 and 2013. The *main aim of the paper* is to evaluate and advance the relevance of the five generic approaches, i.e., the fitting, value-creating, profit-generating, systemizing, and commercializing business ideation vis-à-vis firms and their business units targeting contexts embedded within construction markets. Accordingly, the *three sub-aims* are as follows:

- How is the reviewing being conducted? What are the degrees to which the authors have designed their 34 (out of 71) construction-related BM concepts along the business ideation dimension? The focused review is reported upon in Section 2.
- What are the generic Approaches 1-5 to business ideation? How relevant is each of them in the case of business unit (BU) management vis-a-vis business ideation with contexts embedded within targeted construction markets? Approaches 1-5 and 13 high-degree concepts are briefed as well as the approach-specific relevance is assessed in Section 3.
- How to advance the relevance of Approaches 1-5 vis-à-vis managing business ideation related to contexts within construction? The suggestions are put forth in Section 4.

2. Reviewing of Construction-Related BM Research

2.1 Four reviewing rounds between 1999 and 2014

The four reviewing rounds have been carried out in 1999-2003, 2006, 2010-2012, and 2014. Cooper's (1998) approach and the same limitations have been re-adopted to protect the validity. *The coherence* has been maintained by focusing on research on firms based in the OECD countries. Exceptionally, references originating from Singapore and Hong Kong have been included due to the authors' British Commonwealth heritage and research on international construction. Hart's (1998) guidelines have been relied upon. The design of the *method for the reviewing of conceptual research*, i.e., the replicable handbook-based and invented-here ways have been documented, used, and reported upon in Huovinen (2003a, 2006a-b, 2013 and 2015a-c). The search for eligible concepts has been conducted comprehensively within the volumes of 21 journals in construction and those of 47 journals in business administration. Concerning the other channels, the degrees of the comprehensiveness vary. The reviewer submits the lists of all the channels on request. So far, the reviewing has resulted in the identification of 71 construction-related BM concepts that have been published between 1990 and 2013.

2.2 Focused review of business ideation as a dimension for designing 71 construction-related BM concepts

For the assessment, the *four degrees of the design of a particular construction-related BM concept along the business ideation dimension* were pre-defined as follows:

- *High degree*: A concept's primary parts include all the three core elements of business ideation, i.e., needs and clients, offerings, and operations and/or resources.
- *Medium degree*: A concept includes only one or two core elements.
- *Low degree*: A reference containing a concept only addresses issues in business ideation.
- *No degree*: A reference does not contain any explicit aspects of business ideation.

The assessment revealed that *48 % or 34 (out of 71) construction-related BM concepts include also the elements for managing business ideation*. There are *13 (18%) high-degree,* 6 (8%) medium-degree, and 15 (21%) low-degree BM concepts (Table 1).

Table 1: Four-degree assessment of the design of 71 construction-related BM concepts (published between 1990 and 2013) along the business ideation dimension.

High-degree business ideation No. (%)	*Medium-degree business ideation No. (%)*	*Low-degree business ideation No. (%)*	*No business ideation at all No. (%)*	*All construction-related BM concepts No. (%)*
13 (18)	*6 (8)*	*15 (21)*	*37 (52%)*	*71 (100)*

The assessment validity has been protected against the five biases as follows. *Concept Inclusion Bias 1* involves this reviewer perceiving that an author has designed a concept along the business ideation dimension even if this author has not done so. This bias has been minimized by assessing each reference in the same way and quoting only the necessary parts that contain 34 (48%) construction-related BM concepts designed along the business ideation dimension. Future reviewers can test the inter-concept consistency of inclusion by repeating the assessments, i.e., reading and confirming the same quotations or rejecting them. *Concept Exclusion Bias 2* involves this reviewer perceiving that an author has not designed a concept along the business ideation dimension even if this author has done so. 37 (52%) "no degree" assessments indicate that this reviewer did not identify business ideation. Future reviewers can test the inter-concept consistency of exclusion by repeating the assessments, i.e., reading and confirming the exclusions or identifying business ideation elements in them. After the inclusion, *Degree Assessment Bias 3* is related to this reviewer's reliance on a pre-specified scale of the three conceptual degrees instead of a quantitative scale. This reviewer could assign one of the three pre-defined degrees to each of 34 concepts without hesitation. Future reviewers can test the inter-concept consistency of degree assignments by reading and confirming the same degrees or assessing changes in them. Or, they could re-specify a scale of degrees. *Concept-Approach Correspondence Bias 4* is related to the mapping of each of 13 high-degree concepts onto one or more business ideation approaches (Table 2). This reviewer could map each concept onto one generic business ideation approach based on the identification of the theoretical roots and elements. Future reviewers may deepen this analysis, e.g., by itemizing each (sub-)element within the references and quoting them in a set of more detailed tables to allow cross-approach comparisons and correspondence identification. *Concept Author-Reviewer Bias 5* is related to a fact that this reviewer has designed 14% or 10 (out 71) concepts. 7 (out of 10) concepts have been designed along the business ideation dimension. Thereof, this reviewer assessed that he has designed 3 high-degree, 1 medium-degree, and 3 low-degree concepts. Future reviewers can test the inter-concept consistency of the assessment outcomes versus each of the four other biases in the case of 10 concepts designed by this reviewer.

3. Five Generic Business Ideation Approaches

In general, OED (2012) defines that "*to idea* is to give a particular form or character to…". In turn, *ideation* encompasses "the formation of ideas or mental images of things not present to the senses" or simply **"***the creation of new ideas***".** Aligning with Normann's (2001) root principle of fit, a *business idea* is herein defined to consist of the three core elements, i.e., a focal firm is (i) targeting an environment with potential clients and their needs, (ii) developing and leveraging its offerings that best satisfy targeted needs, and (iii) organizing a BU and, thus, performing operations, enabled by its resources.

How is business ideation being approached within strategic management literature? Previously, this author has identified and differentiated between the *five generic approaches* to business ideation, i.e., fitting, value-creating, profit-generating, systemizing, and commercializing approaches, based on the respective dimensions, preferences, and rationales (Huovinen 2013). The rationales are overviewed, the 13 high-degree, construction-related BM concepts are briefed, and the relevance is only qualitatively assessed approach by approach as follows.

3.1 Fitting business ideation and its relevance

Firms are crafting business ideas and accommodating *causal fit* concerning their offerings and operations versus targeted clients and needs. Applying Normann's (2001) abstract definition, a *business idea* is a unique, historically evolved set of factors related to each other, i.e., an environment with needs and values as well as a BU's offerings and other internal factors. The overall principle is one of consonance or fit. Adopting Drucker's (1994) recognized theory of business, the three sets of assumptions can be defined about (a) an environment, i.e. society, market, clients, and technologies, defining what a BU is paid for, (b) a specific mission, defining what meaningful results are and envisioning how a unit makes a difference in a targeted economy (society), and (c) core competencies, defining where a unit must excel to maintain leadership and accomplish its part of a firm's mission. Such a theory can be validated with the *four specifications*, i.e., the assumptions must fit reality, one another, be known and understood throughout a unit, and be tested constantly. There are the *two measures* for preventing the current theory from becoming obsolete, i.e., to abandon it and study non-customers. Readily, many fitting business ideation concepts have been designed as part of corporate planning concepts.

Among the 13 high-degree, construction-related BM concepts, the four concepts have been designed along the *fitting* business ideation dimension. Winch and Schneider's (1993) *four high-degree strategies* for UK architectural practices, based on the project complexity and the client's quality preference, capture many core *fitting* elements, i.e., (1) the strong, CAD-based delivery of designs with repeat elements for simple buildings at low fees and overheads, (2) strong experience and value engineering, coupled with many disciplines or specialization, to meet requirements related to complex buildings, charging a premium due to high value, (3) strong ideas and identifiable style with the articulation of a competence related to prestige buildings, coupled with charging a premium due to reputation for original, exciting ideas and a figurehead, and (4) strong ambition of young practices with few clients, and charging low fees.

Jennings and Betts' (1996) *high-degree four strategies* for quantity surveying practices in the UK capture many core *fitting* elements, i.e., (1) differentiation-based execution for small and medium-sized practices with a varied client base and simple, tailored, quality services to ensure repeat business, charging average fees, (2) differentiation-based expertise for larger practices with clients in niche markets and predominantly new areas, and complex, technically differentiated services, charging above average fees due to image of quality, adaptability, and professionalism, (3) cost focus-based efficiency for fairly new practices with simple, fixed projects, specific competences, optimized staff/salary levels, and rock-bottom prices, and (4) differentiation focus-based experience for larger, older practices with experience in complex projects and/or hand-holding services, and interpersonally bonded clients, charging a premium. Each strategy also identifies an IT-use level and a staff structure.

Lowendahl (2000) has designed the *three high-degree strategies* for US professional services firms with many *fitting* elements. (a) Client relation based strategies emphasize a unique ability to understand and help particular client groups. Performance is measured as client satisfaction, client retention, and follow-on contracts. Strategic assets involve senior professionals with reputation and client relationships. (b) Solution or output based strategies emphasize the exploitation of superior organizational competences. Vulnerability is related to solution obsolescence. When clients accept contracts without naming professionals, this is a sign of the successful development of collective routines and reputation. A challenge involves the motivation of R&D people to create new solutions to a large group of clients. (c) Problem solving or creativity based strategies result in highly complex firms typically delivering services based on innovations. Firms cannot avoid dependence on key individuals. Top managers are likely to be the best professionals who are willing and able to accept managerial responsibilities.

Helander and Möller's (2007) *high-degree, dynamic model for a system supplier's customer strategy* is based on the categorization of a client's strategies, with many core *fitting* elements, i.e., independence of supplier strategy A, shared expertise with supplier strategy B, and reliance on supplier expertise strategy C. A system supplier assumes (i) an equipment/material supplier role to causally couple with an independent customer's strategy A, (ii) a solution provider role to couple with a sharing client's strategy B, and (iii) a performance provider role to couple with a dependent client's strategy C. It seems that a supplier can extend its role only when a customer's strategy is compatible with the aimed role. A supplier's role may be dependent on interrelated activities and coordination mechanisms so that a client can close its knowledge gaps and start to perform activities that a supplier has performed in the past.

Thus, it is herein argued that in construction *Approach 1 is highly relevant*, at minimum, in the case of BU management aiming at causal fit between buyers and their needs, a BU's offerings to satisfy needs, and its operations enabled by key resources. Targeted professional clients couple needs with accommodating procurement methods whereas a particular BU achieves best fit between its solutions and such client investment and procurement behavior.

3.2 Value-creating business ideation and its relevance

Firms are crafting business ideas, specifying high-value propositions, and organizing BUs to actually produce values under contracts with clients and to capture shares of produced values. Applying Slater's (1997) founding client value-based strategy, market segments are selected, *value propositions* are created to establish positions of competitive advantage, necessary capabilities are developed for understanding client needs, and promised value is delivered. Relying on Ramirez' (1999) pioneering value co-production framework, BUs and clients could increasingly co-invent, combine, and reconcile values where interactions (offerings) are units of value creation and clients' roles are new factors of production. Applying Kothari and Lackner's (2006) typical value creation cycle, value is defined (sources and quantification), created, delivered for clients (flow and outside in -based processes), and captured (shares of profit, wallet and market). The value that clients receive from a focal BU's offerings is being determined by product, access, experience, and cost attributes.

Among the 13 high-degree, construction-related BM concepts, the five concepts have been designed along the *value-creating* business ideation dimension. Pinto et al.'s (2000) *high-degree value chain analysis*, based on partnering and a technique of client-based project success includes many core *value-creating* elements. A project supplier can redefine itself as a long-term partner for enhancing a client's competitive advantages and operations as well as eliminating disadvantages. Through value chain analyses, a supplier tailors project bidding, engineering, design, fabrication, and delivery in a manner and for a price that gives a client an advantage over using alternative methods or competitors. Client satisfaction is ensured through contract development, a client's multiple levels, and project-specific phases. In order to achieve an overall project success, a supplier enters cooperation with subcontractors to offer superior service to clients where technology is to a great extent undifferentiated.

Metais and Meschi's (2005) *high-degree, core competence-based strategy for strategic flexibility* via linking the value chain and resources of an (oil and gas) plant contractor involves many *value-creating* elements. A strategic architecture links a contractor's value chain and core competencies. There are four processes, i.e., (i) to understand market and invent new products, by analyzing products and services in cooperation with customers, (ii) to design generic solutions, (iii) to design and produce customer-specific solutions, and (iv) to operate solutions (constructed facilities). The five core competencies are project development, project execution, technologies, processes, and operation. This architecture enables to make choices between forms of a value chain and between types of competitive advantages. In unstable environments, core competencies allow for varying and adjusting a contractor's value chain, as a resource network, according to an industry's stakes.

Hawk's (2006) *five high-degree, most promising business ideas* for stakeholders in construction are as follows: (i) intelligent systems applications, (ii) lateral thinking capabilities, (iii) environmental concerns, (iv) decentralization needs, and (v) leisure time facilities. The *nine high-degree recommendations for international construction development* include many *value-creating* elements, i.e., (1) embrace consumer ideals, (2) seek new business ideas in cross-border customer relationships, (3) add new value potentials via innovative design and global procurement processes, (4) use of global construction to discover new local visions, (5) accommodate diversity while embracing the contradictory, (6) adapt and adopt cross-border design and production, (7) find and organize new knowledge across the globe, (8) innovatively avoid limits in hierarchies, and (9) integrate the Asian and European models of construction.

Salonen et al.'s (2006) *high-degree supplier centric systems model* for the enhancement of competitive advantages consists of the eight *value-creating* elements, i.e. (i) finding new ways to enhance customer value, (ii) adopting a supplier centric systems model with a shift to a systems integrator's role, (iii) identifying buyers who appreciate maximum value, (iv) insulating a systems integrator from threats via entry barriers, e.g., cost advantages, economies of scale, switching costs, unique and valuable resources, (v) acquiring and possessing required resources, e.g., superior systems know-how, systems oriented sales force, service capabilities, control of physical components, (vi) controlling costs, e.g., through standardization, (vii) integrating value propositions either as lowered total costs or enhanced performance for buyers throughout value chains and the life-cycles of systems, and (viii) communicating value to customers to change the predominant, buyer centric business model to the supplier centric one, e.g., signaling to gain top management's awareness and getting a mandate for containment of customers' line worker opposition as well as maintaining interfaces.

Kujala et al.'s (2010) *high-degree typology of the five empirical business models* of a power plant supplier also captures a *value-creating* scope. A 5-model framework was developed for the analysis of a project supplier's business models based on the six characteristics, i.e. customers, value propositions, competitive strategy, a position in a value network, an internal organization and capabilities as well as logic of revenue generation. The 1st model of basic installed base services involves product-oriented value propositions and transaction-based revenue generation logic. The 2nd model of customer support services involves process-oriented value propositions and transaction-based revenue generation logic. The 3rd model of operations and maintenance outsourcing involves product-oriented value propositions and relationship-based revenue generation logic. The 4th model of the delivery of life-cycle solutions involves process-oriented value propositions and relationship-based revenue generation logic. The 5th model of the development of life-cycle solutions involves process-oriented value propositions and relationship-based revenue generation logic accepting more risk and upfront costs as well as requiring more extensive business, market, and stakeholder management capabilities (in comparison with the 4th model).

Thus, it is herein argued that in construction *Approach 2 is highly relevant*, at minimum, in the case of BU management creating value by specifying high-value propositions, producing such value to clients, and a BU capturing its fair share of produced values. Farsighted clients look for markedly more or novel values for construction investments and, thus, a BU is collaborating with technology-intensive suppliers, proposing integrated offerings, and co-producing value.

3.3 Profit-generating business ideation and its relevance

Firms are crafting business ideas to achieve high-profit BU performance and also to sustain it. Adopting Slywotzky et al.'s (1999) multi-pattern approach to profitability, the rules of games can be redefined and *new profitable business designs* be recreated in terms of high client relevance, a consistent scope of products and value chain activities, a terrific profit model, a powerful source of differentiation and control across markets as well as a supportive, reinforcing organization. All this is enabled by the early, continuous recognition of evolving profit patterns such as mega, value chain, customer, channel, product, knowledge, and organization. The recognition, identification, and analysis of such patterns are based on paying attention to story-telling, mapping a strategic landscape, measuring degrees of mindshare by business designs as well as deciphering conditions and triggers for next profit-making patterns.

Among the 13 high-degree, construction-related BM concepts, only one concept has been designed along the *profit-generating* business ideation dimension. Leinberger's (1993) *high-degree dichotomy of project-oriented and process-oriented businesses* in US real estate markets captures many *profit-generating* elements, coupled with risk management. *Project-oriented business* exhibits five marketing characteristics (one project at a time, no guarantee of a next project, different projects, higher margins, higher risk), six financial characteristics (unique deal, changing financing markets for both equity and debt, project-by-project financing, huge financing needs, limited access to public equity market, and potential for surprises; restructuring of vehicles), and six organizational characteristics (job shop, barely contained anarchy, exciting and ever-changing, fighter pilots, high turnover, addicted to change). *Process-oriented business* exhibits differences in its five marketing characteristics (business stream, repeat business with satisfied customers, customer similarity, lower margins, and lower risk), six financial characteristics (uniform contract structure, consistent financing, corporate financing, working capital needs, broader access to public equity market, stable financing structure), and six organizational characteristics (assembly line, efficiently organized, consistent, ship's crew, stable workforce, slow adjustment when change occurs).

Thus, it is herein argued that in construction *Approach 3 is highly relevant*, at minimum, in the case of BU management focusing on generating profits, achieving high-profit performance levels, and sustaining them. Pioneering clients pursue complex investment aims that can be met only by radical solutions and, in turn, a BU is highly competent in innovating and proposing solution-driven values, realizing values, and capturing exceptionally big portions of them.

3.4 Systemizing business ideation and its relevance

Firms are crafting systemic business ideas as well as modeling or designing businesses and organizing businesses as systems. Applying Osterwalder and Pigneur's (2010) generative business model, rationales can be defined, i.e., how BUs create, deliver, and capture value as well as cover the four areas of a business (clients, offers, infrastructure, and viability). The 9-block logic of how to make money includes (i) client segments, (ii) value propositions, (iii) communication, distribution, and sales channels, (iv) client relationships, (v) revenue streams, (vi) resources, (vii) activity performance, (viii) partnerships for outsourcing and resource acquisitions, and (ix) a cost structure. *Business model innovations* result from the objectives, i.e., (a) to satisfy existing but unanswered needs, (b) to bring new technologies or offerings, (c) to improve, disrupt, or transform markets with better business models, or (d) to create markets.

Among the 13 high-degree, construction-related BM concepts, the three concepts have been designed along the *systemizing* business ideation dimension. Huovinen's (2003a) *high-degree, 5-element, knowledge-based system* for managing a firm's business units in global capital investment markets captures the core *systemic elements in knowledge-based ways*. (i) A unit advances front-line strategies and offerings for best solutions, high client satisfaction, and high firm profitability. Value-adding knowledge enables to pre-empt client needs. (ii) A unit integrates global, local, and contract-specific business processes for high dynamic operative effectiveness, ensured by virtual knowledge. (iii) A firm nurtures core technology for creating advantages. Innovative knowledge involves business-opportunity perceptions, a foresight, a technology platform, a core competence architecture, a core offering portfolio, and innovation paths. (iv) A firm governs and optimizes business-specific frames. This knowledge covers ownership, top management, venturing, financing, and firm-market interactions. (v) A firm extends its frame via collaboration with global and/or local parties. This knowledge includes synergistic ways of opportunity exploitation, benefit balance, and risk avoidance.

Huovinen's (2004) *high-degree, 5-element, organization-based system* for managing a firm's business in capital investment markets captures the *core systemic elements in organization-based ways*. The 1^{st} value-adding front line enables a BU to pre-empt client needs, excel among competitors, and meet its goals in the short term. A unit integrates the 2^{nd} business processes for ensuring virtual effectiveness. A firm nurtures the 3^{rd} back-end core technologies, competences, and offerings. Innovative organizing involves a core competence architecture and a matrix of core processes and project types where teams play flexible, integrative roles. A firm governs the 4^{th} BU frames. Framing solutions cover ownership, top management, venturing, financing, resource silos, and firm-market interactions. The 5^{th} extended frame includes collaborative ways of front-lining, process integration, competence fusion, benefit balance, and risk avoidance.

Huovinen's (2011) *high-degree, 5-element, high-sustainability system* for managing a firm's business in construction-related contexts captures the core *systemic* elements, i.e. a BU advances the 1st strategies and offerings also for the highest degrees of sustainability. Offerings with no/low negative impacts enable to pre-empt or over-satisfy client needs and meet high-sustainability goals in the short term. A unit integrates the 2nd business processes also for minimizing carbon footprints. A firm nurtures the 3rd back-end or core technologies also based on high-sustainability foresights. A firm governs the 4th frame of each business also for high sustainability. The 5th extended frame is also based on sustainability.

Thus, it is herein argued that in construction *Approach 4 is highly relevant*, at minimum, in the case of BU management systemizing or modeling its business around a core idea. Sectoral clients have large, multi-dimensional investment needs and, in turn, a BU is satisfying needs by engineering systems as wholes and delivering them as modularized parts.

3.5 Commercializing business ideation and its relevance

Firms are crafting business ideas and coupling them with new legal and organizational business entities, i.e., through entrepreneurship, innovation, business development, venturing, or spin-offing. Applying Looser and Schläpfer's (2001) traditional, 8-part business plan, business ideas can be identified and rolled out to start up high-growth businesses. Innovating may result in new products/services and/or business systems. Adopting Hamel and Breen's (2007) radical approach, management innovations alter managers' work or modify organizations and, thus, advance the goals of respective BUs. Principles, processes, and practices are being reinvented. A management innovation could have a unique capacity to create a long-term advantage when one or more of three conditions are met, i.e., (a) a novel management principle, (b) systemic with a range of processes and methods, and (c) a rapid-fire innovation. When higher tiers denote higher levels of value creation/defensibility in a hierarchy, the 4th tier of management innovations comes out above the 3rd tier of strategy innovations, the 2nd tier of product/service innovations, and the 1st tier of operational innovations.

None of the 13 high-degree BM concepts has been designed along the *commercializing* business ideation dimension. Nevertheless, it is argued that in construction *Approach 5 is highly relevant*, at minimum, in the case of BU management coupling its business ideas with intensively commercializing dimensions. Risk-taking clients with 'wicked' investment needs desire to enter high-innovation contracts and, thus, a BU is nurturing and using entrepreneurial competencies for the making of novel solutions and the realization of business cases profitably.

4. Conclusions

It seems that the business ideation dimension is being recognized among construction-related researchers, at least by the authors of the 13 high-degree BM concepts published between 1990 and 2013. Indicatively, the number of these high-degree concepts corresponding to one of Approaches 1-5 varies between zero and five (Table 2). Nevertheless, it is herein argued that each generic approach to business ideation is, at minimum, highly relevant in the case of BU management targeting preferred client investment and procurement behavior within construction markets.

Table 2: Correspondence between five generic approaches and 13 construction-related BM concepts designed to high degrees along the business ideation dimension.

Approach	*1 Fitting ideation No. (%)*	*2 Value-creating ideation No. (%)*	*3 Profit-generating ideation No. (%)*	*4 System-izing ideation No. (%)*	*5 Commerc-ializing ideation No. (%)*	*All high-degree BM concepts No. (%)*
No. of concepts	*4 (31)*	*5 (39)*	*1 (8)*	*3 (23)*	*0 (0)*	*13 (100)*

It is suggested that CIB-related scholars design next construction-related BM concepts along the business ideation dimension and adopt the most relevant approaches, respectively. Approach 1 calls for research on how to sustain fit between a business unit and professional clients when changes occur. Approach 2 calls for research on value co-production with farsighted clients, value capture, and offerings integration. Approach 3 calls for research on profit-generating mechanisms related to pioneering clients with complex investment needs and radical solutions. Approach 4 calls for research on systems related to sectoral clients, multi-dimensional investments, and system engineering. Approach 5 calls for research on entrepreneurial competencies related to risk-taking clients, wicked investment needs, and high-innovation contracts. Management in firms competing in construction markets are encouraged to assess the business case-sensitive relevance of each approach and try out those with initial high relevance.

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Towards Responsive Workspaces - Identification of Service Paths for Time-and-Place Independent Work

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Abstract

The development of technologies, change in the ways of performing tasks and user preferences empower time-and-place independent work. Time-and-place independent work is becoming rather the rule than the exception. Half-empty offices and long traveling distances do not motivate employees anymore. Therefore, an attractive and welcoming work environment needs to be created. The definition of a workspace has evolved from strictly physical space to work towards virtual and social dimensions of knowledge creation. Virtual and social dimensions play an important role in a workplace due to digital revolution and empowerment of big data. Particularly, it helps to understand workers and their needs better and provide services that correspond demand which could then be called as a responsive workspace. A change towards responsive workspace becomes a challenge for real estate service providers as well. In order to gain competitive advantage, real estate service providers need to respond to the changes in the market. Therefore, this paper aims to analyse currently available services that support time-and-place independent work and identify key features and the course of service advancement that could help develop responsive workspaces. The aim is achieved by developing a service path framework. Literature review combined with market studies are used as methods for framework development. Literature review handles the trends of working environment and the market study consists of data of a hundred firms that offer services to support time-and-place independent work. As a result, key service paths are identified. Paths refer to a range of services, concepts and other solutions that support or contribute to time-and-place independent work. Four paths, characterized by space, community, technology and logistics as main business drivers, form the primary base of the framework. From this, new service paths that support different steps of knowledge creation processes emerged. Based on the framework, new business opportunities can be explored by real estate service providers. Further research can build on these findings by using other approaches, e.g. service design methodology or value co-creation theory.

Keywords: workspace, time-and-place independent work, services, framework

1. Introduction

New characteristics of the design and architecture of spaces and urban area, organisational transformations and changing ways of work need to be explored in order to support different needs of organisations. These rapid changes in the market and advancement of technologies challenge FM service providers to quickly respond to the developing needs and concentrate, above all, on supporting the worker. To understand the ways how time-and-place independent knowledge work can be supported, various services are analysed and paths are identified.

First, the paper discusses the theory related to knowledge processes and workplaces and identifies components of responsive workspace, then the role of FM service providers is shortly discussed. After the literature and theory review, the analysis of services is described and results are presented. The paper ends with discussion and conclusions related to the development of responsive workspace and the opportunities for FM service providers.

2. Literature

2.1 Knowledge creation

In today's quickly changing environment and technological advancements it becomes difficult to compete with anything other than the knowledge that an organization holds. Nonaka and Toyama (2003) discuss the knowledge theory of the organization to explain the process of knowledge creation and utilization. The knowledge creation is a process of interactions and problem solving happening between individuals, organization and environment. In many organizational theories, the environment outside the organization is ignored and its effects to knowledge creation are disregarded.

Nonaka (1991) tried to overcome this drawback and take environmental and organizational relationships into consideration by introducing the theory of SECI and studying interactions between them. In the knowledge creation theory, the knowledge is classified into tacit and explicit, where tacit knowledge is intangible and related to skills or points of view, while explicit knowledge is objective and rational, and is easily expressed with language and numbers (Senoo et al., 2007).

This classification lead to the development of SECI model for the knowledge creation process in four different conversion models: Socialization, Externalization, Combination, and Internalization. The process usually starts from converting new tacit knowledge through experience sharing and every day social interactions and is called Socialization process. Through the process of Externalization, the tacit knowledge is then transformed into explicit knowledge and gains tangible form such as documents or images. The personal knowledge and experiences are shared, and a person tries to find the meaning in these shared forms of knowledge. After the Externalization process and knowledge sharing with others, the knowledge is collected from different sources, combined, and processed into a more complex explicit knowledge through so called Combination process. In this step of the process, a lot of different tools are used and in many cases it involves virtual environment and virtual tools for knowledge creation and processing. When explicit knowledge is perceived and applied in everyday situations, it is transformed into tacit knowledge again, and benefits the knowledge of one's own. (Nonaka and Toyama, 2003).

Knowledge creation process is time, space, and relationship specific because it needs a place where information gets meaning through interpretation. This need leads to an introduction of "Ba" concept (Nonaka and Toyama, 2003). "Ba" originally means place and is considered a factor in a knowledge creation process that connects time, place and relationships with others (Senoo et al., 2007). Senoo et al. (2007) identified two "Ba" environments: physical (e.g. office) and virtual (e.g. email). However, Nenonen (2004) argues that there should be a combination of virtual, physical, and social places (e.g. mental space, ideas) as only virtual places cannot fully replace face-to-face interactions. These interactions are more important aspects in the knowledge creation process than the space itself (Huhtelin and Nenonen, 2015).

Organisations should aim at better understanding of complex knowledge creation process in order to increase their competitive advantage. Understanding employees and creating an environment that supports their needs should become a main priority of those organisations and their service providers.

2.2 Workplace

For a long period of time, workplace in the office was considered as a setting where employees followed orders (Senoo et al., 2007). In that setting, an office layout was appraised from a management perspective with staff left away from the decision-making process. Only later, starting from early 2000's, the workplace research showed the importance of Facility management (FM), IT and HR collaboration in order to improve collective activities and performance of employees.

In 2008, Vischer suggested that built environment is a necessity and it acts as a mediator between people and tasks and activities they perform. The better users are supported in their tasks, the greater is the effectiveness of the built environment they are in. Author divided users into three groups: individuals, the team, and the organization which was also related to the phenomenological perspective of space, which was considered in layers, starting from the "personal space" and moving towards universal space (Vischer, 2007b).

The understanding of "traditional" office space has changed when technological development created possibilities to carry out tasks in different places, including spaces outside traditional office walls. Data from different observational studies show that, on average, conventional workplace at the office is occupied 42-45% of the typical day (Laing, 2013). In his book "Work and the City" (2008), Duffy discussed traditional practices related to work time and work place. Nowadays, knowledge work is done not only through face-to-face collaboration in the office but also virtually. Virtual and remote teams also cause changes in work times as quite often team members are located in different time zones. Also, most of routine individual tasks can be automated and other highly intellectual tasks can be performed elsewhere and not necessarily in the traditional office building. These changes have an impact in how buildings and cities are used and how work can be combined with other activities.

Traditional office space became less about the employee interactions in a physical environment but more about individual's ability to work with digital information at the workstation and the role of a workplace has gained a different approach both in practice and in research. Nowadays, integration of various activities and possibility to be a part of various virtual and social networks that enable employees to create new knowledge are the most of important attributes of a good workplace (Lister, 2010).

2.3 Knowledge creation in workplace

New approaches towards workplace and its ability to support knowledge creation processes started in early 2000s. In 2004, Nenonen introduced the concept of four places that vary based on the type of work that is performed and space used to perform work (Fig. 1). Author argued that a Connective place is an external space where one needs to perform more intangible work (create tacit knowledge). Structural place includes external spaces where tangible work is performed and Formal place is internal environment where tangible work is done. The last place, used for knowledge creation, is internal, and intangible work is performed there. That place is called a Reflective place.

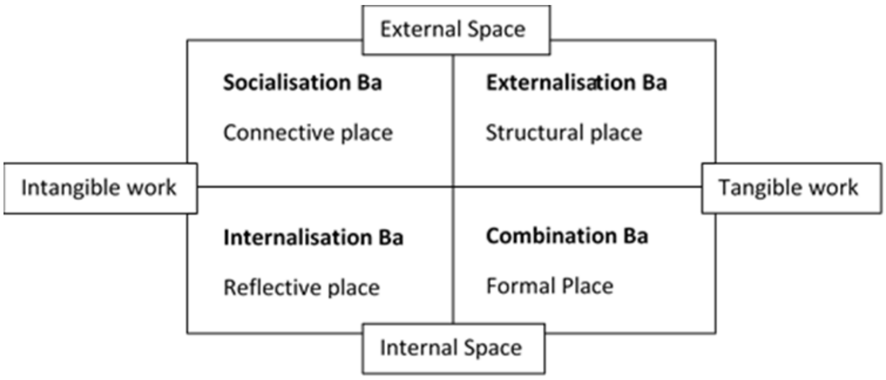

Figure 1: Work environments based on Ba concept (Adapted from Nenonen, 2004)

Huhtelin and Nenonen (2015) discussed the environment that supports knowledge creation and knowledge work. According to the authors, the aspects of spaces and services in Ba framework are:

- Spaces and services that support informal interaction and idea creation – Originating Ba;
- Spaces and services that support formal meetings – Dialoguing Ba;
- Digital platforms - Systemizing Ba;
- Spaces that support learning-by-doing - Exercising Ba.

Originating Ba is supported by spaces and services that support informal interaction – it needs to be a place where tacit knowledge can be transferred and co-created. Dialoguing Ba is supported by services and spaces that support formal interaction, and it is a matter of resources how to organize it as one function for empowering time-and-place independent work.

Table 1 introduces the generalization of discussed topics. According to Nenonen (2004), a workplace is combined of three components: physical space, virtual space, and social space. Thus, support services should be provided to all of those together to ensure smooth knowledge creation process and transition from one quadrant to another. Choo & de Alvarenga Neto (2010) introduced different steps in knowledge processes: knowledge creation, sharing/transfer and use of knowledge. These can be assigned to the three attributes of workplace. Different work types are also identified and categorized under three workplace environments.

Table 1: Ways of working, knowledge processes, and attributes of workplace in three workplace environments

	Physical Space	***Virtual Space***	***Social space***
Attribute of workplace	Place	Technology	Community
Knowledge process	Knowledge creation	Knowledge sharing	Knowledge use
Work types	Formal meetings	Virtual platforms	Informal interaction and idea sharing

2.4 The role of FM service provider

In order to understand the role of workplace and find new ways how to develop spaces that enable time-and-place independent work, two field of research should be analysed. Organizational theories claim that poor physical environment can have a negative impact on the performance but a good physical environment has little or no consequence to performance. Thus, a physical environment was considered as a hygiene factor in Maslow’s pyramid for many years and ignored by organization studies. Then, traditional facilities management (FM) theory divides FM services into three levels: (1) Strategic FM that supports organizations; (2) Tactical FM that supports business units; and (3) Operational FM – supporting end users, or in other words – knowledge work. FM’s role is to place the non-core business at the service of the core business in such a way that real estate would be turned from the cost item into the element that adds value to overall organisational performance. However, in practice, many organisations still consider real estate and workplaces as a hygiene factor and a cost item.

In order to change the understanding of FM as operations’ management, a philosophy was developed by Cairns. Cairns (2003) questioned the “irrelevance” of the physical environment and its placement in the Maslow’s pyramid. He claimed that a modern workplace is “not an activity container for paid work but contains representations of all other major social places in the modern society”. He explained that workplace must be seen as presenting different solutions to various physical and social problems simultaneously within the same assemblage of physical artefacts. This view is supported by Deb Roy (2015) who describes FM as something that: (i) delivers effective and responsive services; (ii) enables changes in the use of space in the future; (iii) makes assets cost effective; (iv) creates competitive advantage to organisation's core business; and (v) enhances organisation's culture and image..

Changes in the ways of working and the needs of employees and, thus, organisations, will affect how facilities are operated, maintained, and what services will be needed. FM service providers need to understand that effective and responsive services can be delivered only if they are flexible and adapt to the changing environment fast. For that, a good understanding of services that support workplace and work processes is needed.

3. Empirical part

3.1 Methodology

This study follows the steps of a qualitative approach in order to build hypotheses from the collected data (Eisenhardt, 1989). According to Yin (2003) a qualitative case study approach is suitable when the phenomenon and conditions are hard to divide and conditions relevant to the phenomenon need to be taken into consideration.

Extensive list of services were analysed with few service examples for an in-depth understanding as they enable creation of more robust theories grounded by diverse evidence (Eisenhard and Graebner, 2007). These services were analysed in multiple levels in order to get a better understanding of cases and the phenomenon related to those (Yin, 2003). The analysis of services was done by using Business Model Canvas tool, developed by A. Osterwalder (2004, 2010). Business model as a concept should be capable of reflecting how that vision can be converted into practice as it is between the strategic and operational layers. The understanding of a workplace covers three environments: physical, virtual, and social and knowledge processes are also divided into three steps: knowledge creation, sharing and usage. So data was analysed by taking into consideration these different aspects. Osterwalder (2004) provided a conceptualized tool to formalize the elements of business, relationships, vocabulary and semantics of a business model. This tool allowed to structure the business offering and logic into several levels with value proposition being the central topic for the approach

3.2 Analysis of data

During the process, 103 service businesses were analysed in total. Based on the Business Model Canvas tool, six key business dimensions were identified: value proposition, main user segment, revenue streams, resources, cost structure, and service providers for the first round of analysis.

After the initial analysis of services, the second round of analysis was conducted in order to identify the emerging patterns in the data. The revenue streams, resources and cost structure were not classified as these were not the focus of this research, so only main user segments, service providers and value propositions were sorted into categories. The main user segments were divided into three user personas which were constructed by using a story-telling approach and based on the time and the way the person works: 24/7 mover; 5-9 executor and 5/7 socializer. Then, the service providers and their value propositions were clustered into 3 main categories: Online platforms and Technology developers who provide technology (software, hardware, etc. e.g. Microsoft, Samsung), Spaces and Landlords – who provide physical infrastructure (e.g. letting spaces), and Places and Community operators – who operate and facilitate connections of people and organizations in either physical or virtual space (e.g. Facebook) and thus supporting knowledge sharing. After the initial clustering of services based on their value proposition, they were combined into four categories:

- Space: businesses and value propositions are mainly driven by real estate. It usually includes renting of premises for a fixed long period of time and is a square-meter based business for single organization or individual. For example, a BC (business centre) Papula can be put to this category;
- Community: businesses and value propositions are mainly driven by a community - likeminded people who have a common goal or want to share their thoughts in a certain theme. This category would include various events, conferences such as Nordic Business Forum, Slush, and others;
- Technology: businesses and value propositions are mainly driven by technology business like the development of a sophisticated software or hardware. Oculus, Built Environment Sensoring or other similar businesses can be put into this category;

Transportation: businesses and value propositions are mainly driven by logistical needs to transfer tangible things or people from one place to another. This category includes businesses such as DHL, VR, various taxi companies and others.

4. Results

After the second round of analysis and clustering of services based on their value propositions, the analysis on ways these services and businesses can support actual knowledge processes in the workplace was done. Results implied that the original four paths do not provide the needed answer, and new categories were emerging, mainly because of the technological development and the need to connect different resources from previous categories. Thus, the emerging new service groups were created based on the resources they are connecting and steps of knowledge processes they support or promote (Figure 2):

- Collaboration – services that support collaboration and businesses are driven by connecting physical space and community. Usually they include flexible contracts and shared spaces, co-working spaces such as Hub13, Kontoret and similar.

For example, mobile applications that allow users to know where people are, what they are doing, and who they are near, this way allowing serendipitous encounters.

- Sharing – services that enable knowledge sharing and businesses are driven by connecting community with technology. Community members participate in creating the content. E.g. LinkedIn, Airbnb, Lyft, Hoffice.

Organizations can create networks through different platforms such as LinkedIn or Facebook that allows organizations to understand how the inside community inside works. Such examples could be tags that are worn by employees to track their social behaviours online and within the organization, create possibilities to collect data and monitor team interactions and styles of communication.

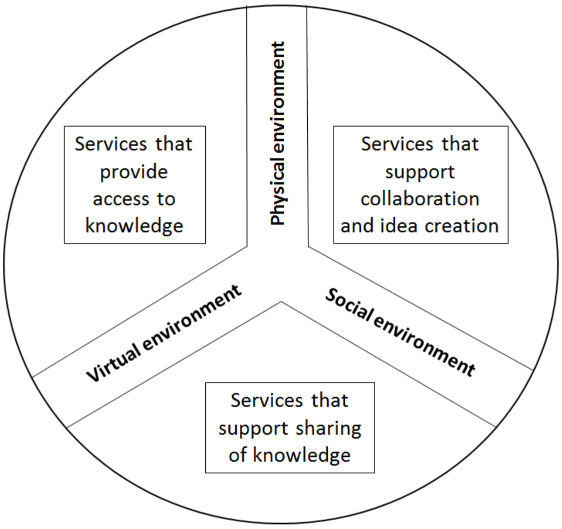

Figure 2: Services supporting work environments and knowledge processes

- Access – services that provide access to knowledge. Service providers create businesses by connecting physical spaces with technology or virtual platforms. E.g. Venuu, LiquidSpace, Foodora, MaaS.

Technologies that also connect people to the Internet of Things (IoT), facilitating marketplaces based on the intelligence of physical proximity.

5. Discussion

Identified service paths demonstrate an emerging trend of connecting multiple resources to provide value to the customer by supporting workplace, its user and knowledge creation processes. The value of new services is perceived through co-creation, in other words, by connecting different service providers and users in service design and value proposition.

The concept of value co-creation was first introduced in theory of service – dominant (S-D) logic, presented by Vargo and Lusch (2004). Value co-creation has been adopted as a core concept for the development of service system science and relates to innovations and collaborative consumption. New emerging services, which were analysed in this research, employ value co-creation and, thus, reflect innovations. Furthermore, changing workplaces indicate collaborative consumption approach. Previous case studies suggest that the future of the workplace will change not only in terms of how and where work is accomplished but also in terms of how the workplace is consumed by its users. For example, a growing relevance of collaborative consumption provides possibilities for users to choose from a wider pool of options and gain greater control of their work environments by using workplaces on as-needed basis in desired location or environment. A good example of these types of collaborations could be WeWork spaces and their Shared resources in USA. The network of small businesses benefits from shared resources such as healthcare plans, car rental memberships, offices amenities, and others.

As stated earlier in the paper, the workplace consists of 3 components: physical space, virtual space and social space. The workplace enables three processes related to knowledge: the creation of knowledge, knowledge sharing and the use of knowledge (Choo & de Alvarenga Neto, 2010). Therefore, FM services for supporting workplace need to take into consideration all three components and three processes - services for informal interactions, formal meetings, and also services that support virtual work. However, analysed services and businesses are mainly connecting two out of the three workplace components and one or two knowledge processes: either supporting knowledge creation, knowledge sharing, or improving the ways of using of the knowledge.

5.1 Limitations

FM services outside traditional categories are researched scarcely. Previous studies concentrated on services provided for organisations and their none-core activities. In parallel, another approach to services supporting knowledge exchange within and beyond organisation has emerged. Therefore, more studies regarding knowledge processes and workplaces that involve premises other than organisational offices are needed to support tentative findings.

The selection of the analysed services might be questioned as a qualitative approach and, also, the inductive research require careful selection of cases in order to avoid informant bias and present empirical richness. Also, according to Yin (2003), returning to the global issues after the analysis of individual units might be challenging.

The clustering of services can be argued as no users and service providers were interviewed, it was intuitive and based mainly on expertize of multiple researchers that were involved in the data gathering and analysis. The usage of Business Model Canvas tool can also be questioned as it is not widely used in research environment.

6. Conclusions

The results of this analysis indicate that FM practitioners should concentrate on offering work environment that supports various knowledge creation processes. It is not enough to provide technological solutions, space, and services related to social environment separately, but collaboration between service providers is necessary. In practice, it might require much closer collaboration and partnerships within organisation’s departments as well as working together with outsourced services’ providers. For FM service providers outside organisations, this increased collaboration and supporting knowledge processes means that they need to change own business strategies and try to understand processes of end users, in other words, employees of organisations, to be able to offer services that meet their needs the best.

Technology is increasing the value of physical places by facilitating both physical and virtual networks together rather than replacing the physical place as it is. So the logic of using technology and combining it with the new ways of working is that new kind of workplaces can be shared, used more intensively, in various ways and on-the-need basis. In order to respond to knowledge workers' demands and improve communication processes through simultaneous transformation of all workplace environments, FM should provide flexible services, and offer various co-working and workplace on as-needed basis models. Workplaces should provide all needed services and be designed in such an environment what would create possibilities for and facilitate various social, intellectual, commercial and other types interactions within and between organisations.

Further research could include a comprehensive analysis of knowledge creation processes and changing ways of working inside organisations could help in identifying service opportunities for real estate service providers. Also, the services under identified categories could be explored in more detail in order to understand how real estate service providers' business strategies should change.

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Role of Water Cooperatives in Water Service Production - Lessons from Finland and Denmark

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Abstract

This paper examines water cooperatives in Finland and Denmark, and in particular it delves into the future of water cooperatives. During recent years, the trend has been that big is beautiful -- larger organisations can achieve economies of scale. Is there still a role for water cooperatives in the future? Both in Finland and Denmark cooperatives have played, in particular in rural areas, an important role in the development of economic activities and improvement of living conditions. Water cooperatives are still very common. More than 40% of the Danish population is supplied water by a total of 2,500 water cooperatives; Finland has roughly the same number of water cooperatives. In both countries municipalities are, in principle, responsible for the provision of water services for the inhabitants. In Denmark cooperatives have a strong status in legislation as water service providers outside large population centres. Finland is a sparsely populated country with large rural areas between built-up areas. Municipal water utilities cannot afford to extent their networks in rural areas. Development of improved water services has been left to the residents and cooperatives have proved to be a workable solution.

Keywords: water, cooperatives, Finland, Denmark

1. Introduction

Finland has a long tradition of water cooperatives, which presently number over 1,500, and supply water to 13% of the population, mainly in rural areas (Luukkonen 2013). Larger towns and cities are typically supplied by public water utilities. Water cooperatives in Finland are quite different from each other even though their basic task – to produce water and often also wastewater services – is similar. The Finnish water sector has a lot in common with that of our neighbour Sweden, except for water cooperatives. Sweden has hardly any water cooperatives, and the same applies to Norway, too.

On the other hand, in another Nordic country Nordic country, Denmark, water cooperatives play an even bigger role than in Finland. More than 40% of the Danish population is supplied water by a total of 2,500 water cooperatives. Contrary to Finland, cooperatives in Denmark have no role in wastewater management which is by legislation the responsibility of the municipalities. At the beginning of the 20th century, virtually all the needs of rural communities were met by cooperatives (Birchall 2004). In farm product processing and distribution cooperatives still play a major role. Dairy cooperatives, for example, hold a market share of 97% (DGRV 2015). A newer development has been windmill cooperatives, which were established in particular during the 1980s and the 1990s so that at the turn of the century 80% of the windmills were owned by cooperatives. This trend has changed in more recent years as more utility-size wind projects have come online. (Cook & Lin 2015)

Elsewhere in Europe water cooperatives exist e.g. in Austria, Germany and Italy. In Austria, cooperatives cover 12% of water services being important for sparsely populated areas (Bauby 2012). Cooperatives have operated as regional energy utilities in many parts of Germany for well over 100 years. Over the last three decades more than 800 new cooperatives have been founded in the field of renewable energies in Germany (DGRV 2015). In the USA, cooperatives are the most common organizational form of water provision in suburban and rural communities and totally there are about 3,300 water cooperatives (ILO 2015).

Water cooperatives are private utilities. They are established, owned and managed by the people who are also the beneficiaries of their services. One basic principle of cooperatives is that members have equal voting rights, which means that an outsider cannot become an owner and thereby a decision-maker in the cooperative.

Cooperatives resemble private companies in that they need to cover their costs with the income they generate. But, according to cooperative principles, there is no need to generate profit to be distributed to the owners. Any profit is used to improve the system and the quality of services. Cooperatives operate on the 'full cost coverage' principle. Thus their tariffs reflect the real cost of the service provided. In many countries the activities of municipal water utilities, on the other hand, are subsidised by the state or local authorities.

This paper examines water cooperatives in Finland and Denmark, and in particular, the future of water cooperatives. In recent years, the trend has been “big is beautiful” – larger organisations can achieve economies of scale. Is there still a role for water cooperatives in the future?

2. Water cooperatives in Finland

Water cooperatives in Finland differ dramatically according to their physical environment, settlement pattern, acute needs of the population, and the legislation in force at the time of establishment. They can be classified into the following five groups (Takala et al. 2011, Pietilä 2015):

1) Water cooperatives established prior to 1950 in rural areas
2) Water cooperatives established in rural areas in the 1950s through the 1970s
3) Water cooperatives established in rural areas during the 1980s and 1990s
4) Water and wastewater cooperatives established since the 2000s.
5) Water cooperatives for rural townships established mainly in the 1950s

Only a few cooperatives of the first group provided sewerage services since wastewater was at the time discharged mainly into the septic tanks of individual properties. These cooperatives were established and operated solely by their members, as municipalities or the state did not have any support mechanisms in place (Juhola 1990). Wooden pipes were widely used and pipe laying and related work were mostly carried out by the members themselves. The initiators of the cooperatives were those whose demand for water was most urgent, such as dairy farmers. Since the 1950s the structure of the Finnish farming sector has changed dramatically: the number of dairy farms is now a fraction of what it used to be, but water cooperatives still exist.

The second group of water cooperatives was established when Finland was slowly recovering from World War II – since 1951 it was possible to apply for a subsidy or loan from the state to construct water or sewerage systems in rural areas. During the early years these subsidies were marginal and had hardly any impact on the economy of the cooperatives. As state authorities supervised all projects funded by state subsidies or loans, the resulting improved workmanship had a much bigger impact. Municipalities were not entitled to these support measures, only rural systems.

The third group of water cooperatives was established as some municipalities decided to extend their water supply and wastewater systems to rural areas in order to provide safe and reliable services to a larger share of their population. Several municipalities supported cooperatives by giving technical assistance in planning and construction, by subsidies, or by guaranteeing cooperatives' bank loans. For instance, the municipality of Pudasjärvi has 40 cooperatives, most established in the 1980s (Pietilä 2015). After Finland joined the EU in 1995, it has also been possible to get subsidies for cooperatives via some EU funding mechanisms.

The fourth group came into being after 2000 to supply water and increasingly also wastewater services in rural areas. People have become more aware and require higher quality drinking water. The water of their own private wells does not necessarily meet their requirements. On the other hand, people have also moved to rural areas thereby increasing population density there, which makes centralised water supply and sewerage a more viable solution. People moving from towns and cities are used to centralised services and ere are not interested in having and operating their own individual water supply or sewerage systems.

In 2004, legislation concerning wastewater disposal requirements for properties not connected to centralised sewerage (with their own disposal system) was tightened radically. As a consequence, most of the water cooperatives established since then also provide sewerage services. In addition, many previously water-only cooperatives have also built sewer systems. It is typical of cooperatives established in the 2000s not to have their own water intake or wastewater treatment facility. They buy water from a larger entity, typically a municipal water utility, and discharge wastewater to a municipality's sewer network. Only a few cooperatives have built their own water intake or wastewater treatment plant in the 2000s. The shift from owning a water intake to buying water from another utility started earlier as can be seen from Table 1.

Table 1. Water sources of private water utilities[1)] in South-West Finland (Ryynänen 2003)

Established	*Own water intake*	*Water bought from another utility*	*Total*
- 1949	*11*	*0*	*11*
1950 - 1959	*19*	*0*	*19*
1960 - 1969	*20*	*2*	*22*
1970 - 1979	*25*	*29*	*54*
1980 - 1989	*16*	*11*	*27*
1990 - 2002	*7*	*64*	*71*
Total	*98*	*106*	*204*

1) In addition to cooperatives, this table also includes small informal units and companies

The fifth group of cooperatives was established at a time when few rural towns had a centralised water and sewer system – residents relied on their own wells and septic tanks. Over the years, these cooperatives have expanded and presently cover not only the township but also the surrounding rural areas so that coverage can be up to 99% of the population of the entire municipality. Many of these cooperatives have from the beginning also provided sewerage and wastewater treatment, while some originally established for water supply only have later expanded their activities to cover wastewater services as well. (Vihanta 2013)

3. Water cooperatives in Denmark

In Denmark water cooperatives have had, and will have also in the future, an important role in the provision of water services to the citizens. Typically in cities and larger towns water is supplied by municipal water utilities, but in smaller towns and in rural areas water is supplied by private water undertakings, which are mainly cooperatives. As municipal water utilities are typically large, their number is only somewhat over 100 while there are about 2,500 water cooperatives. The size of these cooperatives varies from 10 to 20,000 households, while on average one cooperative serves 400-600 households. The number of cooperatives has during the recent decades gradually decreased via mergers, as in 1990 there were still more than 3,000 of them. Water supply is very decentralised in Denmark. In addition to cooperatives, there are some 50,000 households not connected to centralised supply that use their own private well. (GEUS 2015, Sørensen 2010)

In Denmark, the source of water is almost entirely groundwater and normally the quality of the water is good enough for drinking water requirements. In fact it is not allowed to treat drinking water using chemicals. Water is chlorinated only in exceptional circumstances. By area, Denmark is a rather small country (42,900 km^2), with a relatively big population density of 130 inhabitants/km^2, compared with only 16 inhabitants/km^2 in Finland. Extensive farming in Denmark in the vicinity of wells and boreholes has resulted in groundwater contamination in particular in the form of excessive concentrations of nitrogen and pesticides. As a result, annually tens of water supplies have been closed during the last decades. This problem has been tackled in recent years by tighter regulation on the use of fertilizers and pesticides. (GEUS 2015)

Danish water cooperatives have established a joint organisation, Danske Vandværker

(Association of Waterworks in Denmark), to assist and support its members. This association has a staff of about 15 experts who can help the cooperatives in various technical, financial, legal etc. questions. The organisation has also produced tailor-made guides and manuals, and it has arranged education and training events. Danske Vandværker has also negotiated an attractive insurance policy for its member cooperatives. (Danske Vandværker 2016)

4. Strengths and weaknesses of water cooperatives

Cooperatives fit very well into the EU's subsidiarity principle – decision-making at the lowest appropriate level. In Finland, at least in political discussion and decision making, the trend in the recent years has been the opposite – big is beautiful and more economical. That may be true in other sectors, but not necessarily in water services, which are by nature local activities. Merging of large networks in rural areas does not automatically provide the economic benefits of larger units. The relative effectiveness of large water utilities in cities derives more from high population density than the utilities' high productivity. Also in Denmark the trend has been towards lager units. A thorough municipal administration reform was carried out in 2000, when the number of municipalities was reduced from 271 to 98. Consolidation of water sector has also been discussed (Sørensen 2010).

Operation of small cooperatives is typically voluntary work. People are often willing to do voluntary work in their own neighbourhood or at the village level, but if a cooperative covers several villages, people no longer consider it their own and are less motivated to work without compensation. In Denmark the strengths brought up in connection with cooperatives include: a) dialogue and political contacts with many stakeholders through a widespread network, b) large public support, and c) direct contact to local authorities. Possible weakness may be a financially weak starting point but this can be overcome by cooperation with municipalities, utilities and investors. (Danmarks vindmølleforening 2009). In Finland, municipalities have often co-financed the investment costs of water cooperatives with up to 25% and also guaranteed cooperatives' bank loans (Pietilä 2015).

It is true that many water cooperatives are small, and they often lack sector technical or economic skills and knowledge. But, on the other hand, their systems are also often very simple thus requiring much less expertise compared to the utilities of towns and cities. In Finland, the majority of small water cooperatives do not have their own water intake but buy water from a municipal water utility. Similarly, only a few cooperatives run their own wastewater treatment plant but discharge wastewaters into a municipal utility's network. Thus they only have to take care of their own wastewater networks. In Denmark, water supply is almost entirely based on the use of groundwater and water cooperatives draw water from their own wells or boreholes.

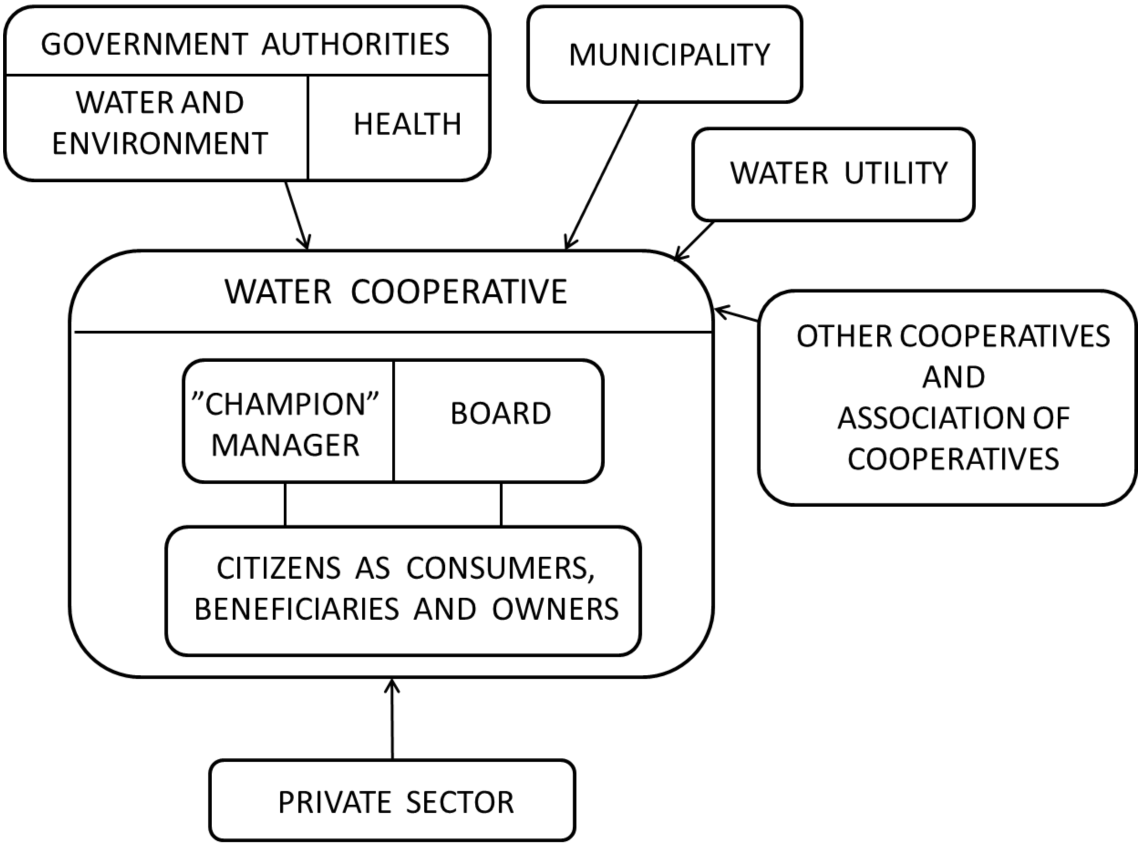

Figure 1. Water cooperatives and various stakeholders

At least in Finland, members of water cooperatives are often quite passive as long as everything goes well, and do not attend official meetings. But the meetings can be crowded and very intense, for example, if there is a need to increase tariffs substantially, or if someone tries to take over the water cooperative against the will of the people.

Many water cooperatives, in particular smaller ones, are facing difficulties. The active members are getting old, and it has proven difficult to get the younger generations involved in voluntary work. All those involved need to increase their knowledge and improve their skills. Undocumented tacit knowledge can also be a problem. Only the older employees of the cooperative who constructed the pipe network know its exact location. When these people retire, locating the networks will require much effort. Cooperatives could buy and utilise certain expert services, but as the members are used to cheap tariffs, higher charges are resisted. On the other hand, as there has not been much demand for expert services suitable for water cooperatives, only a few service providers exist at least in Finland. The situation is gradually improving as cooperatives are slowly becoming more trusting of external expert services, or they just have to use them when none of the members of the cooperative is willing to be in charge of the activities.

Closer cooperation between water cooperatives may ease some of the problems small cooperatives are facing. In Denmark the cooperatives are well organised as they have established their own support organisation, Danske Vandværker. In Finland a similar organisation called SVOSK (Association of Finnish Water Cooperatives) was established in 2009, but so far the resources and activities of SVOSK have been rather modest in comparison with its Danish counterpart. SVOSK has organised annual national water cooperative workshops and training events with various partners. In the Kouvola Region, in South-East Finland, some 30 local water cooperatives established a joint association to support their activities. Similar regional associations are also planned elsewhere. (Pietilä 2015)

In Finland larger water cooperatives (the fifth group) are in a much better situation. They are large enough to employ enough staff to run their operations. In comparison to municipal utilities of the same size, these cooperatives have a clear operating principle – to produce good quality services to members with funds collected through charges. Municipal utilities are subject to political control which often makes long-term planning difficult. The goal of politicians is too often success in the upcoming elections, not necessarily the long-term good of the community.

The benefits and problems of water cooperatives are summarised in the SWOT-analysis below (Vihanta 2013, Pietilä 2015).

Table 2. SVOT analysis of water cooperatives

<u>*Strengths*</u>	<u>*Possibilities*</u>
- *flexible decision-making*	- *official status in municipality's water service structure*
- *decisions normally made without voting*	- *residents no longer need to take care of their individual systems*
- *no political motives in decision-making*	- *cooperation and quality of joint activities can be improved and less need for voluntary work*
- *creates solidarity*	
- *clear operating principle: expenses are covered by charges*	
- *municipal boundary does not restrict activities*	
<u>*Weaknesses*</u>	<u>*Threats*</u>
- *reliance on one person*	- *members get tired of voluntary work*
- *lack of skills*	- *not enough voluntary activists*
- *members get passive after system is operational*	- *in a small unit personal relations may get strained*
- *one or a few active persons may direct activities in an unwanted direction*	- *authorities' requirements become unnecessarily strict*

5. Role of water cooperatives in the future

Water cooperatives will remain important water and wastewater service producers in rural areas in Finland. Municipal water utilities will not be able to cover the rural areas to the extent that cooperatives have been able to. In Denmark cooperatives have a much stronger status as they are defined in the legislation as preferred water supply organisations in rural areas. The number of water cooperatives in both countries is expected to decrease as small cooperatives merge with each other or into a municipal utility.

The majority of water cooperatives are small and largely managed on a voluntary basis. It is useful to have support systems for these small cooperatives so that their operation and management practices reach a more permanent and professional level. In Denmark, this is already quite well organised via Danske Vandværker, but in Finland only the first steps have been made. Cooperation between cooperatives should also be encouraged.

There are a number of larger water cooperatives which operate as professionally as municipal utilities of the same size. Such cooperatives can be expected to remain independent water and wastewater service producers. In a number of municipalities in Finland a cooperative takes care only of water supply and distribution while the municipality is responsible for wastewater services. Some municipalities would like to transfer the responsibility for wastewater treatment to the local water cooperative.

In principle, Finnish water services are not affected by the financial situation of the municipalities since, according to the law, all costs related to water and wastewater service production should be covered by water charges. The charges should be sufficient to also cover maintenance and investment costs in the long term. In the case of municipal water utilities this principle does not always apply. In many municipalities the profit earned by the water utility is used to support other municipal sectors. That is not bad in itself – the money benefits the municipality's residents. Nevertheless, if the water utility is left with too little to spend on renovation and rehabilitation, the future of water services is threatened. With water cooperatives the equation is simple, as all costs are covered by charges, and any profits are used to improve the service.

6. Conclusions

According to the Finnish legislation, municipalities are responsible for water and wastewater services within their areas. Yet, a number of municipalities have no water or wastewater utility but a cooperative provides these services for their residents. In some such municipalities water distribution coverage is up to 99%, which is well over the national average of just over 90%. Several municipalities are currently discussing their sewerage management with the local water cooperative. They would like to transfer the responsibility for the sewerage system to the cooperative.

In Denmark cooperatives have a well-established role in water supply outside large population centres. Wastewater management is by legislation the responsibility of the municipalities. This is different from Finland, where cooperatives often take care of wastewater as well.

The ultimate goal of water and wastewater cooperatives is straightforward: to produce good quality service to their members and cover related costs by the income they generate. As cooperatives are not under municipal administration, they are not subject to political decision-making. On the other hand, as they do not have to earn a profit for their shareholders, no external price regulation is necessary. Cooperatives are well in line with the commonly agreed principle of subsidiarity which suggests that decisions should be made as close to the affected people as possible.

Ageing infrastructure is a common problem in European countries. The renewal rate of the water and wastewater infrastructure of many Finnish utilities is unacceptably low. At the current rate of renewal, the pipelines would have to serve for 200 years, which is simply impossible. In Denmark, too, pipeline renewal rate of municipal water utilities is not sufficient. On the other hand, many water cooperatives have been able to maintain their networks and renew ageing pipelines in due course. Yet, the water tariffs of these water cooperatives can be lower than those of municipal utilities of the same size. Our findings suggest that the cooperative is a more efficient management organisation than a municipal utility, but further research is needed to confirm that.

The public sector in many European countries will face serious financial challenges in the future. People will live longer than before, which is going to increase pension, health care and other social security expenses. At the same time, the share of the working age population will decrease. Consequently, at least in Finland and Denmark, the current welfare state can no longer be sustained on public funding alone. New ways of providing public services must be found. Cooperatives are a successful example in the water sector.

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A Decision Support System (DSS) in the Cloud for Collecting, Measuring, Reporting and Forecasting Productivity in Construction+

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Abstract

Measuring productivity for accurate forecasting in construction scheduling is one of the most important problems that managers face nowadays. The traditional measurement methodologies are obsolete and offer deficits in (measurements of) standardization, which causes inaccurate assumptions during the planning phase of a project, affecting the predictability during its execution. With the aim to contribute to the solution of this issue, a new methodology for information acquisition under cloud computing and storage was developed to provide the necessary tools for collecting, measuring, and reporting the production work in order to compare the results between different projects and subcontractors. The objective of this paper is to introduce how the tool was obtained, the process of its creation and the benefits obtained from its implementation. This approach enables the manager to notice the progress of each of the projects, compare them with each other, and make decisions to improve processes; thus, increasing productivity and reducing variability. In addition, this tool provides a starting point to apply advanced forecasting techniques for more accurate predictions in real, and complex environments under volatile conditions. This paper fits into the category of "Advancing Products and Services" because it describes a program that innovates the production control work.

Keywords: Construction industry, productivity, technology in construction, forecasting in construction.

1. Introduction

Average annual growth of Colombian construction over the last five years is 16.8%, compared to the rest of Latin America and the Caribbean, with an average annual growth of 10.2%. This makes the Colombian construction industry the third largest in the region (data from the Ministry of Commerce, Industry and Tourism, 2013). Despite the elevated operative costs and low productivity yielded by traditional construction methods, project revenue has been considerably high in the past. Nevertheless, competition in the industry has greatly increased over the last few years, which has pushed constructors to restructure construction methods in order to improve productivity to be more competitive in the market.

Measuring production rates in construction plays a crucial role when it comes to improve on-site productivity as these rates are indispensable for the controlling and planning of civil projects. According to a study on productivity rates by the International Labour Office (ILO):

> *The critical figure is the productivity norm. (...) If the task is underestimated by 30 per cent, (..., the direct cost of the project will increase by 30 per cent. Conversely, if the tasks are overestimated, then much of the workforce will not be able to meet its targets and there will be considerable disruption and discontent on site.*
> *Estimating the correct productivity is probably the most important decision for the engineer (ILO, Stield, Brudefords & Shone, 2003).1*

Thus, the importance of developing an efficient method allowing for data collection and analysis of construction productivity is highlighted, with the aim of facilitating the accurate decision making, in order to help improve construction productivity.

Current production rates measurement in Colombia is not standardized or effective. This gives way to sizable issues in planning activities and decision making. In most cases, measurement formats are confusing and inefficient, which fosters the input of incorrect information. Not being comfortable with the structure of the format, the operators in charge fail to put enough effort in filling it out correctly. Moreover, performance measurement is not among the functions of any operative position. Therefore, this task is sometimes accomplished by the Lean engineer, sometimes by the administrative engineer, the foreman or foremen in charge, or is even neglected altogether on occasion. In sum, this absence of staff charged with measuring activity productivity, along with lack of clarity in the formats, makes for low reliability in performance control, thus affecting future construction work and accurate decision making aimed at improving productivity.

Considering the foregoing, a Decision Support System (DDS) was designed, consisting of an application allowing for the measurement of productivity in a friendly, intuitive and efficient fashion. In the same manner, it processes the information and generates reports that can be used to make accurate decisions, thus improving the efficiency of the processes and of the on-site activities.

The main objective of this work was to create a largely useful product for any construction company. For this reason, the development process for the model was based upon the methodologies found in the book The Lean Startup by Eric Ries (2011). The book touches upon the importance of carrying out an iterative process involving the final user, in order to develop a high quality product while investing the least amount of resources possible.

2. State of the art

[1] Taken from http://www.ilo.org/public/english/employment/recon/eiip/download/prod_norms.pdf, Page 7.

Measuring productivity in the construction industry has acquired meaningful importance over the last few decades (Rivas et al. 2011). Nevertheless, Colombia has seen little advance in this topic due to the large revenues left by the industry in past years.

Nowadays, measurement of productivity does not happen for most projects, as it is a dispendious activity. In general, the 5 Minute Test (Koskela, 1992) lean tool is applied instead of measuring the daily progress of a given activity. This Test includes measuring staff performance in a given activity for five minutes, which allows reducing time wastage by optimizing space and processes. However, this is not a tool that allows checking an activity's daily progress. Numerous studies have been conducted on the topic of productivity since the 1960s to this day, largely owing to growing market competition and the need of companies to increase their revenue. Chart 1 shows the percentage of articles published on academic journals since the 1980s. The chart shows that interest for improving productivity is still quite relevant in the construction industry.

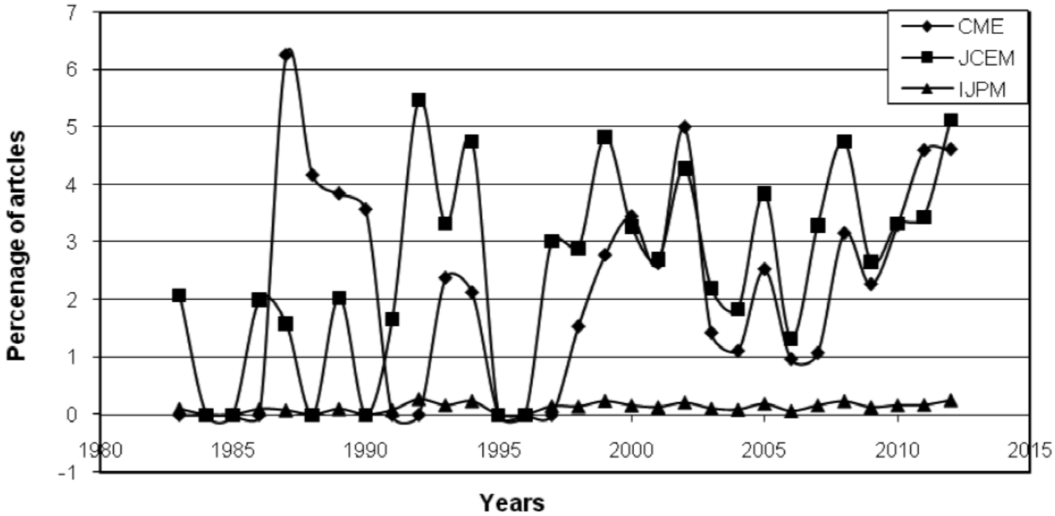

Chart 1: Article Production on Productivity in Construction. Dolage D.A.R. et al. (2013) [Graph]. Progression of Productivity Articles in Journals. Taken from Productivity in Construction – A Critical Review of Research.

In 1965, the United Nations conducted a study on factors affecting on-site productivity, focusing on repetitive processes in construction operations (Enshassi et al. 2014). In 1974, NECA conducted a study on the influence of different climatic factors on workforce productivity (Rivas et al. 2011). Some authors have looked at the topic from other perspectives. For instance, in 1986 Borcherding, Palmeter and Jansma studied unproductive times affecting the efficiency of construction work. Other authors examined the topic in 1997 and 2005, using advanced statistical models and software programmers to determine the variables affecting productivity, as they considered such variables to be too complex for the human brain to process (Dolage & Chan, 2013).

Despite great efforts to improve productivity, Colombia continues to have problems measuring it properly. Construction companies lack standardized methods to collect and process the information, let along consider determining the factors affecting productivity.

2.1. Methodology

The project was developed in three stages, namely: initial analysis of the current situation, proposal of the DDS, and development of the application. These stages shall be described from here on.

2.2. Initial Analysis

The first step in determining the problems to measure production rates was visiting construction sites to observe how the data was collected. The main issues observed in the processing and analysis of production data are as follows:

a. Problems with the construction companies in taking, processing and interpreting the site productivity data. This issue is evidenced in the following aspects:
    1. Lack of item standardization, along with duplicate activities.
    2. Excessive or lacking specificity. Usually, activities are not sufficiently differentiated according to the characteristics directly affecting its productivity (e.g. vertical or horizontal veneers). There are also instances of excessive specificity, differentiating activities by completely irrelevant characteristics (e.g. distinguishing between a 30x30 red horizontal veneer and a 30x30 white horizontal veneer).
    3. Difficulty of standardization activity measuring units, or lack thereof.
    4. Lack of clarity about who is charged with measuring production (DT – Data Taker). Sometimes, data collection is too dispendious, and is therefore neglected.
    5. Though there are adequate formats for data collection and analysis, the DT does not use them properly. This leads to incorrect or incomplete data input, which clutters the reports and makes proper data analysis impossible.

b. Lack of reliability in the results due to the absence of a representative sample. By failing to continuously following up on activity productivity, there is not enough data to have a statistically representative sample, leading to biased reports.

c. Activities are only measured once a day. If only one measurement is available for one given activity, the subsequent reports will reflect that the activity does not vary, that is, that production is constant in time. Construction is a complex system, affected by multiple factors. For this, to state that production is constant and unchanging is unlikely.

d. The reports generated are not easily understood or interpreted.

e. Lack of initiative from the staff involved in proposing measures to improve the internal handling of data collected on-site. Oftentimes, a passable information collection and processing format exists, and no effort is made to improve it.

f. Lack of human and material resource allocation for the development of real follow up and control on project progress.

g. In view of the foregoing problems, the need to devise a system to solve them became evident: the creation of a DDS for the collection, measurement, reporting and forecasting of data productivity rates.

3. Proposal of a DDS for Productivity in Construction

The initial proposal presented to the company contemplated the improvement of the quantification of production units, aimed at bettering estimate reliability. Thus, the purpose was for the amounts to be updated using the amounts obtained in a construction site to design a database with production rates. The objective was to build a relational, parametric database per work unit and project type. To that end, a strategy was defined in order to collect information and feed the database.

At first, the construction company requested the database to be built in Excel. However, doing so in a web server yielded better results, as it allowed for better data processing (greater speed and ease of handling). After submitting these observations, the company agreed. Moreover, the company requested for a strategy sustainable in time to allow anyone to develop this methodology.

Three options for the collection of data were analyzed: the creation of a simple printed format for the use of foremen on-site or, in special cases, of the operator executing the activity to fill out unsupervised;

the creation of an Excel sheet to be accessed from a tablet or smartphone allowing for data input as the site is reviewed; and finally, the design of a web page allowing for data input or, in the event that internet access is not available, for the printing of the format. After studying all three alternatives with the company, the third proposal was selected. Hence, a user-friendly web page was created, that accomplished the efficient collection of production rates on-site, and that also considered the factors affecting the selected type of productivity, in order to conduct a future study about said factors.

To guarantee product quality and user satisfaction, a simple application that ensured easy, quick and human-error-proof collection, was perused. Its main objective is to be a support for on-site decision making. According to these characteristics, the model has the following features:

1. A single data collection format requiring the input of just a few data associated to each productive unit. Also, it differentiates input information according to the periodicity of registration, and sets up daily, weekly or monthly measurement.
2. It allows for the input and storage of productive units, contractors and non-compliance causes in order to standardize data collection, thus avoiding duplication. When the user inputs production data, the activity, the contractor and the non-compliance cause must be selected from a list. If any of these elements does not exist, it must be created.
3. It carries out all the calculations, eliminating the possibility of human error in data processing.
4. It displays the general results (weekly, monthly or general) obtained from the calculations in graphs or dynamic charts to make reading the information, as well as observe trends easy. Moreover, it allows for the download of measured information in Excel format, which can then be used transversally in other applications.
5. It allows for the measurements to be performed on any mobile device with internet access. In the event such a device is not available, data collection formats can be printed out, and the data will have to be entered manually at a later time.
6. It makes the selection of contractors efficient. Based on the compliance percentage found in the database, the process of selecting contractors will be improved considering their previous compliance with their commitments.
7. It uses the results obtained by the page for the planning and programming of current and future projects.
8. It has a wide database, with a considerable amount of man-hours daily production data. With this information, the daily man-hours average will be available, which can be used to forecast the duration of an activity using realistic data based on rigorous observation instead of theoretical data based on experience or the subjective opinion of the planners.
9. It allows for fast data analysis using the general reports it delivers, through comparisons between projects, between activities and in set time periods, with the purpose of finding the problems emerging at the site and plan strategies to help mitigate them to improve on-site production.

4. Development and Implementation of Productivity DDS

Once the web page had been chosen as the means to measure production rates, the exploration of functions that could of interest to the client was perused. To that end, the interface of the web page was the first deliverable to be designed seeking to verify that the client was pleased with the design and considered whether the functions therein selected at the time were relevant. Such functions were:

- The option to create a new project with its corresponding initial characteristics.
- The option to have a database of the production rates per project.
- The option to divide the factors affecting productivity for each project in 4 groups (factors defined at the beginning of the project, factors to be measured monthly, factors to be measured weekly, factors to be measured daily).

The option to have an Excel downloadable report per project with all the production rates data in a user defined date range reporting the following:

- Total daily production.
- Daily production per contractor.
- Number of workers per contractor.
- Non-compliance causes.
- Daily possible production had non-compliance causes been null.

The option to have a tab listing the company's unified activities, with each activity having its own unit of measurement.

Specifically for factors affecting productivity, the possibility to use a neural network or vector methods to determine the real influence each of these factors could have on the activities measured, was proposed. In spite of the great complexity and the elevated number of field measurements needed to configure the aforementioned networks or methods, the decision was made to do so as it was considered to be a very useful tool for any construction company. The client approved the proposal, and these initial proposals were put on production track for the web page.

In a later meeting, the client was shown the tools approved for implementation. Upon exploring the functionality of the web page, the company expressed some concerns. Hence, the functionality expected by the company was revisited. In the following meeting, a series of general reports on the company production rates was proposed, comprising graphs comparing daily production of an activity across projects. It is of note that at first these reports were built in Excel tables and dynamic graphs in order to test and modify them prior to their inclusion in the application.

The first report executed dealt with average daily production per project. This report shows the real production rate, the maximum production rate and the minimum production rate for a specific activity (see Chart 2).

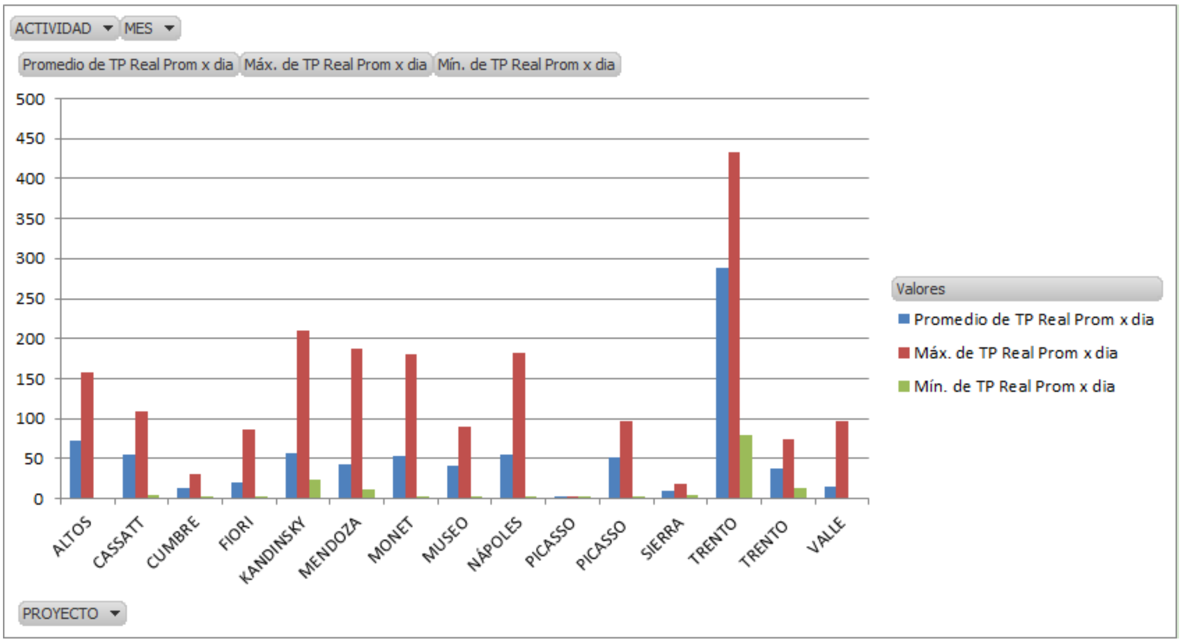

Chart 2: Average Daily Production per Project

The second report executed dealt with the production rate for each activity. This report shows the daily average production rate for each activity using a dynamic table (see Chart 3).

Actividad	Promedio de TP Real Prom x dia
AMARRE VIGAS DE TRANSICIÓN	8,36
CARPINTERÍA DE MADERA	2,29
CLOSETS	1,42
ENCHAPE DE BAÑO	5,64
ENCHAPE DE COCINA	5,53
ENCHAPE LADRILLO	11,17
ENCHAPES	34,90
ESTUCO Y PINTURA	175,86
EXCAVACIONES	184,58
GUARDAESCOBAS	0,80
INST. CLOSETS	3,36
MAMPOSTERÍA BLOQUE	45,50
MAMPOSTERÍA FACHADA	34,16
MARCOS DE MADERA	3,97
MESONES GRANITO	1,20
MESONES MARMOL	1,66
MUEBLES BAÑOS	2,79
MUEBLES COCINA	2,83
PANTALLA TANGENTE	4,18
PAÑETE MUROS	122,69
PAÑETE PLACA	69,75
PUERTAS DE MADERA	4,07
TERCERA MANO DE PINTURA	61,11
VENTANERIA	5,71
VENTANERIA T1	10,05
VENTANERIA T2	9,88

Chart 3: Production Rates for each Activity

The third report executed dealt with the monthly average production rates. This report shows the monthly production rate achieved for each activity or in general (see Chart 4).

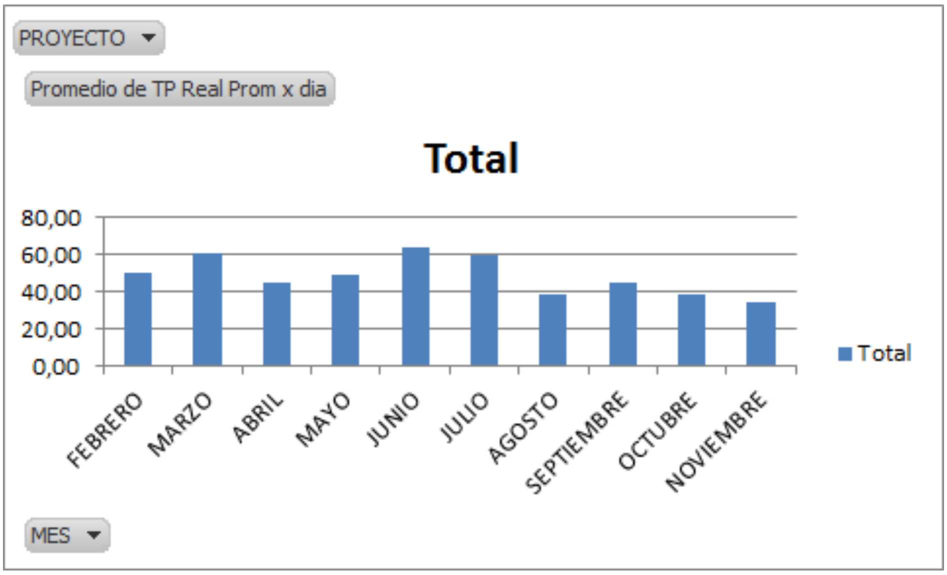

Chart 4: Monthly Production Rates

The fourth report designed dealt with the month-to-month project production rate. This report shows the monthly average production rate for each project (see Chart 5).

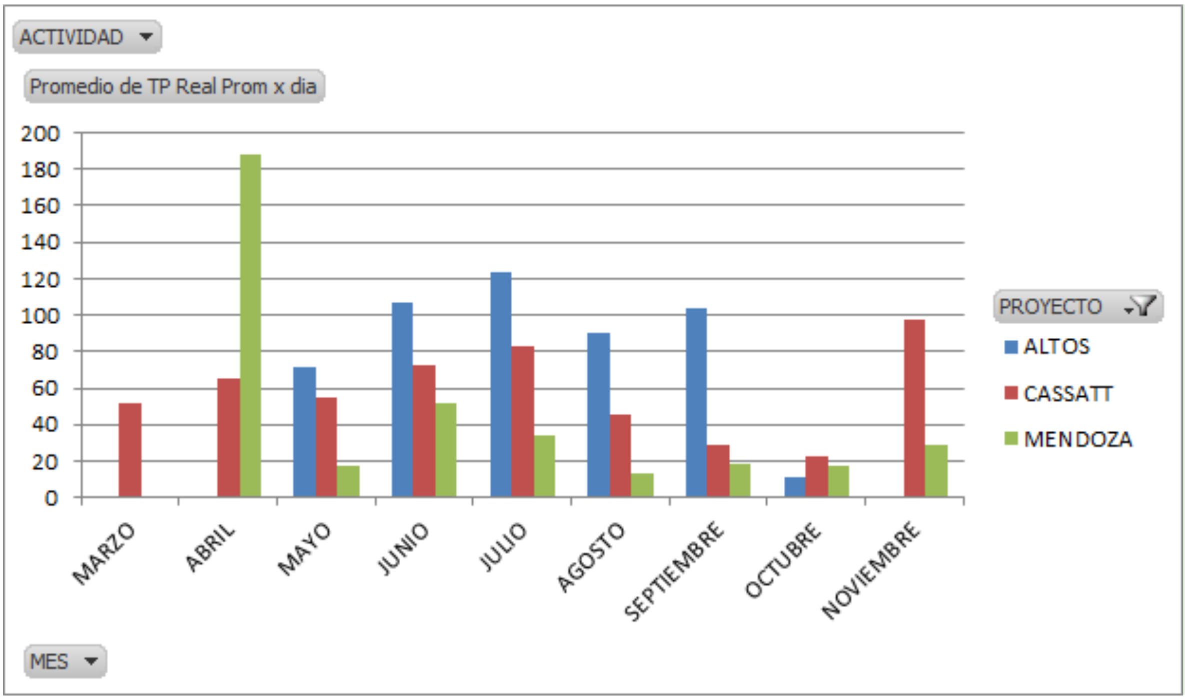

Chart 5: Monthly Production Rate per Project

The fifth report submitted dealt with wasted hours per project. This report showed total hour wastage per project (see Chart 6).

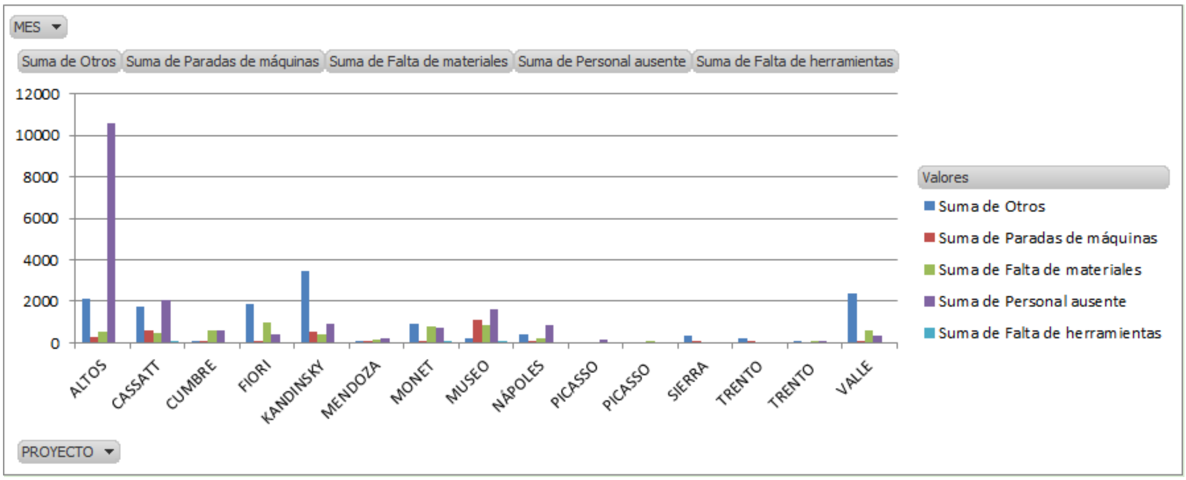

Chart 6: Hour Wastage Average per Project

Once these reports were verified, they were included in the application. This prompted a meeting with the company where several agreements were reached. The company would unify its activities to avoid repetition. Likewise, developers would add the same graphs, but including production per man-hours into the application, in addition to other additional graphs on non-compliance causes per month, and per activity, a graph with the compliance percentage per contractor, and modifications to the format of the graphs. The implementation of these adjustments, including a user manual for the application, satisfied the client's requirements. The manual is included in Appendix (number).

5. Results Obtained

Owing to the foregoing, the DDS allowing for the measurement of activity performance, was developed. In addition to this, the application makes all the calculations and produces general reports for their analysis and consequent improvement of the future company forecasts. This application does not only use the performance of each activity, but also the non-compliance causes and displays compliance percentage, which allows for deeper, more accurate analysis. In order to view the reports, it is necessary to enter the time lapse desired (the software requires a start and an end date). Each of the reports produced by the application shall now be described. See the user manual in Appendix (number) for details on how to produce each report.

5.1. Production Rates per Project (I1.1)

This report shows production rates for each activity differentiated by the different projects created to date. This report includes two graphs. The first shows the Forecasted Production Rates (FPRs), the Measured Production Rates (MPRs), the Maximum Production Rates (MaxPRs) and Minimum Production Rates (MinPR). The second shows compliance percentages (CP) for the activities in each project.

5.2. Real and Forecasted Production Rates per Man-hours (I1.2)

This report shows the FPRs and the MPRs in report I1.1 per man-hours. This report does not include a graph for compliance percentage, as it is the same shown in I1.1.

5.3. General Production Rates (I2.1)

This report shows a chart including the production rates differentiated by project. If no project is selected, the software displays a chart with all created activities measured in the time lapse defined by the user.

5.4. General Production Rates per Man-hours (I2.2.)

This report is similar to I2.1 – General Production Rates, but this one shows production rates per man-hours.

5.5. Weekly or Monthly Activity Production Rates (I4.1)

This report displays daily measured and forecasted average production in months or weeks lapses. It allows selecting a particular project or all projects simultaneously. Additionally, it shows compliance percentages for each month or week.

5.6. Monthly or Weekly Average Real and Forecasted Production Rate per Man-hours (I4.2)

This report is similar to Monthly or Weekly Average Real Production Rate, but this one shows production rates per man-hours. The compliance percentage graph is equal to that in report I4.1.

5.7. Monthly or Weekly Average Real and Forecasted Production Rate (I5.1)

This report shows three graphs. The first graph shows the forecasted production rate. This bar graph shows daily forecasted production for a specified activity in each month or week (depending on the selection). Moreover, daily production per project is differentiated, with each project having an independent bar and color. The second graph shows measured production rate. This graph shows daily average measured production in each project for the specified activity and time lapse. The third graph shows the compliance percentage for the selected activity, in the specified time lapse, in the selected time unit and per project.

5.8. Monthly and Weekly Real and Forecasted Production Rate per Man-hours (I5.2)

This report allows the study of the real and the forecasted average performance of an activity in a specified time lapse. This report is ideal to estimate learning curves and evaluate the impact of measurements taken aimed at increasing productivity.

5.9. Non-compliance Causes per Project (I6.1)

This report shows non-compliance causes per activity in each project. In the event that no activity is selected, the total of non-compliance causes for all activities is displayed. It also allows for the simultaneous selection of several projects for their comparison.

5.10. Non-compliance Causes per Month (I6.2)

This report shows non-compliance causes emerged monthly or weekly. Moreover, the information can be filtered by activity or by project.

5.11. Non-compliance Causes per Activity (I6.3)

This report shows non-compliance causes per activity and the amount of man-hours that production was stopped. This allows to study hour wastage per project and activity, in order to make decisions and see their impact in time.

5.12. Compliance Percentage per Contractor (I10)

This report shows the historic compliance percentage each contractor has displayed in the specified time lapse.

6. Conclusions

This study evidences some of the problem faced by civilian construction work stemming from the lack of an adequate method to collect, process and analyze production data. This makes the use of real data difficult in decision making and future planning processes.

One of the tasks of the Production Data Taker is to check up on the effective advance of the work using the compliance percentage. Comparing the real production rate with the forecasted production rate, the activity's real advance percentage is revealed. This grants better foresight in making decisions affecting the execution of that activity, as well as its predecessors and successors, while preventing errors in intermediate and short-term planning. This allows for reality-adjusted planning to reduce uncertainty regarding a master plan activity, avoiding delays and other problems already identified through the non-compliance causes.

Since the program was designed with the objective of avoiding data collecting mistakes, activity duplication and typing errors were also averted. The software makes all the calculations automatically, which eliminates human error.

In order to make contracting easy, the program allows for the comparing of compliance percentages for each contractor. This lets companies evaluate each contractor and work with those that have greatest compliance with the company. Likewise, the Production Data Taker shall assess whether the actions taken on-site aimed at improving productivity were effective. This will only be achieved if the company devotes the required time to on-site data collection and input, as these are indispensable for the reports to show changes in productivity.

7. Recommendations

- The construction company shall define the degree of specificity for their applications. The same criteria must be applied to all their projects in order to unify the measurements.
- Read the user manual to use the software correctly.
- Inputting information collected prior to the implementation of the program is discouraged, as it can be incomplete or contain unnecessary details for the software.
- The software designed in this study is a pilot software, subject to future improvement. Companies are requested to submit suggestions as they implement the tool.
- A later study on the factors affecting productivity shall be conducted. This study shall define whether the use or a neural network, a vector or another method is convenient. The result of that study is expected to provide arguments for each factor, that is, to experimentally define the factors affecting productivity in the Colombian construction industry.
    - Once the factors affecting productivity are identified, data collection regarding the same is expected, as well as the creation of a database with information relevant to them.
    - The development of a vector method or a neural network is expected in the future, with the aim of mathematically verify the degree at which these factors affect on-site productivity. These methods are expected to provide arguments for each factor, thus aiding in determining which factors are relevant and which are not. In the case of relevant factors, the duration of affected activities can then be adjusted, thus increasing project duration predictability.
    - This information could be used in a later article about the chosen factors affecting productivity, and how to neutralize their negative effects, seeing as some factors cannot be eliminated.
- To learn more about the usage of this tool, click below to download the userguide:

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